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Characterization of Soil Physical Resilience by Index Properties and Strength Characteristics of Selected Indian Soils

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ABSTRACT

The stability (resistance and resilience to disturbance) of a soil system is a key factor influencing ecosystem properties and processes. Soil quality and soil resilience are interrelated but dissimilar attributes. Soil physical resilience is more acute and problematic in nature as it requires long time duration for bouncing back to its original state. Some index properties like plasticity, swell-shrink potential, compaction, maximum dry density and strength characteristics of soil are very important for estimation of soil physical resilience. There is significant correlation between soil strength characteristics and clay content of the soil. Study indicated that *Alfisol* has better resistance and resilience than *Vertisol* and *Inceptisol.* Fly ash and organic amendments had significant favourable effect on soil resilience.

Key words Physical resilience, Index properties, Soil strength, Indian soils

INTRODUCTION

Soil degradation is the loss of actual or potential productivity or utility as a result of natural or anthropogenic factors (Lal, 1993). Essentially, it is the decline in soil quality or reduction in its productivity and environmental regulatory capacity. Yet, most soils have the inherent capacity to resist exogenous and endogenous perturbations and regain and recover, depending on the severity and duration of the degradative processes, and the intensity of restorative mechanisms (Blum and Santelises, 1994). Soil resilience refers to the intrinsic ability of a soil to resist or recover from an anthropogenic or natural perturbation and return to a new equilibrium similar to the antecedent state (Lal, 1993; 1994). Most soils do not offer resistance to perturbation, but are able to recover. The extent and the rate of recovery are high for a resilient soil (Patel *et al.,* 2012). Resilient soils have high elasticity (the rate of recovery) and amplitude (range of change in a property from which recovery is possible), and low malleability (the difference in the new versus the antecedent state) (Lal, 1993). Soil quality and soil resilience are interrelated but dissimilar attributes. Soil quality is related more to productivity and other functions than the ability of the soil to restore itself after a perturbation (Szabolcs, 1994). Soil resistance defined as the capacity of a soil to continue to function without change throughout a disturbance. Soil resilience is related to soil quality in terms of recovery of soil functions. Soil resistance is related to soil quality in terms of the degree of change of soil functions as a result of a disturbance (Seybold *et al.,* 1999). During a disturbance, soil quality becomes a function of soil resistance. After a disturbance, soil quality becomes a function of soil resilience (Lal, 1993; Szabolcs, 1994). Soil physical resilience is more acute and problematic in nature as it requires long time duration for bouncing back to its original state (Patel *et al.,* 2012). Identification of indicators of resilience may be useful prior to adopting any management practices having significant effects on soil quality and resilience (Blum and Santelises, 1994). Soil structure and aggregate stability are the main two soil indicators widely used for soil quality and resilience (Patel *et al.,* 2012). Soil compaction is a worldwide problem especially with the adoption of mechanized agriculture (Soane and Ouwerkerk, 1994). Soil compaction increases soil density, reduces porosity (especially macroporosity), water infiltration and percolation and leads to a degradation of soil structure. Severe compaction is known to cause yield reductions of 25% in maize, 20% in soybeans, and 30% in oats over a seven-year period (Lal, 1997). Compressive behaviour of a soil is expressed in terms of the relationship between

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stress and strain. When no prior stress has been applied, the relationship is usually linear. When soil experienced previous stresses (over-consolidated or pre-compacted), the relationship becomes curvilinear (Mosaddeghi *et al.*, 2003). Compactibility and plasticity were better related to intrinsic soil properties such as particle size distribution and clay mineralogy than to classifications of soil type, such as soil series, based on parent material and drainage (Mosaddeghi *et al.*, 2000). Clays tend to have low shear strengths and to lose shear strength further upon wetting or other physical disturbances. It can be plastic and compressible and they expand when wetted and shrink when dried. Therefore, the present study conducted to evaluate the physical resilience in terms of soil index properties and strength characteristics under various soils of India.

MATERIALS AND METHODS

The study conducted with three major soil orders (*Alfisol*, *Inceptisol* and *Vertisol*) of India. The soil samples were collected from the upper 15-20 cm at various locations like research firm of Birsa Agricultural University, Ranchi (23°23′ N latitude, 85°23′ E longitude at an altitude of 625 m above msl) for *Alfisol* and Indian Agricultural Research Institute, New Delhi (28°38′ N latitude, 77°09′ E longitude at an altitude of 229 m above msl) representing *Inceptisol* and from Indian Institute of Soil Science, Bhopal (23°19′ N latitude, 75°03′ E longitude at an altitude of 495 m above msl) for *Vertisol*. The soils were air dried at 25^{o}C, passed through 2 mm sieve and analyzed for various index properties like plasticity, maximum dry density, optimum moisture content and strength characteristics i.e. Californian Bearing Ratio (CBR) of various soil orders under simulated condition with different moisture and compaction levels. The peak dry unit weight is called the "maximum dry density". The Optimum Moisture Content OMC) is the moisture content at the soil's maximum dry density. The Proctor compaction test (ASTM, 2007) done in laboratory condition for determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density. Liquid limit and plastic limit of the soils were measured by Casagrande's apparatus followed by standard method (Black, 1965). Californian Bearing Ratio (CBR) indicates the soil's resistance to force and the swell and strength potential of the soil with the soil properties. It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston. There were two simulated conditions for moisture content and compaction levels, each. Two extreme conditions of moisture content were unsoaked (without a drop of water) and soaked condition i.e. complete saturation for 96 hours continuously (Photoplate 1a and 1b). There was heavy compaction level, defined as a layer of 5 equal soil portions, each being given 55 blows with a standard rammer weighing 4.89 kg (Photoplate 1c). Similarly for light compaction level, it was having 3 equal soil layers, each being given 55 blows with standard rammer weighing 2.60 kg (Photoplate 1d). CBR measured by standard procedure with the help uniaxial load cell (Photoplate 1e). Resilient modulus (M_r) is defined as the ratio between repeated deviator stress and resilient strain.

Photoplate 1: Various stages of soil compaction study for evaluation of CBR

For any soil, at a given compactive effort, the density obtained depends on the moisture content. An "optimum water content" exists at which it will achieve its maximum density. The peak dry unit weight is

1a: Unsoaked condition (No water added)

1b: Soaked condition (Complete saturation for 96 hours)

1c: Heavy compaction (5 layers, 55 blows to each layer by 4.89 kg rammer)

1d: Light compaction (3 equal layers, each being given 55 blows by 2.6 kg rammer)

1e: Final measurement for CBR and resilient modulus calculation called the maximum dry density (MDD). The Optimum Moisture Content (OMC) is the moisture content at the soil's maximum dry density. M_r of the soils was calculated based on the equation (George, 2004):

$$M_r \text{ (MPa)} = 10.342 \text{ (CBR)}$$

Various soil amendments like FYM, Biochar, Polutry manure and fly ash etc. also tried to evaluate their effect on soil physical resilience. The soils were incubated with these amendments for long period (10 weeks) and then the index properties and strength analysis were done under laboratory condition.

RESULTS AND DISCUSSION

Study indicated that Maximum dry density (MDD) of all the soils increased while optimum moisture content (OMC) reduced under heavy compaction as compared to light compaction (Anon, 2012). In all the soil orders, the dry density initially increases with increase in moisture content up to a certain extent and thereafter dry density decreases with increase in moisture content (Fig. 1). In case of *Alfisol*, MDD and OMC values are 2.02 g/cc

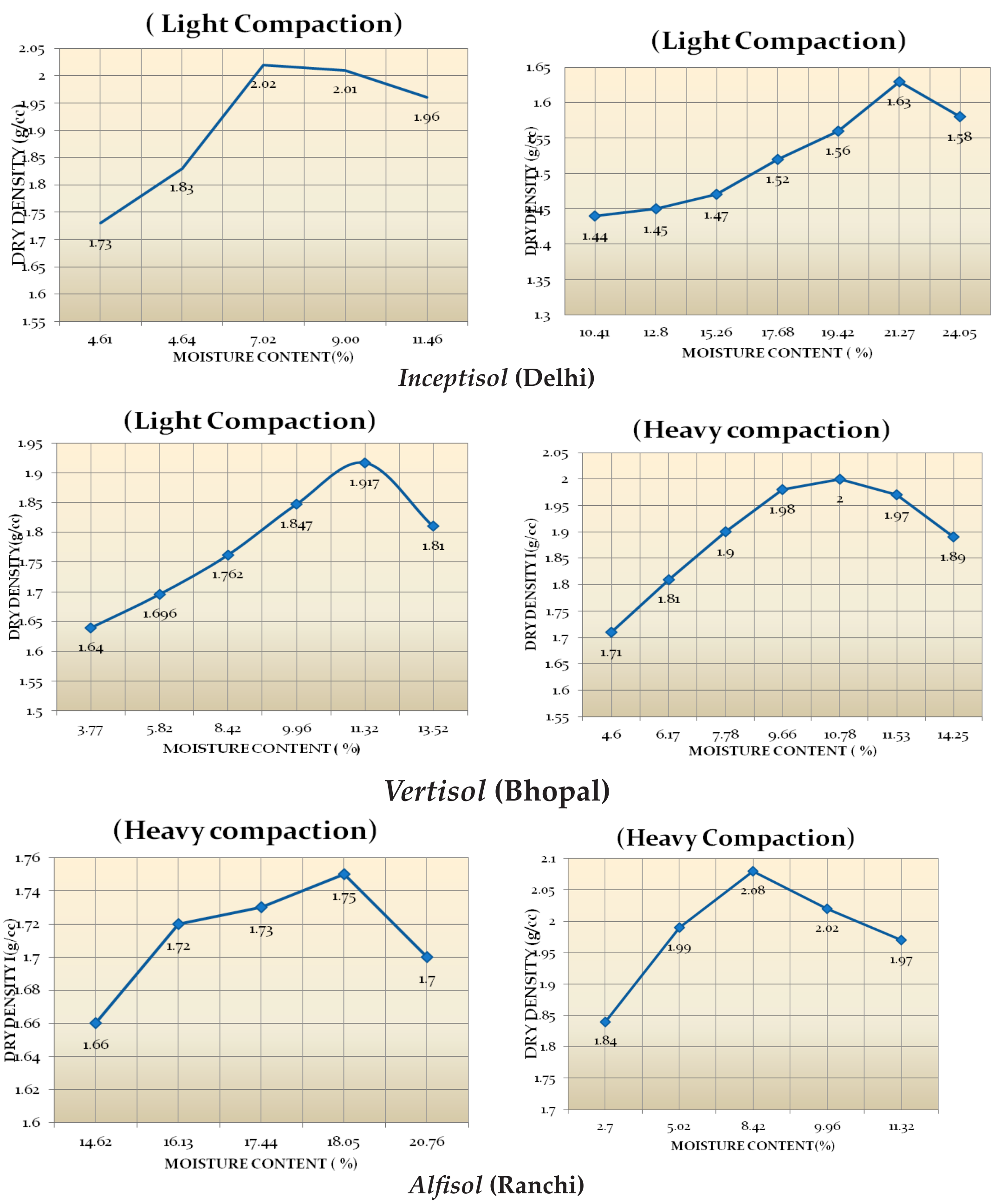

Fig. 1: The relationship between maximum dry density (MDD) and optimum moisture content (OMC) under various soil orders.

and 7.02% under light compaction and 2.08 and 8.42% under heavy compaction level. Similarly for *Inceptisol*, MDD and OMC values are 1.92 g/cc and 11.32% under light compaction and 2.008 and 10.78% under heavy compaction level. In *Vertisol*, these values are 1.63 g/cc and 21.27% under light compaction and 1.75 and 18.05% under heavy compaction level, In general, the MDD values under any compaction level followed the trend: *Alfisol* > *Inceptisol* > *Vertisol*. Results revealed that SOC is closely correlated with liquid limit (correlation coefficient, r=0.94, $P \leq 0.05$), plastic limit (r=0.97, $P \leq 0.05$) and gravimetric water contents at -33 kPa (r= 0.89, $P \leq 0.05$). The clay type and its amount along with organic matter control the soil specific surface and this subsequently determines the plastic and liquid limits (Anon, 2013).

CBR value varies with plasticity index, when plasticity index increases CBR value decreases and when plasticity index decreases CBR value increases. Study (Fig. 2a and 2b) showed low CBR (range 1.65-2.02% and 4.36-5.52% under soaked and unsoaked conditions, respectively) under *Vertisol* and *Inceptisol* (range 2.14-3.72% and 4.29-6.36% under soaked and unsoaked conditions, respectively) as compared to *Alfisol* (range 4.53-6.56% and 33.78-43.06% under soaked and unsoaked conditions, respectively). Low CBR might be due to the inherent low strength which is due to the dominance of the clay fraction (Anon, 2012). The reduction in CBR may be attributed to the water holding capacity of the soil subjected to load (Anon, 2013).

Soil amendments (Fly ash, biochar, poultry manure and FYM) have favourable effect on the plasticity parameters such as liquid limit, plastic limit and shrinkage limit. The liquid and plastic limits decrease (23-37%) while the shrinkage limit increases (19-28%) with the addition of fly ash. The addition of fly ash results in the decrease of liquid limit due to the effect of reduction in the diffused double layer thickness as well as due to the effect of dilution of clay content of the soil (Hakari, and Puranik, 2012). The compaction characteristics like the maximum dry density increases with the corresponding decrease in optimum moisture content. The addition of fly ash results in increased flocculation due to increased availability of free lime content of fly ash. This increases the repulsive forces of soil particles, thereby increasing the resistance to compactive effort (Hakari, and Puranik, 2012; Yadu *et al*., 2011).

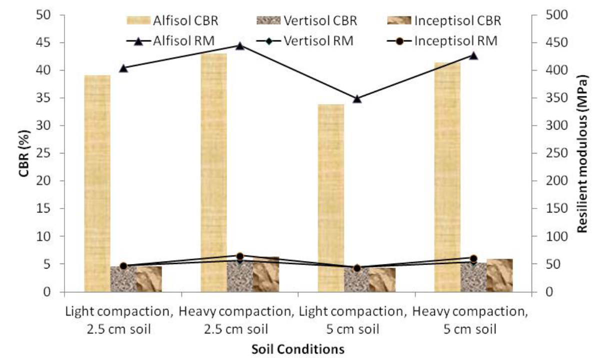

Fig. 2a: Soil strength characteristics of major soil orders under soaked condition

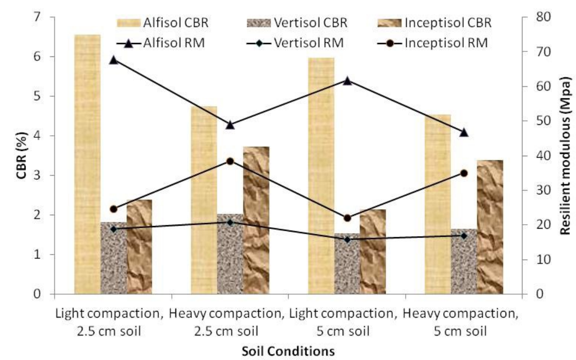

Fig. 2b: Soil strength characteristics of major soil orders under unsoaked condition

CONCLUSION

The present study suggests that soil index properties and strength characteristics are very crucial for soil physical resilience. The bearing capacity has linear correlation with liquid and plastic limits if other factors not effected to that. There is possibility in control of soil foundation load acceptability by maintaining of soil liquid limit and plastic limit in mixed soil under compacted condition. Moreover, fly ash and organic amendments had significant favourable effect on soil resilience. Thus, it can be applied in compacted degraded soil for better resilience and sustainable crop production. However, more studies are needed for better understanding of soil deformation and critical limits of soil indicators for its wide application for soil resilience study.

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