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Impact of Soil Organic carbon on Bulk Density and plasticity index of Arid Soils of Raichur, India

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Abstract

To assess the impact of soil organic carbon (SOC) on Bulk density (BD) and plasticity index (PI) of arid soils, a laboratory study was conducted on four of the arid soils namely black cotton, red, marshy and mountainous, obtained from organic farms. Wastes like humus, pressmud, bagasseash and flyash were used as a source of SOC to amend with the soils. SOC inputs were made volumetrically up to 70% in the increments of 10% of the soil columns which resulted in 0.08 gm/gm-4.18 gm/gm for black cotton, 0.06 gm/gm-2.99 gm/gm for red, 0.06 gm/gm -3.16 gm/gm for marshy and 0.07 gm/gm -3.57 gm/gm for mountainous soil. There was also a control column without any external addition of SOC. The relation between SOC, BD and PI was analyzed by series of experiments carried in triplicate in three different phases based on the mode of application of SOC. The lowest PI were 3.00%, 2.97%, nil and 1.83% similarly lowest BD were 0.73 gm/cc, 0.81 gm/cc, 0.75 gm/cc and 0.83 gm/cc for black cotton, red, marshy and mountainous soils respectively. Phase I performed better for red soil, phase II for black cotton, and phase III for mountainous soils with respect to PI; while it was phase I that performed better for red, phase III for back cotton, mountainous and marshy soils with respect to BD. The positive relation between SOC and BD was observed. Thus, organic carbon input will be a suitable key for sustainable soil management.

Keywords: Bulk density, plasticity index, porosity and aggregation.

Introduction

Soil bulk density is a significant soil property that sum up general soil structural characteristics. It is a fundamental input requirement for describing the transfer and interaction of soil chemical constituents within the earth. Bulk density is a relatively straight-forward property to measure a number of extensive data as stated by Hall[1] et al. and Rawls[2] et al., in the study on soil water characteristics. However, the increasing interest in developing comprehensive national datasets of soil physical properties for use in spatially or stochastically based environmental modeling has inevitably highlighted discontinuities in the existing measured datasets, as per the findings of King[3]et al., and Bruand[4]et al., in the studies on use of pedo-transfer functions in soil hydrology. This has now focused the need in development of methodologies to predict variation in bulk densities according to variation in soil properties.

Structural improvement of soil by assimilation of organic carbon can moderately prevent soil degradation as stated by Thomas[5] et al., in the study on effects of organic matter and tillage on maximum compactibility of soils using the Proctor test. SOC increases stability of soil by reducing compatibility and enhancing in retaining a greater amount of moisture to rebound against compaction as quoted by Paul[6], in a study upon press mud on the soil physical conditions in sandy soil. Soane[9], in the review on practical aspects of soil tillage stated about the role of organic matter in increasing bond between particles, elasticity, electrical charge change and friction. SOC also influences the ability of soil to resist compactive loads, increases consistency limits and the range of soil moisture for optimum trafficability and workability in agricultural fields as stated by Baver[7] et al., in the study of soil physics. Ellies[8], in the study on mechanical consolidation of soils reported lower bulk density and a higher saturated hydraulic conductivity in comparison with similar land under continuous cultivation due to the higher SOC and the more stable structure in the pasture soil. Soane[9], in the study on practical aspects of soil tillage indicated that the effect of SOC on compactibility was likely to be greater at low levels of stress and high moisture contents, whereas Rawls[10] et al., in the study on effect of soil organic carbon on soil water retention, reported that peat application caused a greater effect at a level lower than the critical moisture content (CMC) in cohesive soils, whereas the greatest effect was at the CMC in sandy soils. There is hence a need to determine the link between soil types, optimum SOC and soil compactibility as reported by Soane[9], Rawls[10]et al., and Ekwue and Stone[11] in the studies on soil moisture and physical properties. This helps to select the superlative conditions for agricultural practices as reported by Ekwue and Stone[11] in the study on density moisture relation of soils incorporated with sewage sludge.

Skin formation is one of the major problem in many soils of cultivated land in the arid region. In a research on soils with higher silt content Eghbal et al.[12], reported the formation of skin after the first irrigation which reduced seedling emergence by 50%, because the soil was prone to physical deterioration. Presence of high exchangeable sodium along with physical deterioration of surface structure because of long period of mechanized cultivation created a suitable condition for skin formation and soil compaction.

Defining and assessing soil health and sustainable productivity Doran and Safely[13] stated the suitability of soil for sustaining plant growth and biological activity is a function of physical (porosity, water holding capacity, structure and tilth) and chemical properties (nutrient supply capability, pH, salt content), which are in turn the function of soil organic matter (SOM) content.

Bulk density is dependent on soil texture, organic matter and their packing arrangement. Generally, loose, porous soils and those rich in organic matter have lower bulk density. Since total pore space in sands is less than that of silt or clay soils sandy soils have relatively high bulk density. Fine-textured soils have good structure having higher pore space and lower bulk density compared to sandy soils.

Bulk density increases with soil depth due to overburdened soil pressure, which reduces root penetration thus reduced organic matter and aggregation, compared to surface layers. The wetting/drying and freeze/thaw cycles hardly have their effect on soil bulk densities. Bulk density changes by land management practices. Cultivation destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to damage caused by water and wind and can result in compacted soil layers with increased bulk densities. Such soils with poor structure and particle arrangement are prone to erosion. Erosion fills the pore space, reduce porosity and increase bulk density. High bulk density is an indicator of low soil porosity and soil compaction. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion. Eroded soils cause restrictions to root growth, and poor movement of air and water through the soil. Ideal bulk densities that support root growth are respectively < 1.60 gm/cc, < 1.40 gm/cc and < 1.10 gm/cc for sandy silty and clayey. Similarly bulk densities > 1.80 gm/cc, > 1.65 gm/cc and > 1.47 gm/cc restrict the root growth.

Climate of Raichur, a district head quarter located in the northern region of Karnataka state (16022’32.38”N 77021’38.50”E) is characterized by dryness for the major part of the year and a very hot summer with the average temperature of 40^{0}C and normal annual rainfall of 621mm as reported in GOI booklet[14]. Figure-1 shows the location of the study area. Laying in arid tract of the country it has low and highly variable rainfall rendering it liable to drought. Farmers of this region rely on chemical fertilizers to maintain crop yields, while many of the organic carbon rich industrial wastes are fluently available in the surroundings, which if utilized can alleviate the SOC content in agricultural fields. Bahremand and Afyuni[15], in the study on Short and mid-term effects of organic fertilizers on some soil physical properties stated, there is a little research concerning effects of organic amendments on soil physical properties and compactibility. This study was taken up to experiment the nexus between organic amendments on soil physical properties by utilizing the organic waste as a source of SOC and explore its effect on soil bulk density and plasticity indices.

Figure-1
Bird View of Raichur showing places of collection of soil samples

Material and Methods

Soils Used: A preliminary survey was carried out in different locations in and around Raichur, to select the soil samples for the study. Four soils namely black cotton, marshy, red and mountainous soil were taken from different locations by removing the top 5cm soil with ten samples from each location. Such of the collected samples were analyzed for particle size, field density and SOC as depicted by Walkley and Black[16].

Soil Amendments: Flyash: Ash produced during combustion of coal, combustion has certain amount of loss on ignition (LOI) value that speaks of the unburnt matter this will still retain its organic carbon content as reported by Ram et al[17]. and Inderk et al.[18], in the studies on flyash. Class "F" category procured from Raichur thermal Power plant of Karnataka, called Raichur Fly ash (RFA) was used in the study as a source of SOC and an amendment. Composition of Fly ash is given in table 1

Bagasseash: Sugar cane Bagasse is an industrial solid waste obtained after having extracted the juice, it is used worldwide as fuel in the same sugar industry. The combustion yields ashes containing high amounts of unburnt matter, silicon and aluminum oxides as main components. Bagasse ash was obtained from the Core Green Sugar and fuels Pvt. Ltd. An Industry located in Yadgir, Karnataka, and composition of Bagasse ash is given in table 1.

Humus: It is the plant/animal residue that does not completely mineralize. A certain part of this residue is more or less resistant to microbial decomposition and remains for a period of time as an un-decomposed or in a somewhat modified state, and may even accumulate under certain conditions. Typical composition of humus as stated by Selman[19], is given in the table 1.

Pressmud: One of the waste by-product from sugar factories is Pressmud or filter cake. It is a soft, spongy, amorphous and dark brown to brownish material containing sugar, fiber, coagulated colloids, including cane wax, albuminoids, inorganic salts and soil particles. By virtue of organic carbon, the usefulness of pressmud as a valuable organic manure has been reported by several workers like Nehra and Hooda[20] and Ramaswamy[21] in the studies on waste application and crop yield. It is a potential source of major minerals as well as trace elements that can substitute chemical fertilizers. Press mud was obtained from the above said sugar industry. Composition of Press mud is given in table-1.

Particle size analysis of soils and amendments: Sieve analysis was performed for all the collected soil samples as per IS: 460-1962 and grouped accordingly in soil class. BC soil was clayey sand with high plasticity, having 38% sand and 62% silt and clay. Red soil was clayey sand with intermediate plasticity, having 41% sand and 59% silt and clay. Mountainous soil was silty sand with low plasticity, having 42% sand and 58% silt and clay and marshy soil was non Plastic, with 77% sand and 23% silt and clay.

Similarly Bagasseash particles were uniform non-granular and average particle sizes ranged between 7 µm to 12 µm, Fly ash had 1% clay, 12% of silt and 87% of sand content. Pressmud was coarser than rest of the amendments with its particle size ranging from 0.1µ to 1mm (20%), 1mm to 10mm (80%). Humus had 38% of fine sand fraction, 35% silt sized fraction and 27% clay sized fraction.

Test Procedure: Soil columns with dimensions 10 cm diameter and 30 cm length were fabricated by acrylic tubes and were then packed with the collected soil samples to their respective densities. The study was carried out in three phases based on the mode of application of SOC to soil as explained below.

Table-1
Composition of amendments

Constituents	Flyash	Bagasse ash	Constituents	Humus	Constituents	Pressmud
	%	%		%		% (Except pH)
SiO_2	61.10	78.34	Water soluble fraction	7	pH	4.95
Al_2O_3	28.00	08.55	Hemicelluloses	18.52	Total Solids	27.87
TiO_2	1.30	1.07	Cellulose	11.44	Volatile Solids	84.00
Fe_2O_3	4.20	3.61	Lignin	47.64	C.O.D	117.60
MgO	0.80	-	Protein	10.06	B.O.D	22.20
CaO	1.7	2.15	Ether-soluble fraction	5.34	OM	84.12
K_2O	0.18	3.46	pH	5.6	N	1.75
Na_2O	0.18	0.12	SOM	0.83	P	0.65
LOI	2.40	7.42	SOC	0.28	K	0.28
SOM	0.89	0.85	-	-	Na	0.18
SOC	0.3	0.29	-	-	Ca	2.7
-	-	-	-	-	SOM	0.71
-	-	-	-	-	SOC	0.24

Phase I: Soil-amendment combinations were individually assessed for their threshold SOC limits (based on obtained highest Water Holding Capacities) by replacing 0 to 40% volumes of soil with waste (SOC) and blending it with the top 15cm soil in the soil column, which resulted in 0.09 - 0.55gm/gm with humus, 0.1-0.62 gm/gm with bagasseash, 0.2-1.19 gm/gm with pressmud and 0.08-0.5 gm/gm with flyash for BC soil.

For red soil it was 0.07 -0.39gm/gm with humus, 0.07-0.45 gm/gm with bagasseash, 0.14-0.86 gm/gm with pressmud and 0.06-0.36 gm/gm with flyash.

For marshy soil it was 0.07 -0.41gm/gm with humus, 0.08-0.47 gm/gm with bagasseash, 0.15-0.9 gm/gm with pressmud and 0.06-0.38 gm/gm with flyash.

For mountainous soil it was 0.08 gm/gm -0.47gm/gm with humus, 0.09-0.53 gm/gm with bagasseash, 0.17-1.02 gm/gm with pressmud and 0.07-0.42 gm/gm with flyash.

Phase II: Soil-amendment combinations were individually assessed for their threshold SOC limits by replacing 0 to 70% volumes of soil with waste (SOC) and blending it with the complete soil of the column, which resulted in 0.09 -1.92gm/gm with humus, 0.1-2.18 gm/gm with bagasseash, 0.2- 4.18 gm/gm with pressmud and 0.08-1.74 gm/gm with flyash for BC soil.

For red soil it was 0.07 -1.37gm/gm with humus, 0.07-1.56 gm/gm with bagasseash, 0.14-2.99 gm/gm with pressmud and 0.06-1.25 gm/gm with flyash.

For marshy soil it was 0.07 -1.45gm/gm with humus, 0.08-1.65 gm/gm with bagasseash, 0.15-3.16 gm/gm with pressmud and 0.06-1.32gm/gm with flyash.

For mountainous soil it was 0.08 gm/gm -1.63gm/gm with humus, 0.09-1.86 gm/gm with bagasseash, 0.17-3.57 gm/gm with pressmud and 0.07-1.49 gm/gm with flyash.

Phase III: This phase was similar to phase II with the only difference that amendments were just stacked at top without blending with soil.

Bulk Density Determination: After having performed WHC the soil columns were the utilized for BD determination. The soil samples was extracted from the bottom most side opening of the soil column and were then determined for the moisture content by oven drying and then BD was found by the following relation

$$BD(g/cc) = \frac{\text{oven dry weight of soil}}{\text{volume of soil}}$$

Determination of Plasticity Index : PI was determined by the difference between liquid and plastic limits. Liquid and plastic limits were obtained by following the procedures as depicted in IS 2720 (Part V)-1985 and 1965.

Results and Discussion

To assess the impact of soil organic carbon (SOC) on Bulk density (BD) and plasticity index (PI) of arid soils, individual assessment of soil and waste amendment was made in particular with the mode of SOC application. The results so obtained are shown below phase wise with the suitable discussions.

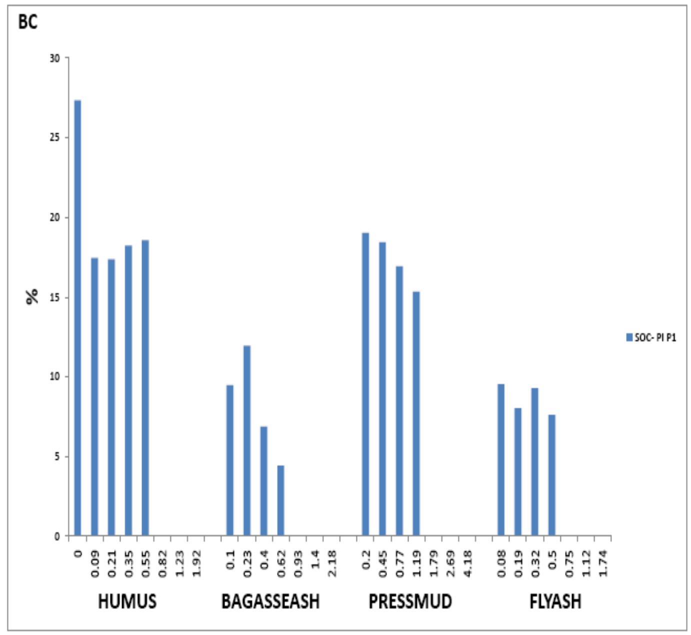

Figure-1a
SOC Vs PI on BC soil @ phase I

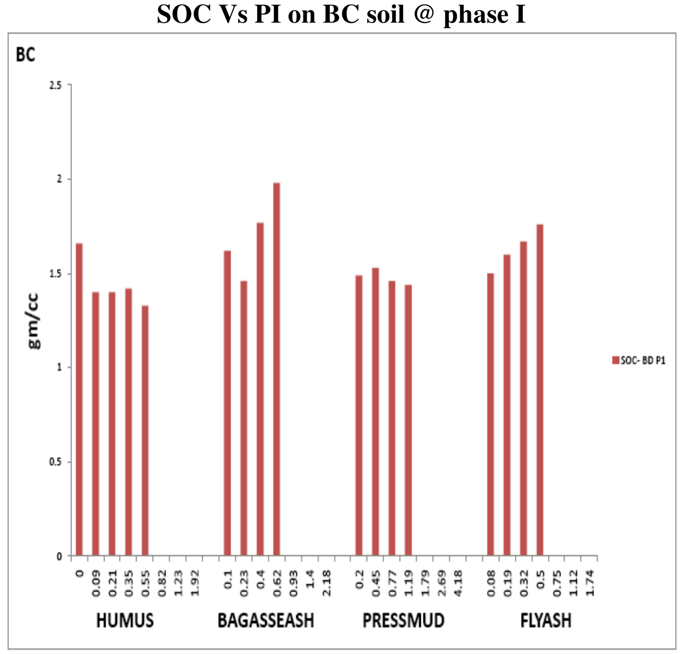

Figure-1b
SOC BD on BC soil @ phase I

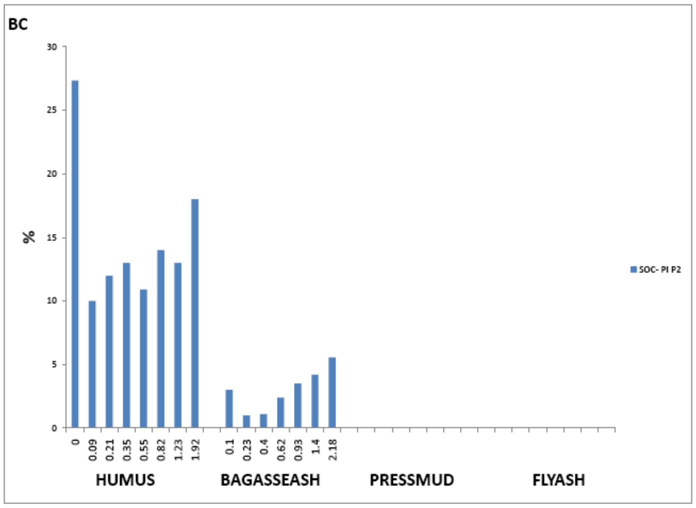

Figure-1c
SOC Vs PI on BC soil @ phase II

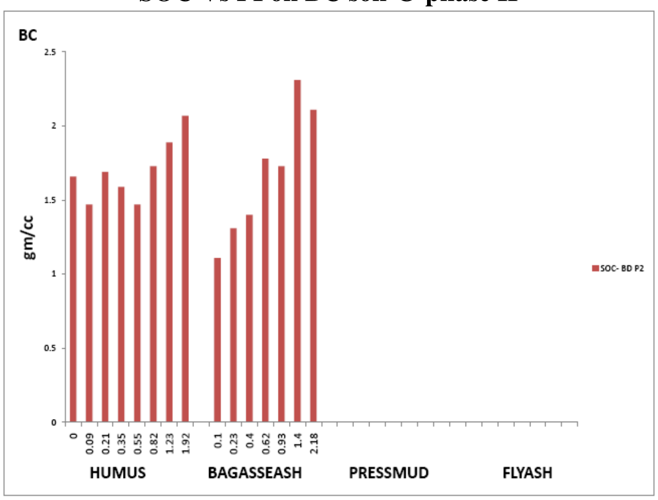

Figure-1d
SOC Vs BD on BC soil @ phase II

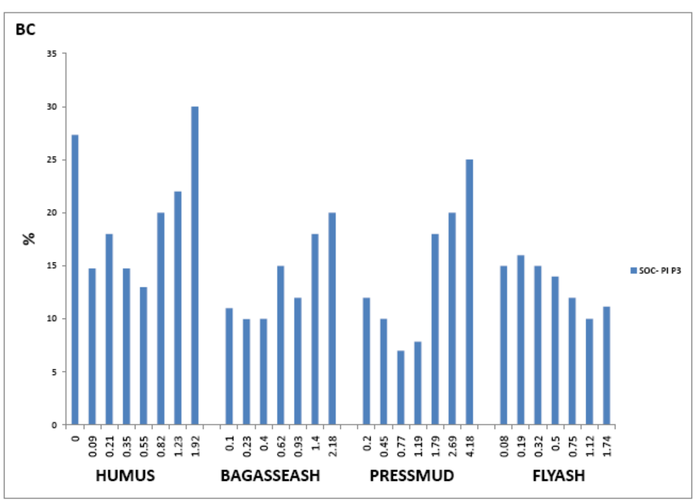

Figure-1e
SOC Vs PI on BC soil@ phase III

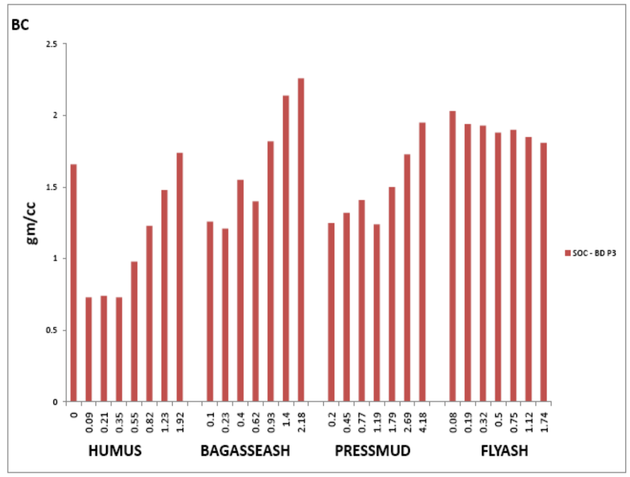

Figure-1f
SOC BD on BC soil@ phase III

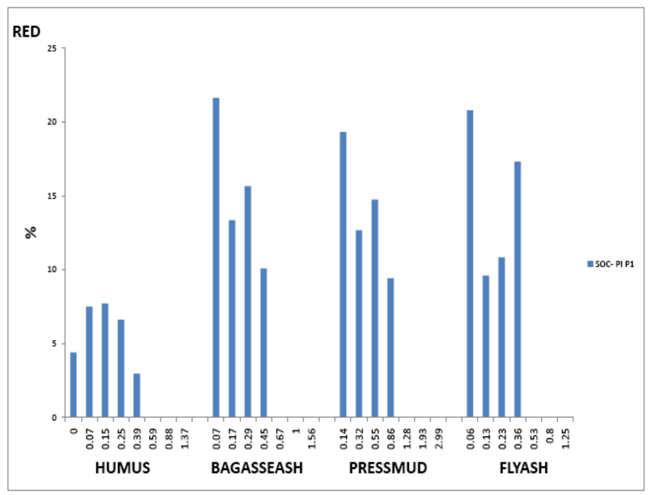

Figure-2a
SOC Vs PI on Red soil @ phase I

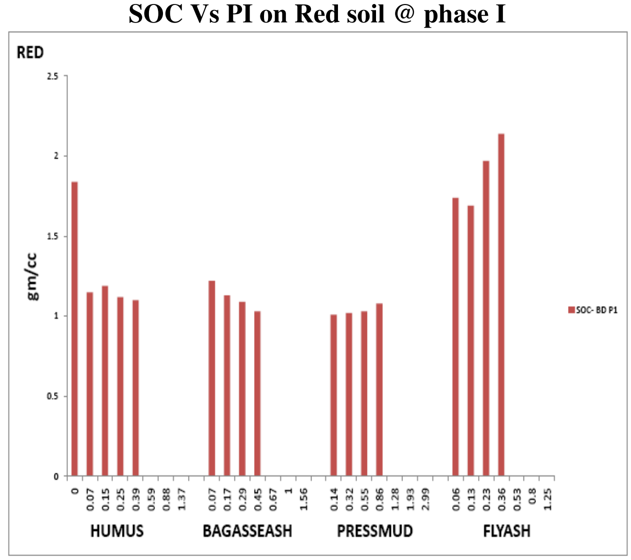

Figure-2b
SOC Vs BD on Red soil @ phase I

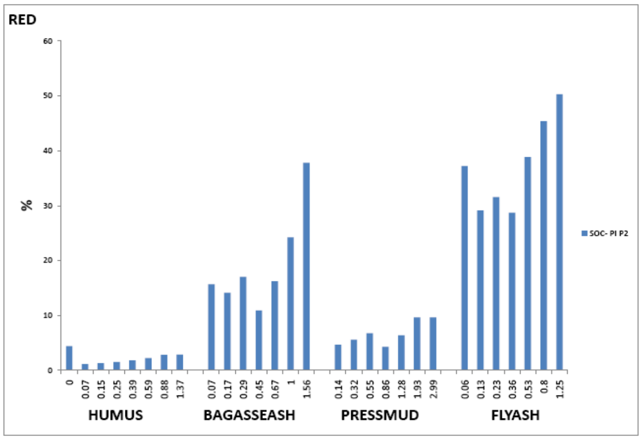

Figure-2c
SOC Vs PI on Red soil @ phase II

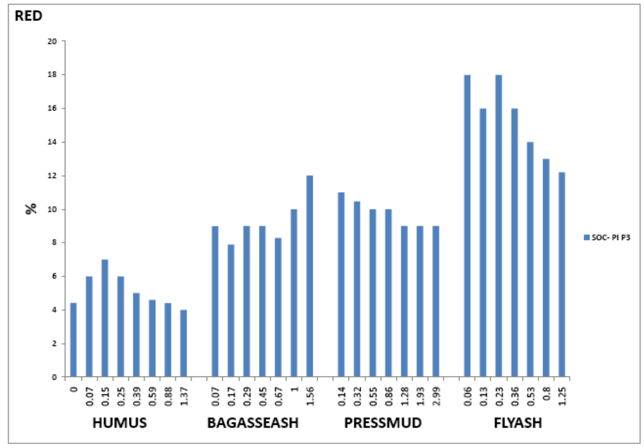

Figure-2e
SOC Vs PI on Red soil @phase III

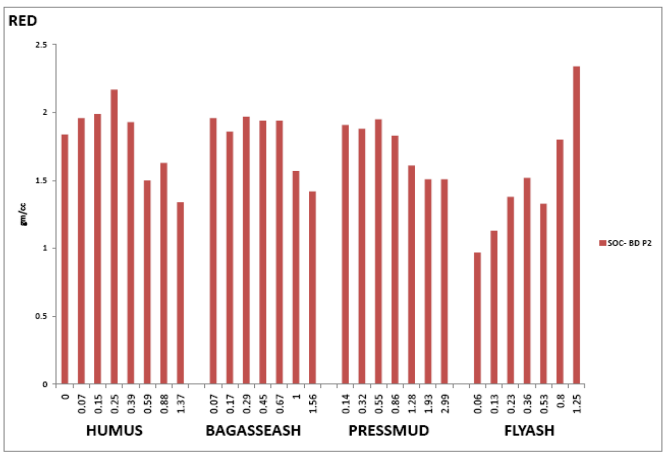

Figure-2d
SOC Vs BD on Red soil @ phase II

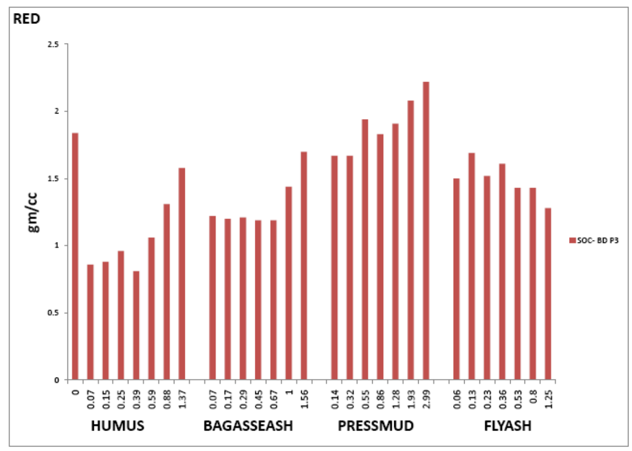

Figure-2f
SOC Vs BD on Red soil @ phase III

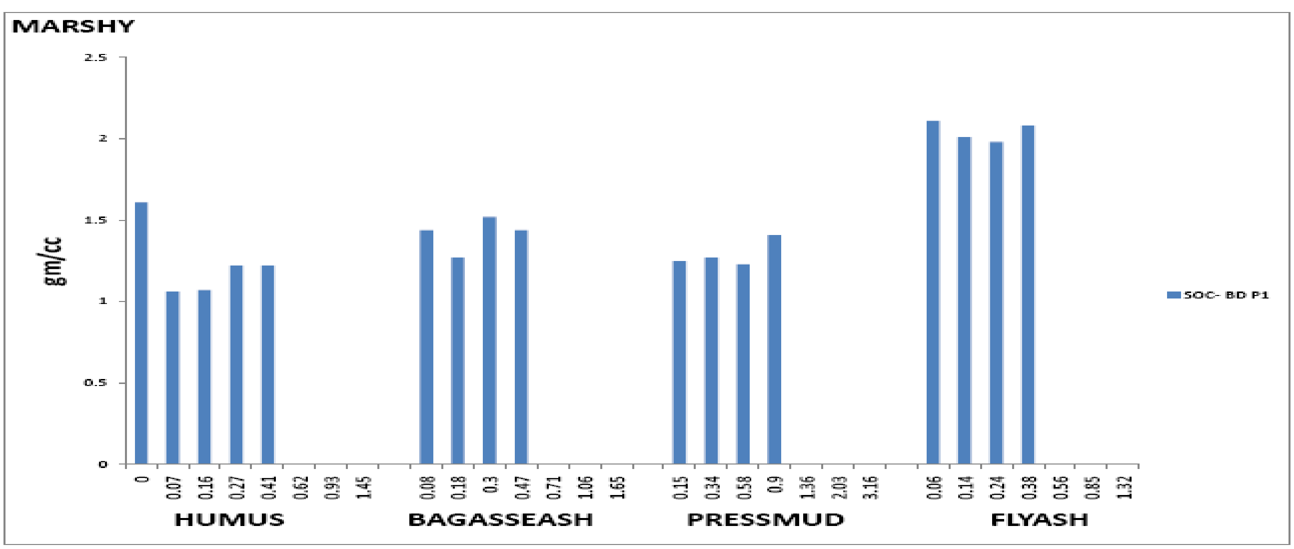

Figure-3a
SOC Vs BD on Marshy soil @ phase I

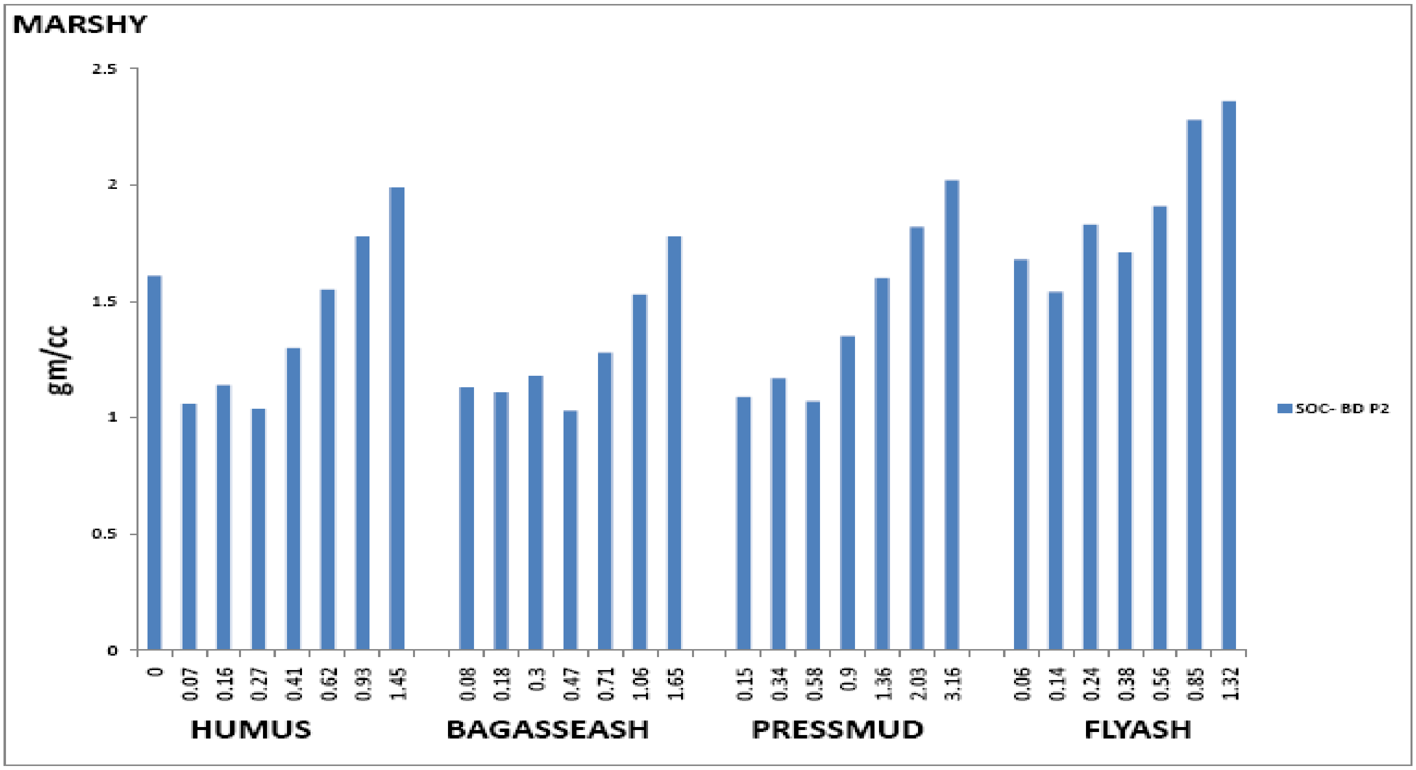

Figure-3b
SOC Vs BD on Marshy soil @ phase II

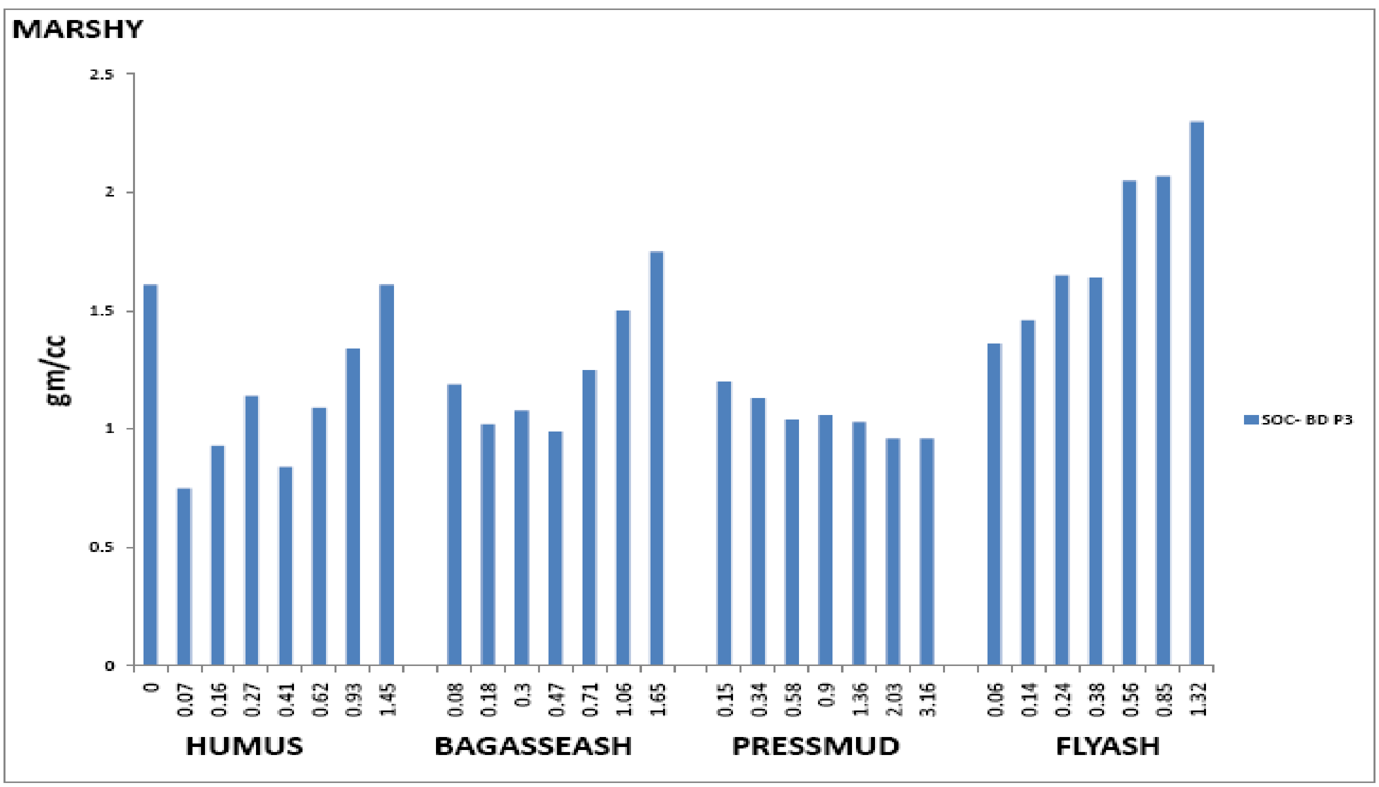

Figure-3c
SOC Vs BD on Marshy soil@ phase III

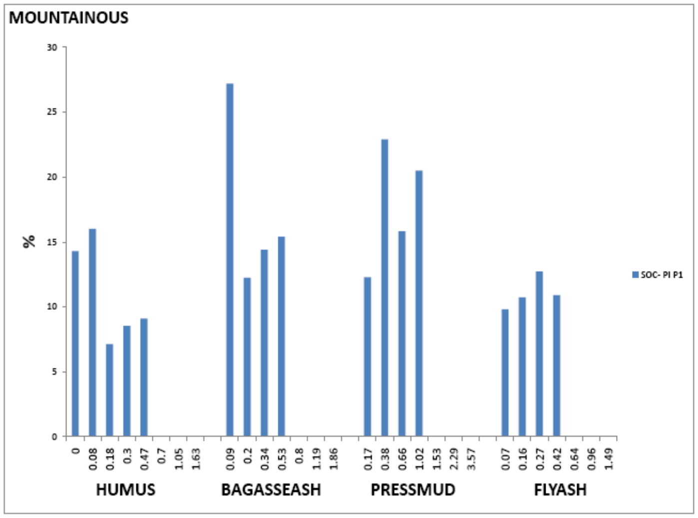

Figure-4a
SOC Vs PI on Mountainous soil @phase I

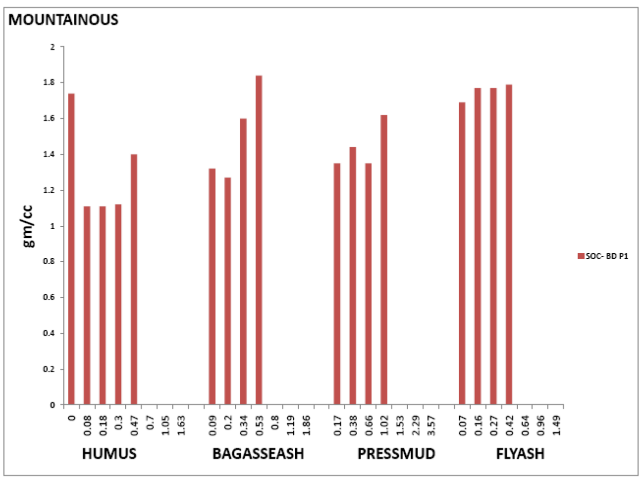

Figure-4b
SOC Vs BD on Mountainous soil@phase I

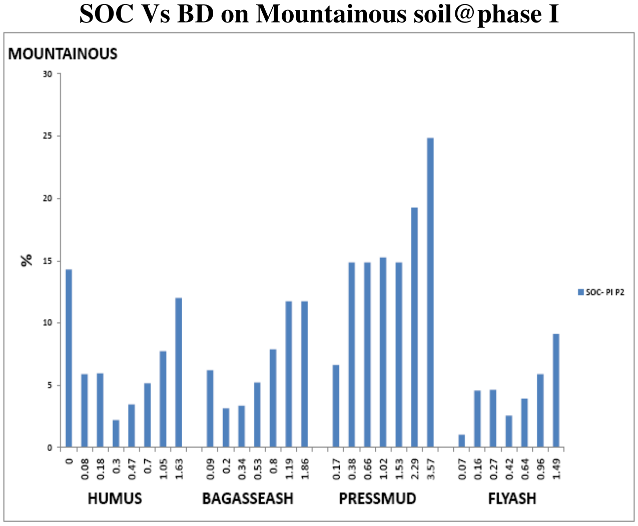

Figure-4c
SOC Vs PI on Mountainous soil phase II

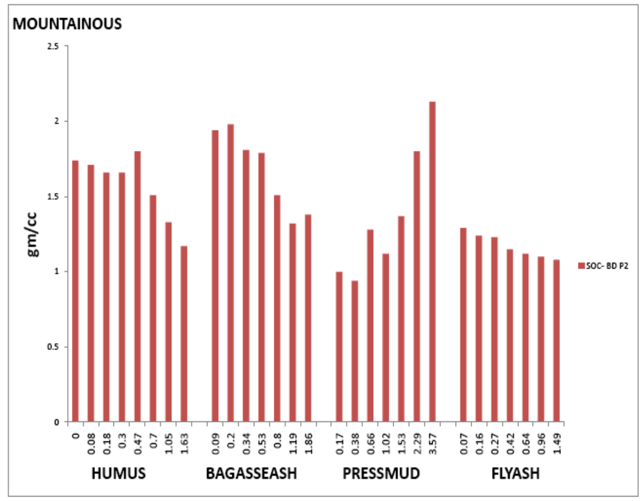

Figure-4d
SOC Vs BD on Mountainous soil@phase II

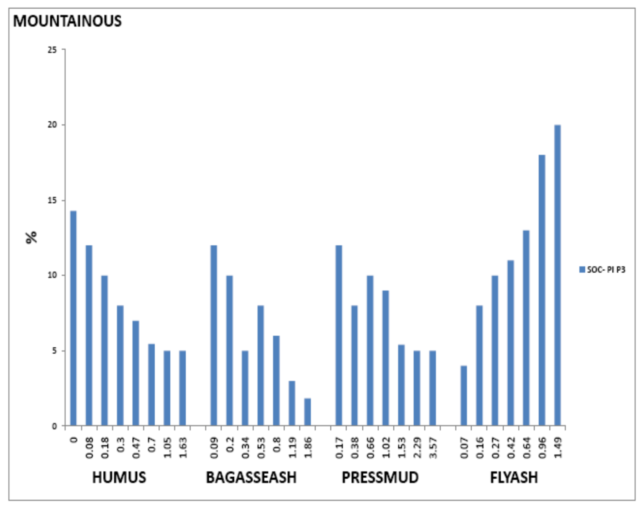

Figure-4e
SOC Vs PI on Mountainous soil@phase III

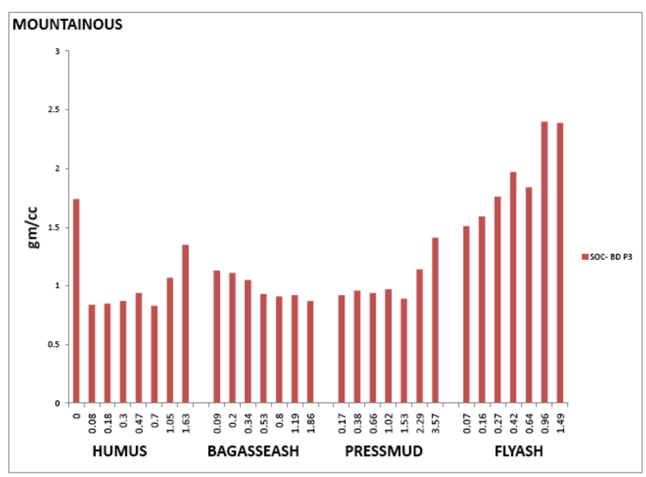

Figure-4f
SOC Vs BD on Mountainous soil@phase III

Plasticity Index (PI): The plasticity index is the range of water contents where the soil exhibits plastic properties. Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 tend to have little or no silt/clay content.

BC soil*:* Amending SOC reduced PI irrespective of phase in comparison with the control as seen in figure- 1 (a, c and e). Reduction in the PI was the sign of reduction in the percentage of fines. Increment in SOC increased PI only in phase I for humus amendment while for rest of the two phases increment in SOC reduced PI.

Red soil: Amending soil increased PI irrespective of phase as in comparison with the control as seen in Figure- 2 (a, c and e), except humus in phase I and II where the PI was reduced.

Marshy soil: Marshy soil was non plastic in nature.

Mountainous soil: Amending soil reduced PI in phase I as seen in figure- 4a. Similarly except pressmud in phase II PI reduced because of amending in comparison with the control as seen in figure- 5.4 (c and d).

PI for BC, red, mountainous soils in their natural forms were respectively 27.35 (High plastic), 4.41 (Slightly plastic), 16.77 (medium plastic), marshy soil was much of sand and little of clay hence it was non plastic. By amending these soils PI of all the soils was brought down to slightly plastic range (1-5). The reduction in PI is due to the decrement in the fines as a consequence of aggregation. Thus amending the soils enhances the physical property of soil making them highly permeable and protects them from high swell or shrink hence soils exhibit less compressibility and will be structurally strengthened. All the amendments reduced PI for BC soil. Except humus in phase II rest increased PI only for red soil, while for mountainous soil except phase I rest of the phases reduced PI, but the relation of SOC input with PI was varying.

Bulk Density: BC soil: Amending soil reduced BD irrespective of phase in comparison with the control at threshold limits of SOC as seen in figure- 1 (b, d and f). Reduction in BD was the sign of increased porosity. BDs were reduced for all phases with all amendments except flyash in phase III.

Red soil*:* Amending soil decreased BD irrespective of phase as in comparison with the control at threshold limits of SOC as seen in figure- 2 (b, d and f). A small input of pressmud was sufficient in reducing BD, increment in SOC hiked BD, while for the rest increment in SOC was reducing BD in phase I and III. In phase II little dose of flyash input was sufficient in reducing BD, increasing input of SOC increased BD, while the rest decreased BD with increasing SOC input..

Marshy soil*:* BD was reduced at threshold limits of SOC in comparison with the control as seen in figure- 3 (a, b and c). BD reduced in comparison with the control, due to amending less dense material to the soil.

Mountainous soil*:* Irrespective of phase BD was reduced at threshold limits of SOC for all the amendments in comparison with control as seen in figure- 4 (b, d and f). In phase I humus reduced the BD when compared with the rest. Pressmud reduced the BD to the lest when compared with rest of amendments in phase II. Except flyash rest of the amendments reduced bulk densities.

Amending soil with less dense material increased the specific surface area and enhanced the porosity which helped in the increment of WHC; Moisture preservation in the porous soil is dependent on the shape and angularity of individual pores. Natural pore spaces do not resemble cylindrical capillaries. since natural porous media are formed by aggregation of primary particles, the resulting pore space is more realistically described by angular or slit-shaped pore cross sections than by cylindrical capillaries as reported by Li and Wardlaw[22]and Mason and Morrow[23] in the study on soil moisture retention. Angular pores offer other advantages over cylindrical tubes in terms of liquid behavior, when angular pores are drained, a fraction of the wetting phase remains in the pore corners. This aspect of "dual occupancy" of the invaded portion of the tube, is not possible in cylindrical tubes as found by Morrow and Xi [24] in the study on Surface energy and imbibition into triangular pores. SOC induces soil aggregation and leads to the decrement in the bulk density of soil.

Irrespective of type of amendment, amended soils reduced their bulk densities as required for the plant growth. Humus irrespective of the soil type reduced the BD of soil to its least, as it promotes total porosity because bacterial glue acts as soil particle binding agent. These binding agents decrease the bulk density of the soil by improving soil aggregation and increase porosity. Next to humus it was bagasseash and pressmud that decreased the soil BD's the reduction in BD has been may be related to the mixing of soil with less dense organic material or by enhancing the fine particle aggregation leading to the higher pore volume in the soil as well as a decreased particle density. Thus increase in organic matter caused a relatively larger decrease in soil bulk densities.

It was phase III mode of amending that drastically reduced the BD of all the soils except red soil which had its BD reduced in phase I.

Conclusion

Experiments were conducted with disturbed soil samples to study the response of SOC on the arid soils. SOC helped in fine particle aggregation which leads to the increment in porosity of soils. Such of the pores hosted water, where soil water will be held by adhesive and cohesive forces within the soil leading to an increased water holding capacities of the soil. After fine particle aggregation soil turns coarse, even in the coarse state soil holds water which is due to the occurrence of angular pores created by the combination soil and amendment particles thus reducing the bulk densities of soils. There exists a definite threshold limit of SOC for the soil amendment combination below and beyond which bulk density cannot reduce anymore. Mode of application appreciably affects bulk densities. Humus irrespective of soil reduced the bulk density to least. Except in red soil performance of flyash was meager in other soils when compared with the rest of amendments.

Threshold limit of SOC had no appreciable role on PI. Though WHC of amended soil enhanced, PI reduced indicating reduction in silt/clay contents thus the soil is strengthened. Plasticity indices of soil amendment combinations at threshold were at low plastic range, while beyond threshold limit of SOC, PI were in slightly plastic range, this infer apart from SOC, type of amendment and its structure also matters for PI.

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