# Soil degradation effect on soil productivity, carbon pools and soil enzyme activity

**Narendra K. Lenka[1,*], S. P. Jaiswal[1,2], J. K. Thakur[1], S. Lenka[1], A. Mandal[1], A. K. Dwivedi[2], B. L. Lakaria[1], A. K. Biswas[1], A. K. Shukla[1] and D. S. Yashona[1]**

[1]Indian Institute of Soil Science, Nabibagh, Bhopal 462 038, India
[2]Jawaharlal Nehru Krishi Viswa Vidyalaya, Jabalpur 482 004, India

**Land degradation is one of the major causes of decline in soil productivity. However, the quantitative relationship between degradation and productivity is not fully understood in soils of India. Thus, an experiment was conducted under a range of native soil organic carbon (SOC) levels in two soil types (Inceptisol and Alfisol) of subtropical India. The SOC content under the treatments was 1.61%, 1.01% and 0.77% in Inceptisol and 0.36%, 0.25% and 0.21% in Alfisol under $C_1$ (undepleted soil), $C_2$ (low depletion) and $C_3$ (medium depletion) treatments respectively. Soybean was grown under each SOC level, with four management practices, viz. (1) control, (2) recommended dose of fertilizers (RDF) + 10 Mg farmyard manure (FYM) ha$^{-1}$, (3) 20 Mg FYM ha$^{-1}$ and (4) 150% RDF, in three replicates in a factorial completely randomized design. Results indicated significant and positive effect of both SOC and management treatment on plant biomass yield, labile ($KMnO_4$ oxidizable) carbon, soil microbial biomass carbon (SMBC), dehydrogenase activity, soil bulk density (BD) and penetration resistance (PR). The plant biomass reduced by 45% and 29% under $C_3$ (compared to $C_1$) in Inceptisol and Alfisol respectively. The effect of SOC depletion was conspicuous in Inceptisol. The labile C reduced by 47% and 16% under $C_3$ in Inceptisol and Alfisol respectively. SMBC showed a corresponding decrease of 33% and 29%. The soil physical properties, viz. BD and PR showed conspicuous effect of SOC depletion. PR increased by 324% and 75% for Inceptisol and Alfisol respectively.**

**Keywords:** Labile carbon, soil degradation and productivity, soil microbial biomass, soil physical properties.

THE role of soil towards food and nutrition security and providing ecosystem services is being increasingly recognized in the context of widespread land degradation in various parts of the world[1]. The decline of soil organic carbon (SOC) is one of the major causes of land degradation. SOC is both a source and sink of nutrients and contributes significantly to providing ecosystem services, including maintenance of soil fertility and adaptation to climate change risks. The SOC level is also critical in determining crop response to nitrogen (N) and phosphorus (P) fertilization[2,3], maintaining good soil structure and aggregation[4] and improving plant–soil–water relationship.

The decline in SOC content due to various factors is one of the major constraints to crop productivity and food security across the globe[2,5,6]. However, of greater concern is the decline in the labile carbon fractions[7]. The labile carbon (C) pool is the fraction of SOC with the most rapid turnover rates and is important from the point of soil nutrient dynamics and soil structure stability. This pool is also sensitive to land management changes[7]. When a soil is subjected to degradation cycle, it is the labile fraction that gets depleted first[8,9].

The positive effects of soil organic matter (SOM) on soil properties which influence crop performance, are well documented. However, quantitative information on the contribution of increment of SOM to soil productivity from experimental findings is meagre or based on estimates[4,5,10,11]. From a fertility rating study in central Uganda[4], each unit increase in SOC concentration in the surface soil was reported to contribute 966–1223 kg ha$^{-1}$ of grain yield. Increase of 1 Mg of soil carbon pool of degraded cropland soils was estimated to enhance crop yield by 20–40 kg ha$^{-1}$ in wheat, 10–20 kg ha$^{-1}$ in maize, and 0.5–1 kg ha$^{-1}$ in cowpeas[5]. In a different experiment, 1 Mg organic matter (OM) ha$^{-1}$ was reported to contribute 35.2 kg ha$^{-1}$ of dry biomass and 15.6 kg ha$^{-1}$ of wheat yield[10]. In an experiment in semi-arid sub-tropical India[11], wheat productivity increased from 15 to 33 kg ha$^{-1}$ per 1 Mg increase in SOC.

Further, a degraded soil with better management practices responds and recovers to the near original level. However, soils vary in their capacity or ability to respond, which not only depends upon the soil type but also on the stage of degradation and SOC content[8,12]. Thus, the question of existence of critical level of SOC content with regard to soil productivity may be valid[2,13]. In the context of widespread soil degradation, it is important to study the behaviour of a degraded soil in terms of key properties such as soil structure and penetration resistance favouring root growth, microbial and enzymatic activity and overall capacity of the soil to produce a crop, under specific management practices. However, only a few studies report the effect of degradation on soil physical

*For correspondence. (e-mail: nklenka@rediffmail.com)

properties, labile carbon and soil productivity. Hence, the present study was conducted in two soil types at three different SOC levels with the objective to examine the relationship between native SOC and degradation level and that of soil productivity, SOC pools and selected soil properties.

The study was taken up as a controlled experiment in pots at the Indian Institute of Soil Science, Bhopal, Madhya Pradesh. The study site is located at 23°15′N lat. and 77°25′E long., at 427 m amsl and is characterized by a humid subtropical climate with a mild, dry winter and a hot summer followed by a humid monsoon season. The present investigation was carried out by artificially degrading the soils under study through depletion of native soil carbon to obtain a gradient of SOC. Two contrasting soil types, viz. silty clay loam and sandy loam soil, collected from Aizawl region, Mizoram, North East India and Ranchi region, Jharkhand, eastern India respectively, were used for the study. According to the USDA soil classification, they belong to Inceptisol and Alfisol respectively. The native SOC level and other soil properties widely differed in the two soils (Table 1).

Soybean (cultivar: JS 335) crop was taken during July to November 2011 in net enclosures and kept in the open. Prior to raising the experimental crops in the selected soils, a gradient of SOC was created through partial oxidation treatment of the soils with mild concentration of hydrogen peroxide ($H_2O_2$). The depletion of native SOC was accomplished by partial oxidation of the soil with 3% and 6% $H_2O_2$ for achieving low and medium depletion levels. The partially oxidized soil was dried followed by grinding and sieving through a 2.0 mm sieve. The soil that passed through a 2.0 mm sieve was used for filling the pots. Before initiation of the crop experiment, the pots were subjected to three cycles of wetting and drying, so as to achieve optimum settling of the soil and remove any residue of $H_2O_2$. To testify the same, germination test with wheat seeds was carried out with untreated and treated soil samples. The test showed no difference in germination per cent between the treated and untreated soil samples.

**Table 1.** Physical and chemical properties of soils used in the present study

| Properties | Silty clay loam (Inceptisol) | Sandy loam (Alfisol) |
|---|---|---|
| Sand (%) | 24.5 ± 2.5 | 61.0 ± 1.0 |
| Silt (%) | 27.5 ± 2.5 | 15.5 ± 1.5 |
| Clay (%) | 48.0 ± 4.0 | 23.5 ± 0.5 |
| pH (1 : 2.5) | 5.36 ± 0.02 | 4.53 ± 0.02 |
| EC (1 : 2.5) μS $m^{-1}$ | 334 ± 12 | 84.6 ± 5 |
| SOC (g $kg^{-1}$) | 16.1 ± 0.82 | 3.6 ± 0.11 |
| Available nitrogen (kg $ha^{-1}$) | 285 ± 20 | 150 ± 14 |
| Available phosphorus (kg $ha^{-1}$) | 13.6 ± 2.2 | 7.4 ± 0.16 |
| Available potassium (kg $ha^{-1}$) | 361 ± 23 | 151 ± 10 |

Three distinct SOC levels were obtained for each soil type through oxidation, representing three SOC depletion levels ($C_1$, undepleted soil; $C_2$, low depletion and $C_3$, moderate depletion). For Inceptisol, SOC values as determined by Walkley and Black wet digestion method were 1.61%, 1.01% and 0.77% for $C_1$, $C_2$ and $C_3$ treatments respectively. The corresponding values for Alfisol were 0.36%, 0.25% and 0.21% respectively. The three different SOC levels under each soil type were treated with four management practices, viz. (1) control, (2) recommended dose of fertilizers (RDF) + 10 Mg FYM $ha^{-1}$, (3) 20 Mg FYM $ha^{-1}$ and (4) 150% RDF, resulting in 12 treatments for each soil type. The treatments were replicated thrice and thus, 36 pots were used for each soil type. The crop was fertilized at the rate of 30 : 60 : 30 $N–P_2O_5–K_2O$ kg $ha^{-1}$ through urea, single super phosphate and muriate of potash at the time of sowing. Seeding was done at 4 cm depth @ five plants in each pot containing 10 kg of soil. The crop was irrigated on alternate days and housed in a rain-proof structure, but open to the ambient atmosphere from four sides. Recommended agronomic practices were taken up to keep the crop weed- and pest-free.

Soil samples were collected before the crop was sown and after harvest of the crop from 0 to 10 cm depth. The samples were air-dried and processed for further analysis. For the analysis of soil microbial biomass and dehydrogenase activity, fresh soil samples were collected from each pot at field moist condition. Soil bulk density (BD) was estimated by core method from 0 to 5 cm depth. Root penetration resistance was measured *in situ* by a hand-held cone penetrometer. Labile carbon ($KMnO_4$ oxidizable) was estimated by the method of Blair *et al.*[7] and Weil *et al.*[14]. The aboveground biomass samples of the test crop were collected from each pot at harvest. The plant samples were dried in a hot-air oven at 70°C to constant weight and then weighed for computation of aboveground biomass per pot.

Soil microbial biomass carbon (SMBC) was determined by fumigation extraction method[15]. For each pot, one out of three sub-samples (each 10.0 g fresh soil) was fumigated with ethanol-free chloroform for 24 h at 25°C in a vacuum desiccator. The remaining non-fumigated samples were used as control and for estimation of moisture content. Fumigated and non-fumigated soils were extracted with 25 ml 0.5 M $K_2SO_4$ and shaken for 30 min on a reciprocal shaker. The extracts were filtered and 10 ml of the filtrate was used for estimation of organic carbon using 0.2 N $K_2Cr_2O_7$ digestion procedure.

SMBC was calculated as

$$\text{SMBC} = \text{EC}/K_c,$$

where EC = (organic C extracted from fumigated soils) – (organic C extracted from non-fumigated soils) and $K_c = 0.25$ according to Bremner and Kesssel[16].

**Table 2.** Summary of analysis of variance showing significance ($P > F$) of effect and least significant difference ($LSD_{0.05}$) values at 95% level of significance for studied parameters

| | Inceptisol | | | Alfisol | | |
|---|---|---|---|---|---|---|
| Parameters/factors | d*f* | *P* value | LSD (0.05) | d*f* | *P* value | LSD (0.05) |
| Aboveground biomass | | | | | | |
| *A* | 2 | <0.01 | 1.88 | 2 | <0.01 | 1.81 |
| *B* | 3 | <0.01 | 2.18 | 3 | 0.01 | 2.09 |
| *A* × *B* | 6 | 0.01 | 3.76 | 6 | 0.51 | NS |
| Labile carbon | | | | | | |
| *A* | 2 | < 0.01 | 66.35 | 2 | 0.06 | NS |
| *B* | 3 | < 0.01 | 76.62 | 3 | 0.07 | NS |
| *A* × *B* | 6 | 0.01 | 132.70 | 6 | 0.50 | NS |
| Microbial biomass C | | | | | | |
| *A* | 2 | <0.01 | 15.2 | 2 | 0.03 | 18.7 |
| *B* | 3 | 0.16 | NS | 3 | 0.18 | NS |
| *A* × *B* | 6 | 0.54 | NS | 6 | 0.14 | NS |
| Dehydrogenase activity | | | | | | |
| *A* | 2 | 0.01 | 15.12 | 2 | 0.03 | 9.06 |
| *B* | 3 | 0.12 | NS | 3 | 0.26 | NS |
| *A* × *B* | 6 | 0.37 | NS | 6 | 0.42 | NS |
| Bulk density | | | | | | |
| *A* | 2 | <0.01 | 0.026 | 2 | <0.01 | 0.013 |
| *B* | 3 | 0.03 | 0.03 | 3 | 0.01 | 0.015 |
| *A* × *B* | 6 | 0.74 | NS | 6 | 0.53 | NS |
| Penetration resistance | | | | | | |
| *A* | 2 | <0.01 | 0.48 | 2 | <0.01 | 0.32 |
| *B* | 3 | 0.08 | NS | 3 | 0.85 | NS |
| *A* × *B* | 6 | 0.23 | NS | 6 | 0.59 | NS |

*A*, Soil organic carbon level; *B*, Nutrient management; NS, Not significant; d*f*, Degrees of freedom.

For estimation of dehydrogenase activity[17], 1 g of air-dried soil sample was saturated with 0.2 ml of 3% triphenyl tetrazolium chloride (TTC) solution. After 24 h of incubation, 10 ml of methanol was added followed by shaking. The clear pink colour supernatant was withdrawn after 6 h and absorbance was measured in a spectrophotometer at 485 nm wavelength. The amount of triphenylformazan (TPF) formed in each sample was calculated from the standard curve and dehydrogenase activity was expressed as μg TPF formed/g soil/24 h.

The experimental data was analysed using analysis of variance (ANOVA) as relevant for factorial completely randomized design (CRD). The data were tested to be normally distributed with homogeneity of variances. The individual effect of the two factors (SOC level and nutrient management) and their interaction effect were compared at 95% level of significance. For post-hoc analysis, least significant difference (LSD 0.05) test was carried out using SAS Version 9.2.

The native SOC level showed significant and positive ($P < 0.05$) effect on plant biomass under both soil types (Table 2 and Figure 1). In most treatments, $C_1$ was significantly higher than $C_2$, while $C_2$ was significantly higher than $C_3$, and the trend was similar in both the soils. Under all the management practices in Inceptisol, there was a significant reduction in the biomass yield with depletion in SOC level, and on an average, 32% and 45% lower biomass was observed under $C_2$ and $C_3$ treatments respectively compared with that in $C_1$. However, the trends were different in Alfisol, where biomass reduction was not consistently observed between $C_1$ and $C_2$ in all the management treatments (Figure 1). The significant reduction compared to $C_1$ was observed only under moderate depletion ($C_3$). The effect of management was significant in both the soils, though the interaction effect was significant only in Inceptisol. The data indicated that the decline in biomass yield was compensated most under $M_2$ in case of Inceptisol, whereas it was under $M_3$ in Alfisol. In case of Inceptisol, biomass yield of $C_2$ recovered by 21% under $M_2$ and 11% under $M_3$. The corresponding values for $C_3$ were 21% and 20% for $M_2$ and $M_3$ respectively. In Alfisol, the ameliorative effect was higher, with 41% and 56% recovery under $M_2$ and $M_3$ respectively, at the $C_2$ level. At the $C_3$ level, the corresponding values of recovery were 8% and 22% respectively.

In general, the labile C was significantly higher under $C_1$ and gradually reduced from $C_1$ to $C_2$ and from $C_2$ to $C_3$ in both the soils under study. There was a significant and positive effect of native SOC on labile C in both the soils, though the effect of nutrient management was non-significant in Alfisol. The interaction effect was significant for Inceptisol only (Table 2). With respect to management practice, trends were different for both the soil types (Figure 2). The values were higher under $M_3$ in

Inceptisol, and under $M_2$ in case of Alfisol. The effect of SOC level was also conspicuous, with significant reduction in labile C with decrease in SOC content. The reduction was observed under all the management practices. Averaged over management practices, there was about 27% reduction in labile C from $C_1$ to $C_2$ and 47% reduction from $C_1$ to $C_3$. In Alfisol also, there was a trend of decrease in labile C with reduction in SOC under all the management practices. On an average, there was 7% reduction in labile C from $C_1$ to $C_2$ and 16% from $C_1$ to $C_3$, but the effect was not significant.

SMBC was significantly ($P < 0.05$) and positively influenced by SOC level in the two soils. However, there was no significant effect of nutrient management and interaction in both the soils (Table 2). At all the SOC and management levels, SMBC was relatively higher in Inceptisol than in Alfisol. Further, it was significantly higher at $C_1$ and significantly decreased with depletion of SOC level, with the trend uniformly observed in both the soil types (Figure 3). Averaged over management practices, and compared to $C_1$, SMBC was lower by 19% at $C_2$ and by 33% at $C_3$ in Inceptisol, and the corresponding values for Alfisol were 17% and 29% respectively. SMBC responded to recovery with management practices, particularly under $M_3$ followed by $M_2$.

The dehydrogenase activity (DHA) was significantly ($P < 0.05$) and positively influenced by SOC level (Table 2). However, the effect of management treatments and the interaction of SOC and management were not significant in both the soils (Figure 4). DHA varied from 72 ($C_3M_2$) to 112 ($C_2M_3$) µg TPF/g soil/24 h in Inceptisol and from 47 to 80 ($C_2M_1$) µg TPF/g soil/24 h in Alfisol. In both the soils, DHA reduced at $C_3$ and response to management treatments could not be observed. Though there was a trend of recovery in DHA under depleted SOC level in $M_2$ and $M_3$ the effect was non-significant.

With the reduction in SOC, soil bulk density was significantly ($P < 0.05$) higher in both the soils (Table 2).

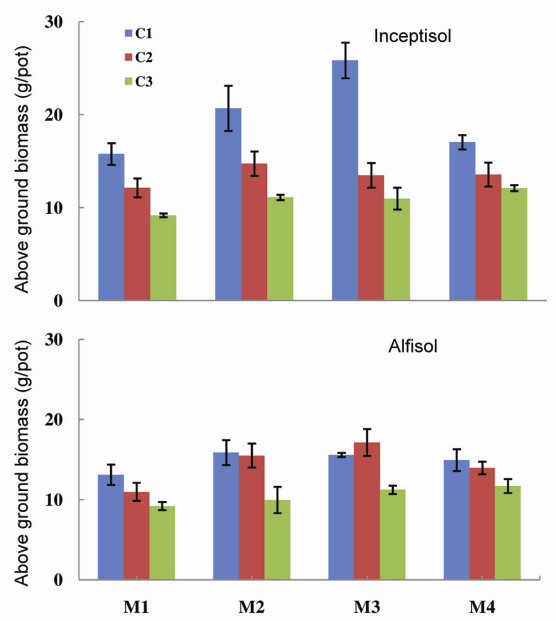


**Figure 1.** Effect of native soil organic carbon (SOC) levels ($C_1$, $C_2$, $C_3$ referring to undepleted, low and moderate soil C depletion) and nutrient management practices ($M_1$, control, $M_2$, 100% RDF + 10 t FYM/ha; $M_3$, 20 t FYM/ha and $M_4$, 150% RDF) on aboveground biomass of soybean. Vertical bars indicate standard error of mean (SEM).

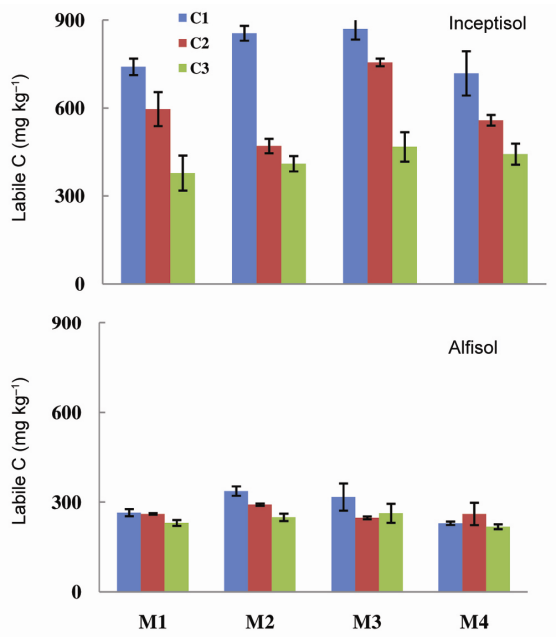


**Figure 2.** Effect of native SOC levels ($C_1$–$C_3$) and nutrient management practices ($M_1$–$M_4$) on soil labile carbon content (mg kg$^{-1}$). Vertical bars indicate SEM.

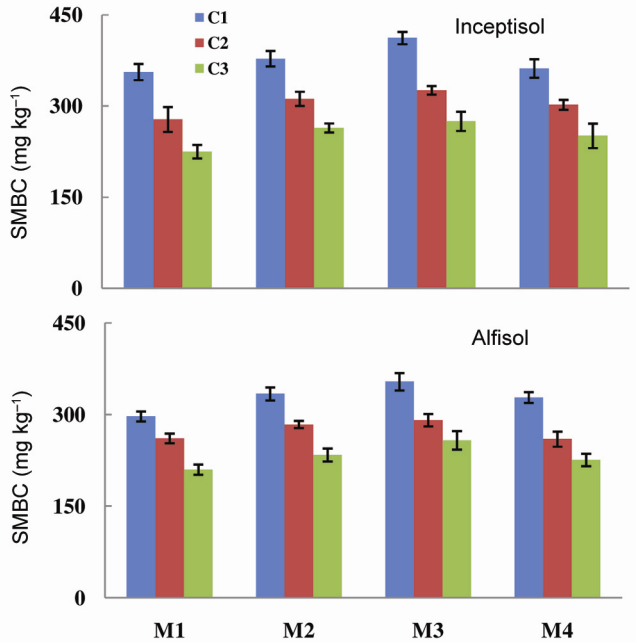


**Figure 3.** Effect of native SOC levels ($C_1$–$C_3$) and nutrient management practices ($M_1$–$M_4$) on soil microbial biomass carbon (SMBC) content (mg kg$^{-1}$). Vertical bars indicate SEM.

The effect of management was also significant in the two soils, but the interaction effect between the two factors was not significant. The soil bulk density (BD) varied from 1.18 ($C_1M_3$) to 1.36 ($C_2M_1$) Mg $m^{-3}$ in Inceptisol and from 1.51 ($C_1M_3$) to 1.58 ($C_3M_4$) Mg $m^{-3}$ in Alfisol (Figure 5). For all the management practices, $C_3$ had significantly highest BD followed by $C_2$ and $C_1$. Averaged over management practices, BD increased by about 9% when the soil was depleted to $C_2$ level and by 10% at $C_3$ level in Inceptisol. In Alfisol, the corresponding values were 2% and 3% respectively. The increased BD due to depletion of SOC was significantly ameliorated under $M_2$ and $M_3$, with the maximum benefit of amelioration under $M_3$ in both the soil types.

The root penetration resistance was significantly ($P < 0.05$) and negatively influenced by SOC level. There was also a significant effect of management treatment and interaction of SOC and management in both the soils (Table 2). In Alfisol, the depletion of SOC from $C_1$ to $C_2$ did not result in significant increase in the penetration resistance, but further depletion to $C_3$ level caused a significant increase. Averaged over management practices, the penetration resistance in Inceptisol increased by about 2.97 times under $C_2$ and by 3.24 times under $C_3$ to $C_1$. However with $M_3$, there was a reduction in the resistance (compared to $M_1$) by about 27% under $C_2$ and 18% under $C_3$, indicating the ameliorative effect. In Alfisol, $C_3$ treatment resulted in 75% higher resistance compared to $C_1$, but $C_2$ and $C_1$ were at par. However at both the depletion levels, nutrient management treatments helped loosen the soil compared to the control (Figure 6).

The decline in crop growth performance as estimated through aboveground biomass was due to the adverse effect of SOC depletion on root growth and soil structure because of the hardening of soil upon loss of SOC and also due to reduced soil fertility and enzymatic activity. This could be clearly observed from the increase in soil penetration resistance values with depletion in SOC. The plant biomass was reduced by 45% in the lowest SOC level ($C_3$) compared to $C_1$ in Inceptisol and 29% in Alfisol. More prominent effect in Inceptisol was due to the fact that Inceptisol used in the present study had relatively higher SOC level (1.61%) and thus, SOC was presumed to play prominent role in maintaining the structure and aggregation properties in that particular soil. On the other hand, Alfisol had lower SOC (0.36%) with coarse-textured soil. As Alfisol had low SOC, the depletion did not have much impact.

The treatments with depleted soil C responded positively to management practices such as $M_2$ and $M_3$, indicating initiation of the recovery process. There was a recovery of about 11–32% in crop biomass yield in Inceptisol and 8–56% in Alfisol due to management treatments. Data from a long-term experiment showed a positive yield trend under treatments with higher SOC and negative yield trend under imbalanced use of inorganic N and NP application[18].

The impeded crop growth as observed in both the soils was due to a higher BD and increased penetration resistance which constrained the root growth. Higher the SOC, lower is the BD and lower is the soil resistance. However, the effect of increase in both the parameters due to SOC depletion was higher in Inceptisol and was also detrimental for crop growth. For instance, the penetration resistance measured at 60% field capacity reached the level of 2.0 MPa in Inceptisol and about 1.0 MPa the Alfisol. This indicates root penetration resistance to be a

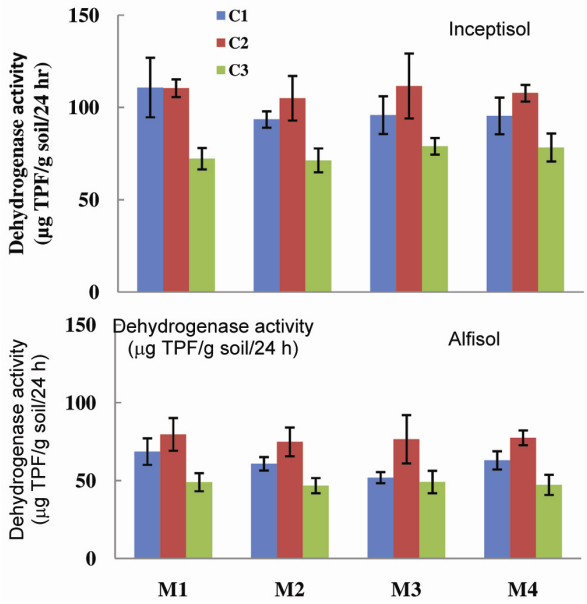


**Figure 4.** Effect of native SOC level ($C_1$–$C_3$) and nutrient management practices ($M_1$–$M_4$) on dehydrogenase activity in soil. Vertical bars indicate SEM.

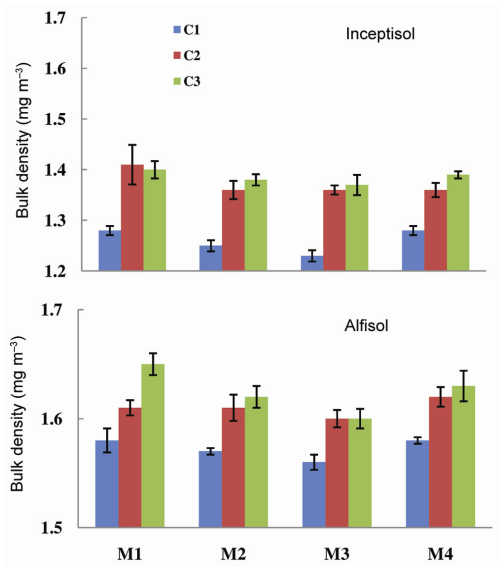


**Figure 5.** Effect of native SOC levels ($C_1$–$C_3$) and nutrient management practices ($M_1$–$M_4$) on soil bulk density (Mg $m^{-3}$). Vertical bars indicate SEM.

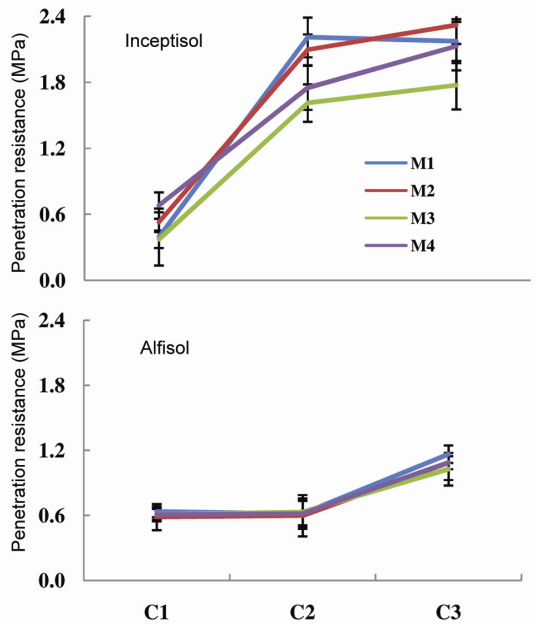


**Figure 6.** Effect of native SOC levels ($C_1$–$C_3$) and nutrient management practices ($M_1$–$M_4$) on soil penetration resistance (MPa). Vertical bars indicate SEM.

key parameter to assess the effect of decline in SOC. The decline in the favourable range of soil properties got reversed with management practices, particularly under $M_2$ and $M_3$. Soils that are degraded and depleted with native C often respond linearly to management practices[6,19]. In the present study, relatively higher recovery in terms of SOC pools was observed at maximum SOC depletion ($C_3$) in both the soils. This might be due to the fact that $C_2$ corresponded to a low level of depletion, possibly much above the tolerable limit of the soil. On the other hand, relatively higher depletion was imparted at $C_3$ and thus a quick response was noticed. This was also true in case of DHA. The results with regard to SMBC, labile C and DHA values obtained in the present study are in agreement with those of other studies[18].

The depletion of native SOC and consequent deterioration of soil physical properties (soil structure and hardness as measured in terms of bulk density and penetration resistance), microbial biomass and enzymatic activity led to degradation in soil productivity. Such soil conditions result in reduced crop growth, and accelerate the processes of land degradation due to higher soil erosion and run-off. The two contrasting soils also showed differential response to depletion as well as recovery in the studied parameters. The soil with higher native carbon content (Inceptisol) showed a conspicuous effect to depletion in terms of the studied parameters, than the one with low native soil organic carbon (Alfisol). With better management, there were signs of recovery in the soil labile carbon and microbial biomass carbon, indicating that they are better indicators of soil recovery in the aggradation phase.


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