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# Assessment of soil physical characteristics as affected by soil conservation treatments under a semiarid tropical environment

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**ABSTRACT**

Water erosion affects not only the productivity of agricultural land but also the economic and social well-being of the present and future generations on the earth. However, cultivating maize wheat as arable land use with outdated technology makes water erosion more damaging in the foothills of Shivalik. Thus, keeping these points in view, an investigation was undertaken at DR Bhumbla Zonal Research Station for Kandi Area, Ballowal -Saunkhari, district SBS Nagar, Punjab to assess soil chemical and physical characteristics as affected by soil conservation treatments. The four different soil conservation treatments imposed were: cultivation along the slope with recommended doses of inorganic fertilizers ($T_1$), Contour bunding and cultivation across the slope with the application of recommended doses of inorganic fertilizers ($T_2$), cultivation of leveled land with application of recommended doses of inorganic fertilizers ($T_3$), and cultivation of leveled land with recommended doses of inorganic fertilizers plus farmyard manure ($T_4$). The 5- depth layers considered for soil sampling were such as 0-5cm, 5-10 cm, 10-15 cm, 15-30 cm, and 30-60 cm. However, each treatment was replicated thrice, and Factorial Randomized Block Design was followed. The maize crop variety Prakash was sown on June 25$^{th}$. In total, 60 soil samples (Treatments -4, depths- 5, and replications -3) were collected and analyzed for their physical characteristics. Soil conservation treatments $T_2$, $T_3$, and $T_4$ over $T_1$ improved significantly soil physical characteristics such as bulk density, porosity, penetration resistance, and saturated hydraulic conductivity, respectively. However, the interactive effects of soil conservation treatment(s) and depth(s) differed in their magnitude in affecting soil physical characteristics. Whereas, of the evaluated treatments, the treatment $T_4$ proved promising in improving soil physical characteristics and maintaining more sustainable soil quality in the area.

***Keywords:*** Soil physical parameters, sustainable agriculture, undulating terrain

## INTRODUCTION

Land degradation by water erosion and the decline in the productivity of agricultural land are challenging the economic and social well-being of the current and future generations on the earth (Haregeneyn *et al*., 2012; Keno and Suryabhagavan 2014). Water erosion is one of the main leading factors contributing to poor agricultural development in the foothills of Shivalik (Hadda *et al*., 2006). In addition, the undulating terrain and anthropogenic activities by the human population are the other major factors responsible for the increased vulnerability of agricultural lands to soil degradation in the area. (Thapa, 2003). However, the resource-poor farmers have settled for earning their livelihoods through agriculture and other alternative means in the area (Hadda *et al*., 2005). In addition, cultivating the area with outdated technology makes water erosion more severe in the area (Hadda *et al*., 2000). Therefore, it warrants that land degradation is one of the main challenges influencing the sustainability of agriculture in the area. Soil conservation activities were initiated during the 7th five-year plan by the government of India to solve the problem of land degradation (Singh Karam *et al.*, 1993). The main thrust of the initiatives was to minimize water erosion, rehabilitate degraded lands, restore soil fertility, and increase agricultural productivity (Hadda *et al.*, 2006). However, the effectiveness of the soil conservation treatments has not been evaluated earlier on soil physical characteristics which change over longer periods in the agricultural catchment in the Shivalik. Therefore, keeping these points in view, the present investigation was undertaken to assess the soil's physical characteristics as affected by soil conservation treatments under semiarid tropical environments.

## MATERIALS AND METHODS

The present investigation was conducted in an agriculture watershed at DR Bhumbla Zonal Research Station for Kandi Area (ZRSKA), Ballowal- Saunkhri District SBS Nagar, Punjab. Since genetic factors and the severity of past soil erosion can influence the soil depth, the sites were selected within the same parent and landscape unit. The study was undertaken by imposing the different treatments such as i) $T_1$-Cultivation along the slope with an application of recommended doses of inorganic fertilizers, ii) T2-Contour bunding and cultivation across the slope with an application of recommended doses of inorganic fertilizers, iii) $T_3$-Cultivation of leveled land with application of recommended doses of inorganic fertilizers, iv) $T_4$ -Cultivation of leveled land with application of recommended doses of inorganic fertilizers + farmyard manure (FYM). However, each treatment was replicated thrice, and Factorial Randomized Block Design was followed. The *Parkash* variety of maize was sown on 25$^{th}$ June. The crop maize was sown using the seed rate @ 20 kg ha$^{-1}$ and treated with Bawiston 3g kg$^{-1}$. The inorganic fertilizers viz., Calcium Ammonium Nitrate (CAN), Single Super Phosphate (SSP), and Urea were applied as per recommended doses i.e., 162, 262, and 180 kg ha$^{-1}$, respectively in the treatments $T_1$, $T_2$, and $T_3$. The full dose of CAN and SSP and half dose of Urea were broadcasted before sowing and another half dose of Urea was broadcasted after 1 month of sowing maize crop. However, in the treatment $T_{4,}$ farmyard manure (FYM) was mixed at the recommended rate i.e., 15 t ha$^{-1}$ with the same doses of inorganic fertilizers as applied in the other three treatments. On maturity, the maize crop was harvested on the 4$^{th}$ of October and the yields were recorded.

The soil samples were collected from 5 depths 0-5, 5-10, 10-15, 15-30, and 30-60 cm depth, employing 3 replications. This makes a total of 60 soil samples (Treatments- 4; Depths- 5 and Replications- 3) were collected and analyzed further to determine their chemical and physical characteristics.

However, for the sake of brevity, the determined soil's physical characteristics are reported in this paper. The physical characteristics determined were bulk density, total porosity, soil particle size analysis, aggregate size distribution, penetration resistance, and saturated hydraulic conductivity. The aggregate size distribution was determined using the wet sieving procedure of Van-Bavel (1949), soil particle size analysis by Day (1965), and total porosity by Russel (1949). However, the penetration resistance was recorded by the Prowine Cone Ring Penetrometer following the procedure of Wong (2009), and the saturated hydraulic conductivity was determined with the Constant Head Permeameter Technique employing the Darcys equation.

### Description of the area

#### *Climate*

The study area is a mixed watershed of 150 hectares and comprises arable, physically degraded, and treated lands. This is situated at an altitude of 355 m above the mean sea level, having a semi-arid to sub-humid type of climate. However, it is situated in the agro-climatic zone I of Punjab. The zone lies in the N-E of the state in the form of a long narrow strip of 10-20 Km width and located between 30° 40' to 32°30′ N latitude and 75°30′ to 76°48′ E longitude. The mean annual rainfall is 850 ± 150 mm. The rainfall distribution is bimodal with a maximum monthly in July and a minimum in November at Ballowal- Saunkhri. The summer monsoon rains are received in 20 to 30 rainstorms, of which 8 to 12 produce runoff and overland flow (Hadda and Sur, 1986). However, 1 to 2 rainstorms occur with an average intensity of 95 mm hr$^{-1}$ to 120 mm hr$^{-1}$ and a maximum fifteen minutes ($I_{15}$) intensity of 240 mm hr$^{-1}$ in the area (Hadda and Sur, 1986). The area's runoff and soil loss vary from 35-45 percent of annual rainfall and 25-225 t ha$^{-1}$ yr$^{-1}$ respectively (Sur and Ghuman, 1992). The mean maximum temperature

**Table 1.** Information on area, land, climate, and soils at Ballowal-Saunkhri

| Parameters | Range |
|---|---|
| Elevation (MSL,m) | 355 |
| Area (ha) | 150 hectares |
| Slope steepness (%) | 10 |
| Annual rainfall (mm) | 850 ± 150 |
| Temperatures mean maximum (°C) | 39.1 |
| Temperatures mean minimum (°C) | 5.2 |
| Annual Evaporation (mm) | 1403 |
| Aridity index | 20-35 |
| Major soils groups | Haplustepts, Ustorthents, Ustipsamments, Haplustalfs |
| Texture | Sandy clay loam to Sandy loam |
| pH (0-60 cm) | 7.3-8.4 |
| Organic carbon (%, 0-60 cm) | 0.07-0.20 |
| Total soil N (%, 0-60 cm) | 0.03-0.06 |
| Available P (kg $ha^{-1}$, 0-60cm) | 5.1-8.1 |
| CEC ($C^{+}$mol $kg^{-1}$, 0-60cm) | 9.0-11.3 |
| Bulk density (Mg $m^{-3}$, 0-30 cm) | 1.4-1.6 |
| Total Soil porosity ($m^3m^{-3}$, 0-30 cm) | 0.40-0.47 |

varies from 18.6°C in January to 39.1°C in May and the mean minimum from 5.2°C in December to 24.7°C in June.

The soils are generally moderate to alkaline in reaction, non-saline; contain low amounts of organic matter, low in Nitrogen and Phosphorus but medium to high in Potassium contents (Sehgal, 1970). However, the information relevant to the area, soils, and climate is given in Table 1.

## Soil characteristics

### *Physical characteristics*

The physical characteristics of soils varied in penetration resistance (19.7%), saturated hydraulic conductivity (9.1%), bulk density (3.4%), and porosity (3.5%) as listed in Table 2. The factor analysis demonstrated that both bulk density and porosity were significantly different in depths and treatments (Table 2; P<0.05). Similarly, the treatments differed significantly in their effect on bulk density, total porosity, penetration resistance, and saturated hydraulic conductivity (P<0.05). The interaction of treatment and depth has significantly affected the bulk density as well as the total porosity (Table 2; P<0.05). However, the interactive effects of the treatment and depth on saturated hydraulic conductivity were non-significant (Table 2 ; P>0.05).

The bulk density varied from 1.40-1.56 Mg $m^{-3,}$ total porosity 0.42-0.48 $m^3$ $m^{-3}$, saturated hydraulic conductivity 3.17-3.53 cm $hr^{-1}$, and penetration resistance 9.13-29.07 kg $cm^{-2}$ (Table 2). The soil constitutes 52.5 - 75.1 % sand, 9.9 - 14.8 % silt, and 14.9 - 32.7 % clay respectively (Table 3). The sand content was higher by 41.7 % and silt and clay contents were lower by 49.5 and 107 % respectively in the surface over the sub-surface soil depth. However, the aggregate size distribution decreased with an increase in the depth of soil. The mean weight diameter varied from 0.43 to 0.67 mm with a mean of 0.57 mm. (Table 4).

**Table 2.** Analysis of variance for soil physical characteristics

| Parameters | No. of depths sampled | CV (%) | Factor | | |
|---|---|---|---|---|---|
| | | | Treatment (T) | Depth (D) | T × D |
| | | | LSD < 0.05 | | |
| Bulk density (Mg $m^{-3}$) | 4 | 3.4 | 0.02 | 0.02 | 0.04 |
| Total porosity ($m^3$ $m^{-3}$) | 4 | 3.5 | 0.02 | 0.02 | 0.03 |
| Penetration resistance (kg $cm^{-2}$) | 3 | 19.7 | 2.57 | 3.00 | NS |
| Saturated hydraulic conductivity ($cm^{-1}$) | 3 | 9.1 | 0.59 | NS | NS |

**Table 3.** Percent proportion of sand, silt, and clay and texture about soil depth

| Soil depth (cm) | Particle size distribution | | | Texture |
|---|---|---|---|---|
| | % Sand 2.00-0.05(mm) | % Silt 0.05-0.002(mm) | % Clay < 0.002(mm) | |
| 0-5 | 74.4 | 9.9 | 15.8 | Sl |
| 5-10 | 75.1 | 10.1 | 14.9 | Sl |
| 10-15 | 75.1 | 10.0 | 14.9 | Sl |
| 15-30 | 55.4 | 13.6 | 31.0 | Scl |
| 30-60 | 52.5 | 14.8 | 32.7 | Scl |

**Table 4.** Water stable aggregates about soil depth

| Soil depth (cm) | Aggregate size distribution Mean weight diameter (mm) |
|---|---|
| 0-5 | 0.66 |
| 5-10 | 0.67 |
| 10-15 | 0.58 |
| 15-30 | 0.51 |
| 30-60 | 0.43 |

## Statistical analysis

The observations on 12 soil variables were checked for multivariate normality and homogeneity of covariance matrices. However, the variables were categorized into soil chemical and physical parameters. Then, the multivariate analysis was conducted in two steps as suggested by Hatcher and Stepanski (1996). The Multivariate Analysis of Variance (MANOVA) was the first step used to determine whether there were significant management effects on at least one of the soil chemical and physical variables assessed. After this criterion was met, an Analysis of Variance (ANOVA) of individual parameters was run on all the parameters. After that, the F Statistics was obtained, and it was reviewed to test the null hypothesis of overall no treatment effects. The second step consisted of interpreting the univariate ANOVAs. These variables for which the management F-statistics was significant at $P < 0.05$ and that had CVs < 50 (Hatcher and Stepanski, 1996) were retained for further analysis. Both MANOVA and ANOVA were identified with significant interactions of soil management practice(s) x depth for several parameter(s) where data was gathered with different depths. However, the treatment means were interpreted using the LSD results.

## Soil physical characteristics as affected by soil conservation treatments

### *Physical characteristics*

The soil conservation treatments such as $T_2$, $T_3$, and $T_4$ compared to $T_1$ significantly improved the bulk density, total soil porosity, penetration resistance, and saturated hydraulic conductivity, respectively (Table 5; $P<0.05$). These soil conservation treatments, such as $T_2$, $T_3$, and $T_4$ over the $T_1$ decreased bulk density by 2.0, 0.7, and 6.0 per cent; increased total porosity by 2.3, 0, and 9.1 per cent; decreased penetration resistance by 4.7, 8.7 and 17.1 per cent and increased saturated hydraulic conductivity by 39.7, 24.8 and 44.3 per cent, respectively.

The soil conservation treatments ($T_2$, $T_3$, and $T_4$) have improved the soil conditions as a result of uniform distribution of soil moisture, reduction in runoff, and soil loss. This was noticed by significant variations in soil physical characteristics (Singh, 2002). The soil conservation treatments in $T_2$ to $T_4$ created barriers to runoff flow and runoff velocity, reduced slope steepness, and uniformly distributed soil moisture and provided more opportunity for runoff to infiltrate the soils. In addition, the removal of finer soil fractions, crop residues, and other organic components can be limited in soil conservation treatments, which improves the soil condition over the untreated (control) plots.

**Table 5.** Effect of soil conservation treatments on soil physical characteristics*

| Treatments/ Physical parameters | Parameters mean values** | | | |
|---|---|---|---|---|
| | Bulk density ($MGM^{-3}$) | Total soil porosity ($m^3 m^{-3}$) | Penetration resistance ($kg\ cm^{-2}$) | Saturated hydraulic conductivity ($cm\ hr^{-1}$) |
| $T_1$ | 1.50 $^a$ | 0.44 $^a$ | 19.50 $^a$ | 2.62 $^a$ |
| $T_2$ | 1.48 $^b$ | 0.45 $^a$ | 18.59 $^a$ | 3.66 $^b$ |
| $T_3$ | 1.51 $^a$ | 0.44 $^a$ | 17.80 $^a$ | 3.27 $^c$ |
| $T_4$ | 1.42 $^c$ | 0.48 $^b$ | 16.17 $^b$ | 3.78 $^d$ |
| LSD<0.05 | 0.02 | 0.02 | 2.57 | 0.59 |

*Comparisons were made based on analysis of variance (ANOVA) and least significant differences (LSDs) determined at the 0.05 level of probability

**Values within columns and factor categories not followed by the same letter are significantly different at the 0.05 level of probability

**Interactive effects of soil conservation treatment and depth on soil physical characteristics**

***Physical characteristics***

*Bulk density*

The treatment (T), depth ( D), and the interaction of TXD have significantly affected the bulk density (P<0.05: Table 6). The bulk density (Db) (averaged over treatments) significantly increased with an increase in depth. The differed Db values were 1.40, 1.44, 1.52, and 1.56 Mg $m^{-3,}$ respectively, in depths of 0-7.5, 7.5 -15, 15-22.5, and 22.5 -30 cm. However, the Db (averaged over depths) through different treatments viz., $T_1$, $T_2$, $T_3$, and $T_4$ were 1.51, 1.48, 1.50, and 1.42, Mg $m^{-3,}$ respectively. In addition, the Db values were lower in magnitude under treatment $T_4$ over other treatments ($T_1$, $T_2$, and $T_3$) in different depth(s). These differed Db values with depths 0-7.5, 7.5 -15, 15-22.5, and 22.5 -30 cm were 1.37, 1.38, 1.44, and 1.49 Mg $m^{-3}$ under the treatment $T_4$. The results demonstrated that the treatment $T_4$ was most effective in lowering the Db values with an increase in different soil depths. The higher bulk density in the treatment $T_1$ may be caused by exposure of subsoil depth by water erosion and removal and oxidation of the organic C from the topsoil. Also, the water erosion by runoff and decomposition of a relatively small amount of organic C caused the decline of soil structural characteristics and increased the soil bulk density. The results of the study revealed that the untreated plots and higher slope steepness resulted in higher bulk density and were associated with a decline in soil organic C content. In addition, higher bulk density in untreated plots could be related to the washing out of fine organic matter-rich soils by water erosion, thereby exposing slightly heavier soil particles (Kumar *et al*., 2020). However, the other causes may explain the lower bulk density in soil conservation treated plots due to lesser effects of water erosion and relatively higher soil organic C content. This might have resulted from the accumulation of crop-decayed residues and less vulnerability for easy removal of finer soil material. The results of the study were consistent with the findings of Hishe *et al*. (2017) and Hailu *et al*. (2012) for Middle Silluh Valley, northern Ethiopia, respectively. Meanwhile, the studies (Selassie *et al*., 2015; Challa *et al*., 2016) reported a statistically lower bulk density in soil conservation treated plots over the untreated plots.

**Table 6.** Interactive effect of soil conservation treatment and depth on bulk density and total soil porosity

| Soil depth (cm) | Treatments | | | | |
|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean |
| | | **Bulk density, Mg $m^{-3}$** | | | |
| 0-7.5 | 1.40 | 1.39 | 1.42 | 1.37 | 1.40 |
| 7.5-15 | 1.53 | 1.43 | 1.41 | 1.38 | 1.44 |
| 15-22.5 | 1.52 | 1.52 | 1.58 | 1.44 | 1.52 |
| 22.5-30 | 1.60 | 1.58 | 1.57 | 1.49 | 1.56 |
| Mean | 1.51 | 1.48 | 1.50 | 1.42 | - |
| LSD <0.05 | | Treatment (T) | 0.02 | | |
| | | Depth (D) | 0.02 | | |
| | | T × D | 0.04 | | |
| | | **Total soil porosity, $m^3$ $m^{-3}$** | | | |
| 0-7.5 | 0.47 | 0.48 | 0.46 | 0.48 | 0.48 |
| 7.5-15 | 0.42 | 0.46 | 0.47 | 0.48 | 0.47 |
| 15-22.5 | 0.43 | 0.43 | 0.40 | 0.46 | 0.44 |
| 22.5-30 | 0.40 | 0.40 | 0.41 | 0.44 | 0.42 |
| Mean | 0.44 | 0.45 | 0.44 | 0.48 | - |
| LSD < 0.05 | | Treatment (T) | 0.02 | | |
| | | Depth (D) | 0.02 | | |
| | | T × D | 0.03 | | |

*Porosity*

The effect of T, D, and their interaction with TXD significantly affected soil porosity (f) (Table 6; P<0.05). The f (porosity) (averaged over treatments) was 48, 47, 44, and 42 per cent, respectively, in soil depths 0-7.5, 7.5 -15, 15-22.5, and 22.5 -30 cm. Similarly, the f (averaged over depths) differed in magnitudes such as 44, 45, 44, and 48 per cent through treatments $T_1$, $T_2$, $T_3$, and $T_4$, respectively. Also, the f values were higher in magnitude in each soil depth layer, i.e. 0-7.5, 7.5 -15, 15-22.5, and 22.5 -30 cm, through treatment $T_4$ over other treatments such as $T_1$, $T_2$, and $T_3$.

*Penetration resistance*

The penetration resistance (PR) was affected significantly by treatment and depth (P<0.05; Table 7). However, the interactive effects of TXD were non-significant on penetration resistance (P>0.05). The penetration resistance (averaged over depths) was lower in magnitude through treatments $T_2$ (18.59 kg $cm^{-2}$), $T_3$ (17.8 kg $cm^{-2}$ ), and $T_4$ (16.17 $cm^{-2}$) than in $T_1$ (19.5). There was a tendency for a decline in penetration resistance by 4.7, 8.7, and 17 per cent through treatments $T_2$, $T_3$, and $T_4$ over treatment $T_1$, respectively. However, the penetration resistance (averaged over treatments) was higher in magnitude

**Table 7.** Interactive effect of soil conservation treatment and depth on penetration resistance and saturated hydraulic conductivity

| Soil depth | Treatments | | | | |
|---|---|---|---|---|---|
| (cm) | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean |
| **Penetration resistance, kg cm$^{-2}$** | | | | | |
| 0-5 | 10.50 | 9.72 | 9.18 | 7.11 | 9.13 |
| 5-10 | 16.73 | 16.84 | 15.27 | 14.58 | 15.86 |
| 10-15 | 31.28 | 29.22 | 28.95 | 26.81 | 29.07 |
| Mean | 19.50 | 18.59 | 17.80 | 16.17 | - |
| LSD < 0.05 | Treatment (T) | 2.57 | | | |
| | Depth (D) | 3.00 | | | |
| | T × DNS | | | | |
| **Saturated hydraulic conductivity, cm hr$^{-1}$** | | | | | |
| 0-7.5 | 2.73 | 3.89 | 3.34 | 4.02 | 3.50 |
| 7.5-15 | 2.64 | 3.59 | 3.29 | 3.81 | 3.33 |
| 15-22.5 | 2.48 | 3.50 | 3.18 | 3.50 | 3.17 |
| Mean | 2.62 | 3.66 | 3.27 | 3.78 | - |
| LSD < 0.05 | Treatment (T) | 0.59 | | | |
| | Depth (D) | NS | | | |
| | T × D | NS | | | |

by 73.7 and 28.1 per cent in depths of 5-10 and 10-15 cm than that in the depth of 0-5cm. The results demonstrated that the treatment $T_4$ proved most effective in lowering the resistance to penetration in soils.

*Saturated hydraulic conductivity*

The saturated hydraulic conductivity ($K_s$) was significantly affected by soil conservation treatments (Table 7; $P<0.05$). However, the effects of depth and interactions of treatment × depth were non-significant ($P>0.05$) on $K_s$. The $K_s$ (averaged over depths) were higher in magnitude by 39.7, 24.8, and 44.3 per cent through treatments $T_2$, $T_3$, and $T_4$ over $T_1$, respectively. The saturated hydraulic conductivity depended on the attributes of the added farmyard manure. Studies (Ehlers, 1977; Simunek *et al*., 2008) demonstrated similar results in increasing the $K_S$ due to the addition of FYM. The severity of water erosion and velocity of runoff can also affect $K_s$ (Dexter *et al*., 2004; Simunek *et al*., 2008).

In general, the application of farm yard manure improved soil organic C content (Hevia *et al*. 2003; Yimer *et al*., 2006; Meena *et al*., 2018), which enhanced aggregation, geometric mean weight diameter, soil moisture retention (Huang *et al*., 2010; Mishra *et al*., 2015) and maintain better soil sustainability (Berg and Mcclaughertz, 2008). The application of organic manures especially of animal waste either alone or in combination with inorganic fertilizers increased the water-holding capacity, and soil moisture retention (Gong *et al*., 2009). However, the application of inorganic fertilizers demonstrated contradictory results on soil water retention, either suppression (Ghani *et al*., 2003; Gong *et al*., 2009), enhancement (Wang *et al*., 2010), or no effects (Gong *et al*., 2009).

The soil particle size distribution and mineralogy govern C sink capacity and soil aggregation (Hunag *et al*., 2010). However, as per the theory of hierarchy, clay, micro-aggregates, and aggregates are formed in interactions between clay, polyvalent cations, and complex organic polymers (Tisdale and Oades, 1982; Six *et al*., 2002 ). Such conditions persisted in treatment $T_4$, where the application of farm yard manure enhanced soil aggregation and soil organic C content.

## CONCLUSION

The large-scale developmental works were initiated during the 7th five-year plan by Govt. of India. However, the major aim of the plan was to arrest the problem of land degradation and initiate soil conservation activities. It was to further improve agricultural productivity and sustainability in semiarid tropical environments. The imposed treatments such as $T_2$, $T_3$, and $T_4$ over $T_1$ improved soil physical characteristics viz., Db, f, PR, and Ks, respectively. Whereas the evaluated soil conservation treatments, the cultivation of the leveled land with the application of inorganic fertilizers and farm yard manure, significantly improved soil physical characteristics and maintained sustainable soil quality.

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