Chapter 5

Land Degradation in the Çelikli Basin, Turkey

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Additional information is available at the end of the chapter

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Abstract

The relationship between soil degradation and wheat yield was analyzed in the Çelikli basin, Turkey. Geographic information system (GIS) and factor analysis techniques were used for evaluations. Wheat yield has changed between 600 and 3780 kg ha^{-1}. Soil penetration resistance (PR) was below 2 MPa in 34.92% of the topsoils and was over 2 MPa in the entire of subsoils. The soil loss changed from 0 to 152.8 ton ha^{-1} $year^{-1}$. Soils in the study area were generally low in plant-available water (PAW) content. Compared to P, K content was sufficient in top and subsoils in most of the study area. The results showed that B and Zn contents were low, and Cu, Mn, Fe, and Cd contents were adequate. Boron content was less than 0.5 mg kg^{-1} in 85.5% of the cultivated and 82.9% of the grassland, and Zn was less than 0.5 mg kg^{-1} in 99.7% of the study area. Low organic matter, low water-holding capacity, high penetration resistance, and deficiency of some macro- and micronutrients were the most important limiting factors of wheat yield. Crop rotation and P, B, and Zn application can help restore soil productivity in cultivated areas of the study area.

Keywords: land degradation, wheat yield, organic matter, water-holding capacity, penetration resistance, crusting index

1. Introductıon

Land degradation comprises human-induced processes that affect land resources and environmental sustainability. Land degradation is recognized as one of the most serious ecological and economical problems globally. Soil erosion, soil compaction, deterioration in soil structure, nutrient depletion, acidification, and salinization have been defined as major soil degradation processes [1]. The human activities such as fires, floods, soil loss (SL), and yield reduction may affect land degradation directly or indirectly. In the twenty-first century, land degradation is considered an important factor affecting food security. The world's agricultural land that is seriously degraded is estimated to have reached up to 40% [2].

Land degradation in Turkey has been mainly in the form of soil erosion, agricultural mismanagement, deforestation, and overgrazing, and is a result of human activities for the last century. The most prominent result of soil degradation in Turkey has been soil erosion, which develops due to the region's climate, topography, soil, and land-use problems. In Turkey, 59% of rangelands, 54% of forest lands, and 71% of agricultural lands are under active erosion threat [3]. Furthermore, an area of 4.2 million ha has lost its productivity partly or completely due to salinity problems [4]. Topographic and climate conditions have made it necessary to combat soil erosion. In Turkey, 24.1 million livestock graze on pastures, but the pastures can no longer provide sufficient roughage for the livestock to feed, and the existing land cover on pasture areas are used intensively. Overgrazing, especially noticeable in Turkey's Mediterranean, Aegean, Southeastern, and Central Anatolia regions, damages vegetation, increases runoff, and promotes erosion. The surface coverage of pasture areas ranges from 15 and 30%. Severe water and wind erosion are visible in those areas. To avoid soil erosion, surface coverage should be increased in the pasture areas where misuse is taking place—an area of 21.7 million ha. The amount of grazing animals and their grazing time must be brought under control [5]. Land use has changed in significant ways over the last 100 years in Turkey due to agricultural expansion. For example, while pasture areas made up about 56.8% (44.2 million ha) of land use in 1940, today they are only 18.6% (14.6 million ha). Most of changes to land use occurred on pasture land that was converted to agricultural purposes [3].

The main objective of this study is to evaluate soil degradation regarding wheat yield (WY) as affected by deteriorated soil properties in the Çelikli basin, located in North Central Anatolia of Turkey.

2. Materials and methods

2.1. The study area

This study was conducted in the Çelikli basin, located in Tokat province, which is known as the transitional belt of Turkey. This area is situated between Central Anatolia and Black Sea regions (latitude 40º06′31″N, longitude 36º21′40″E). The types of soil in the basin are classified as Entisols, Mollisols, and Alfisols according to Soil Survey Staff [6] and are moderately well to well drained with a slope of 2–12% in the majority of the area. The basin is 1041.2 ha and has an average elevation of 1300 m above sea level. Although native land use of the basin was for pasture and forest, over the last five decades, most of the pasture and forest areas were converted to agriculture. The main crop in the cultivated areas is wheat, which is grown under rainfed conditions. Although 14.07% of the basin is available for agriculture, the dry farming area occupies 67.88% of the basin. The main vegetation type in uncultivated areas is degraded pasture with *Graminea*, *Fabaceae*, and *Labiatae* as the dominant species, occupying 24.86% of the basin. The coverage rate in the degraded pasture areas is about 50%. Other features in the area

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are shrubs, bare rock, and water surfaces, which make up 5.45, 0.82, and 0.98%, respectively, shown in **Figure 1**. The study area has semiarid climate. The average annual temperature is 8.1°C, and the mean annual precipitation is 535.9 mm, 84.7% of which falls between October and May. The amount of evaporation from Class A pan between March and October is about 900 mm, which is greater than almost two times of the yearly precipitation [7].

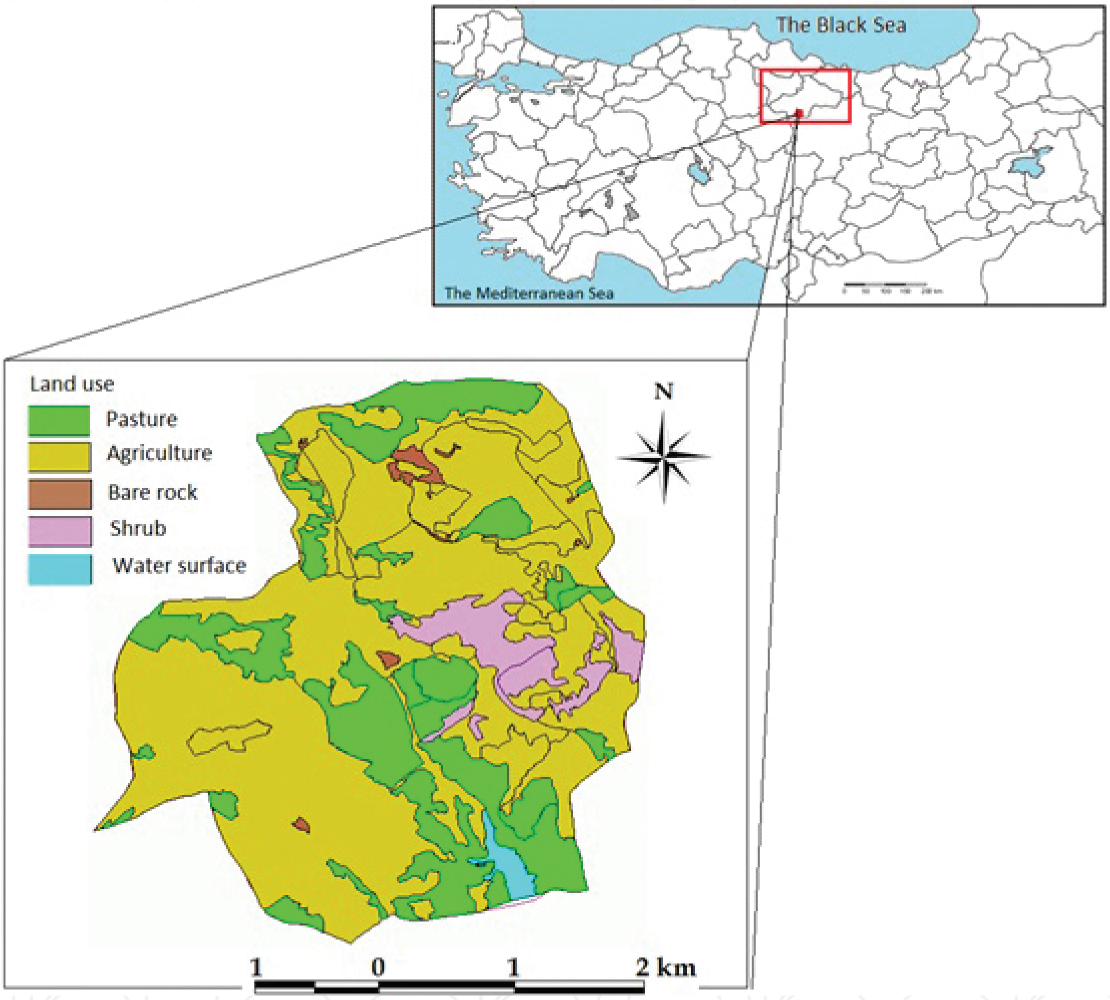

Figure 1. The location and land-use map of the Çelikli basin.

2.2. Soil sampling and laboratory analysis

A total of 142 georeferenced soil samples were taken from topsoil (0–0.3 m) and subsoil (0.3–0.6 m) (**Figure 2**). Organic matter [8], soil pH [9], lime ($CaCO_3$) [10], electrical conductivity (EC) [11], cation exchange capacity (CEC) [12], textural distribution [13], saturated hydraulic conductivity (HC) (Ks) [14], and volumetric water content [15] were analyzed. Erodibility was calculated by a soil erodibility nomograph [16].

Fractions that were greater than 2 mm in diameter were separated and reported as coarse material (CM) [12]. Saturated hydraulic conductivity (Ks) was measured on undisturbed

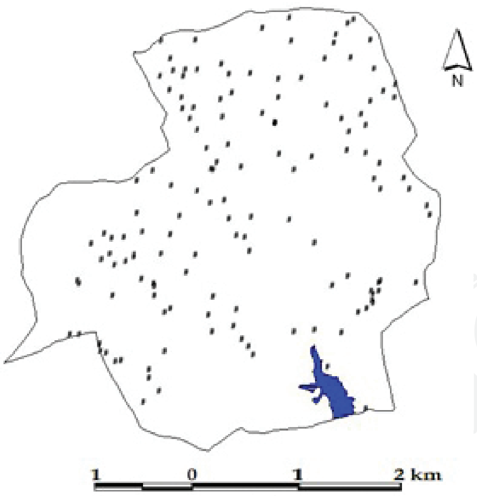

Figure 2. Locations of soil sampling points in the basin.

cores [14]. Soil penetration resistance (PR) was measured with a cone penetrometer at depths of 0–10 and 30–40 cm [17], and the soil-crusting index (CI) was calculated by Eq. (1) using soil organic matter (SOM), clay, and, silt contents [1]:

$$CI = \frac{100SOM(\%)}{Clay\% + Silt\%} \quad (1)$$

Wheat yield was measured at sampling sites. Field capacity ($\theta_{0.33\text{MPa}}$) and wilting points ($\theta_{1.50\text{MPa}}$) were determined with a pressure plate [14], and plant-available water content (PAWC) was calculated by Eq. (2):

$$PAW = (\theta_{0.33MPa}) - (\theta_{1.50MPa}) \quad (2)$$

Slope, %	**Permeability classes**					
	Rapid-very rapid	**Moderate rapid**	**Moderate**	**Moderate slow**	**Slow**	**Very slow**
Concave	N[a]	N	N	N	N	N
<1	N	N	N	L	M	H
1–5	N	VL	L	M	H	VH
5–10	VL	L	M	H	VH	VH
10–20	VL	L	M	H	VH	VH
>20	L	M	H	VH	VH	VH

N[a], negligible; VL, very low; L, low; M, medium; H, high; VH, very high.

Table 1. Indices determined for surface runoff classes in the study area.

Surface runoff was calculated using slope steepness and permeability of the soils (**Table 1**) [18]. Soil loss was calculated by the Universal Soil Loss Equation (USLE) [19] as

$$A = RKLSCP \tag{3}$$

where A is the soil loss (Mg ha^{-1}), R is the rainfall factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), LS is the topography factor, C is the crop management factor, and P is the management practice factor.

2.3. Data analysis

Descriptive statistics of mean, standard deviation (SD), coefficient of variation (CV), kurtosis, skewness, maximum, and minimum were calculated for the variables of particle-size components, coarse material, wheat yield, soil loss, available water content (AWC), runoff, crusting index, penetration resistance, saturated hydraulic conductivity (Ks), soil organic matter, electrical conductivity, pH, cation exchange capacity, available K, available P, and available micronutrients (Fe, Cu, Mn, Cd, Zn, and B).

Factor analysis was conducted separately on topsoil and subsoil using Statistical Package for the Social Sciences (SPSS; Chicago, IL) to summarize correlations among variables [20]. First, correlation matrices, eigen values, and eigen vectors were calculated. Second, main factors were determined by the maximum likelihood method [21] and scree analysis [20]. Factors with a loading of >0.5 were retained. Finally, principal components were determined [22]. Relations among the variables were explained using the factor loadings. The principal components derived from the prepared correlation matrices were subjected to an orthogonal rotation of axes (varimax rotation) when multiple loadings occurred. Nine factors (Factor 1: "erodibility factor"; Factor 2: "soil fertility factor"; Factor 3: "soil chemistry factor"; Factor 4: "soil-crusting factor"; Factor 5: "soil erosion factor"; Factor 6: "soil conductivity factor"; Factor 7: "plant-available water content factor"; Factor 8: "macroelement factor"; Factor 9: "crop yield factor") for topsoil and seven factors (Factor 1: "microelements factor"; Factor 2: "soil physics factor"; Factor 3: "soil fertility factor"; Factor 4: "soil chemistry factor"; Factor 5: "yield factor"; Factor 6: "soil potassium factor"; and Factor 7: "soil cadmium factor") for subsoil were retained. The loading (or eigenvectors) of a variable in a factor is similar to the correlation between the variable and the factor.

2.4. Data processing with geographical ınformation system

Spatial relations between soil properties (EC, pH, SOM, P, K, B, Zn, Cu, Fe, Mn, Cd, CEC, Sand, Clay, Silt, K factor, CI, PAWC, PR) and wheat yield were investigated by GIS. Soil, digital elevation, land use, productivity, soil compaction, plant-available water content, surface runoff, and soil loss maps were prepared using ArcView 3.1 GIS Software [23]. The basin soil, elevation, and land-use maps with a 1:25,000 scale were digitized in vector format and then transformed to raster format to prepare GIS applications [24].

3. Results and discussion

3.1. Wheat yield

Wheat is the main crop in the study area, covering 68% of the study area. Although only 14% of the basin is suitable for cultivation, most of the pasture areas have been converted to agriculture for the last 60 years. The agricultural areas in the basin are mostly shallow, varying between 20 and 50 cm. The mean plant-available water content for the cultivated areas is about 100 mm. Therefore, water stored in soils often fails to meet crop water requirement. In the dryland farming areas receiving less than 400 mm annual precipitation such as the Çelikli basin in Turkey, a winter wheat-fallow system is used to reduce the risk of uneconomical yield [24]. Wheat yield was measured at 115 sites with three repetitions in the basin (**Table 2** and **Figure 3**). While the wheat yields ranged from 600 to 3780 kg ha^{-1}, only 4.78% of the cultivated areas had yield greater than 2500 kg ha^{-1} as shown in **Table 3**.

	Yield (kg ha^{-1})
Sample number	115
Maximum	3780
Minimum	600
Average	1794
Standard deviation	744
Coefficient of variation	0.41

Table 2. Statistical results of the wheat yield.

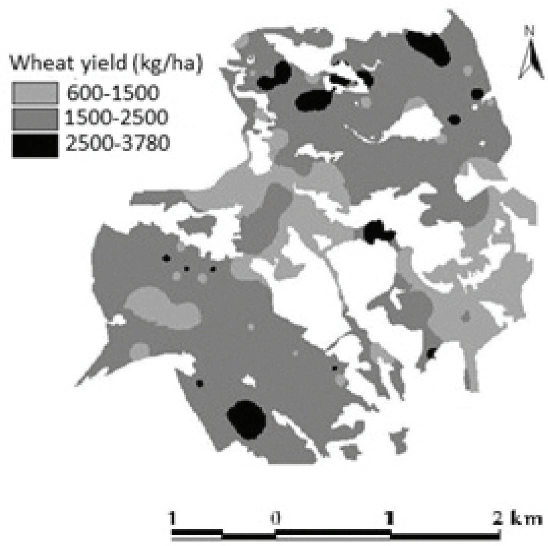

Figure 3. The wheat yield distribution in the basin.

Wheat yield (kg ha^{-1})	600–1500	1500–2500	2500–3780
Area, km^2	1.715	5.016	0.338
Area, %	24.26	70.96	4.78

Table 3. Areal distribution of the wheat yield in the basin.

3.2. Evaluation of soil degradation in the basin

3.2.1. Soil penetration resistance

The penetration resistance values and their statistical results for the basin are given in **Tables 4** and **5** and **Figure 4a** and **b**. While 34.92% of the topsoils in the basin had under 2.0 MPa, the penetration resistance of all subsoils had penetration resistance values over 2.0 MPa. High PR values were attributed to soil texture (fine) and low water content of the soils. Penetration resistance is sensitive to soil water content. In addition, in subsoils, high penetration resistance could be attributed to the existence of a dense plow layer, which is mainly the case in cultivated fine-textured soils subjected to conventional tillage. The mean penetration resistance values of the surface and subsoils were 1.671 and 2.579 MPa, respectively, which are below 3.0 MPa above which growth of many crops is inhibited [25]. The penetration resistance was measured in 0–20 cm only due to that soil depth was too shallow in grasslands. In general, the coefficient of variation and standard deviation for penetration resistance in topsoil were greater than in the subsoil due to soil tillage effect.

	The penetration resistance, kPA				**Tendency to crust, CI**		**Plant available water content, PAWC**		
	Topsoil		**Subsoil**						
	<2000	**>2000**	**<2000**	**>2000**	**0–5**	**5–10**	**27–50**	**50–100**	**100–160**
Area, km^2	6.776	3.636	0.081	10.331	9.940	0.472	0.445	4.686	5.281
Area, %	65.08	34.92	0.78	99.22	95.47	4.53	4.27	45.01	50.72

Table 4. Areal distribution of the penetration resistance, crusting index, and plant-available water content of the basin soils.

	Penetration resistance		**Crusting index**
	Topsoil	**Subsoil**	
Sample numbers	142	115	142
Maximum	3882.38	3522.00	9.41
Minimum	170.78	1590.03	0.78
Mean	1671.22	2579.63	3.21
Standard deviation	1080.86	332.04	1.75
Coefficient of variation	0.65	0.13	0.55

Table 5. Statistical results for penetration resistance and tendency to crust of the basin soils.

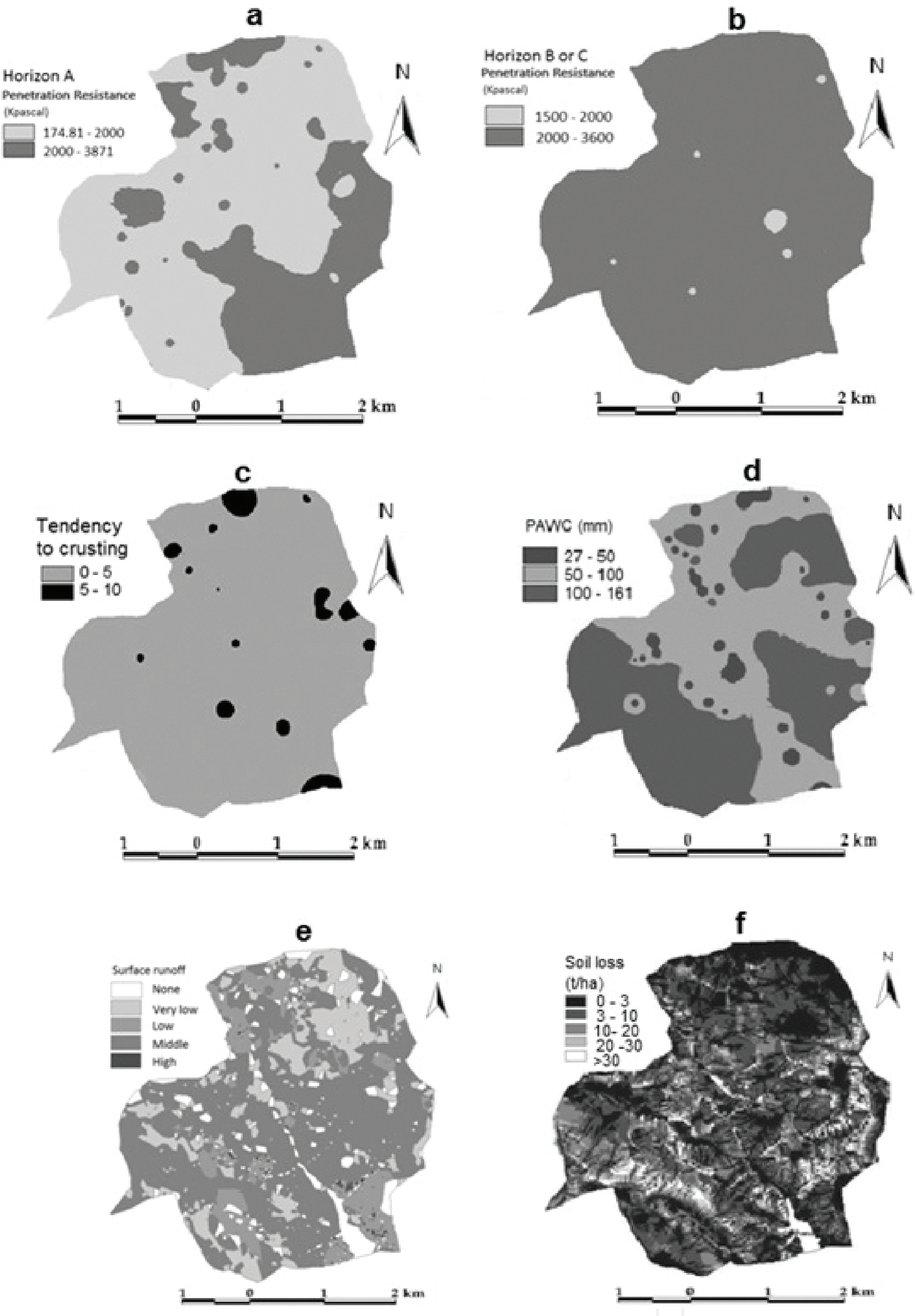

Figure 4. The penetration resistance (a and b), crusting index (c), plant available water content (d), surface runoff (e) and soil loss (f) maps of the basin.

The penetration resistance affecting crop yield is not a constant value and varies according to other soil properties. Indeed, it was reported that there was no penetration problem under 2000 KPa, but crop yields were affected over 2.00 MPa [26]. However, some researchers claim that the crop yield is affected by PR of >3.00 MPa [27–29]. Soil penetration resistance is a valuable indicator of the soil physical quality. A value of 2 MPa has been widely used as a critical limit to determine PR in both no-tillage and conventional systems [25, 26]. PR varies spatially as well as temporarily and is related to clay type, clay content, and soil water content. It is used to evaluate soil quality and to identify layers with increased compaction [30].

Soil compaction is a deterioration process that weakens the plant growth, reducing the soil porosity, slowing the infiltration rate, and restricting the root growth. The most effective factors on soil compaction are accepted as vehicular traffic and wetting-drying circles. Soil compaction impacts pore-size distribution and reduces total soil volume, increases surface runoff and soil erosion in sloping areas, causing ponding in level areas [31].

Results from recent studies showed that plant growth could continue in soil with PR values as high as 3.5 MPa in no-tillage conditions due to the presence of continuous and biological pores, which allowed plant-root development in areas with low PR [32]. The PR and soil moisture showed a spatial relationship where lower values of PR concentrated on smaller values of soil moisture [33]. In another study, PR values varied with the density of the soil, regardless of moisture and penetration rate. The relationship between PR and moisture was not always linear, once it is influenced by soil-bulk density [34]. While PR was indicated as a good indicator of physical soil-crust formation in scalped soils over time, it was not of any effect on biological soil-crust development, erosion behavior of the soils [35]. PR in shallow ploughing in autumn at 10–25 cm was significantly higher than deep ploughing at 45–50 cm in a research [36]. The root length of soybean was obtained as the most susceptible to soil compaction, and the change in soil PR was poorly related with the change in the degree of compactness [37]. The mechanized cultivation system presents greater soil PR values to penetration down to 0.15 m depths and less humidity, when compared to the manual cultivation system [38].

3.2.2. Soil crusting

Crusting index is recognized as one of the major forms of soil degradation. In this study, CI was calculated using soil organic matter, clay, and silt contents. Soils with high CI values tend to have a higher tendency to form crust [39]. Soil organic matter content ranged from 0.41 to 4.33% for topsoil and from 0.14 to 2.32% in subsoil. Approximately 95% of the soils in the basin had low CI values (CI of <5), which indicates low tendency to form crust. The CIs of the basin soil results are shown in **Tables 4** and **5** and **Figure 4c**.

3.2.3. Surface runoff and soil loss

Surface runoff was low in 83.51% of the basin soils and moderate to high in 16.49%. In spite of low runoff, a considerable siltation was observed in Çelikli pond, which was attributed to high-intensity rainfall causing high water erosion.

The mean predicted annual soil loss was 7.66 tons ha^{-1} for Çelikli basin. Total soil loss for basin is approximately 8028.42 tons per year with 86.91% of the loss occurring from agricultural areas (73.56% of total land area). Pasture and shrublands contribution to soil loss was 9.51 and 3.58%, respectively. When soil loss was considered in terms of soil depth in the basin, the mean soil loss tolerance values [40] were around 4.5 tons ha^{-1}, which may be accepted as the threshold level of the basin. In the basin, the agricultural areas are mainly converted from forest and pasture. According to USDA land capability classification, most of the agricultural land-use areas fall under classes VI and VII [24]. In these areas, conventional tillage should not be used. Due to limitations of slope and depth, these areas are mostly suitable for rangeland, pasture, wildlife habitat, or forestland. Although only 14% of the basin is suitable for cultivation, currently 68% of the entire basin is used for agriculture. Surface runoff and soil erosion maps of the study area (**Figure 4e** and **f**) reveal that the area has high potential for erosion, suggesting that measures should be taken to lessen soil erosion in the area.

Globally, soil erosion is responsible for 84% of soil degradation, 56% of water erosion, and 28% of wind erosion [41]. Soil erosion removes the nutrient-rich topsoils. It was pointed out that soil loss by erosion is a widespread global problem and has adverse effects on natural ecosystems such as agriculture, forests, and rangelands [42, 43]. Its effect is accepted as one of the prime environmental problems, impacting water availability, energy, and biodiversity. It causes several environmental damages such as nutrient loss, sedimentation, pollution, and flooding thus impacting productivity and sustainability of the soils [44].

3.2.4. Plant-available water content

Soil in the study area is generally low in PAWC (**Table 4**). Approximately 50% of the soil had PAWC values of <100 mm, and the PAWC values in the area varied (**Figure 4d**). This implies that the stored water in the soil cannot meet the plant water requirement during the summer months (from June to August) as per calculated daily evapotranspiration for reference crop of 6.4–6.8 mm in Tokat province [45].

Plant-available water content is generally considered as one of the most critical properties of soils, especially in the dry farming regions [46]. In semiarid regions, precipitation is generally scarce in summer, and evapotranspiration needs are not met due to low and improper distribution of the precipitation. Plant-available water content is a limiting factor for the rooting depth [47–49]. The amount of rainwater stored in the soil depends on water-holding capacity of soil in effective rooting depth. The remaining water moves beyond the plant-root zone. Thus, the amount of water held by the soil may be critical in dryland areas.

3.2.5. Other soil properties

Physical and chemical soil properties of the topsoil and subsoil with 142 and 115 sampling points, respectively, showed a moderate to high variability. Coarse material exhibited greatest variation in topsoils and P content in subsoils. The soil properties were inconsistent in the coefficient of variation by depth. Values of CV for soil properties of EC, pH, K, Zn, Fe, Mn, and CEC were relatively uniform by depth and this could be attributed to the similarity in the distribution of clay in topsoil and subsoil as these variables are mainly controlled by soil clay content and types of clay.

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Variable	Mean	SD	Min	Max	CV	Skewness	Kurtosis
#EC, mmhos cm^{-1}	0.63	0.14	0.32	0.92	22.73	0.06	0.57
pH	7.41	0.47	6.37	8.63	6.28	0.30	0.67
#SOM, %	1.61	0.65	0.41	4.33	82.19	1.25	2.50
P, mg kg^{-1}	6.65	5.47	0.92	35.20	51.34	2.40	8.91
K, mg kg^{-1}	220.71	113.32	34.04	1008.58	40.46	3.37	17.72
B, mg kg^{-1}	0.20	0.44	0.01	4.67	20.67	8.25	75.82
Zn, mg kg^{-1}	0.20	0.15	0.05	1.82	30.32	8.33	83.99
Cu, mg kg^{-1}	1.86	0.89	0.41	5.03	16.86	0.90	0.56
Fe, mg kg^{-1}	9.69	4.52	2.20	24.02	40.08	0.48	0.34
Mn, mg kg^{-1}	162.00	1805.00	3.00	21524.00	57.09	11.79	137.00
Cd, mg kg^{-1}	0.04	0.02	0.00	0.10	215.93	0.37	0.60
#CEC, cmol kg^{-1}	34.98	9.67	17.63	67.04	27.64	0.66	0.45
Sand, %	46.55	9.62	28.27	74.84	76.53	0.57	0.41
Clay, %	30.01	9.10	4.08	47.88	47.72	0.13	0.36
Silt, %	23.45	3.95	12.91	33.20	46.61	0.14	0.02
#CM, %	19.66	11.22	4.14	67.92	1114.20	1.11	1.80
#HC, cm h^{-1}	22.17	8.89	4.13	47.79	54.91	0.36	0.22
K Factor, t ha h ha^{-1} MJ^{-1} mm^{-1}	0.11	0.06	0.00	0.30	52.46	0.50	0.27
#CI, dimensionless	3.18	1.67	0.78	9.41	52.55	1.74	3.04
#PAWC, mm	100.38	45.79	27.40	161.40	45.62	0.40	1.39
Soil loss, Mg ha^{-1}	6.15	7.99	0.00	62.97	129.90	3.16	16.84
#PR, KPa	1671.20	1080.90	170.80	3882.40	6.47	0.11	1.44
WY, Mg ha^{-1}	1.79	0.72	0.60	3.79	4.04	0.63	0.15

#SD, standard deviation; CV, coefficient of variation; EC, electrical conductivity; SOM, soil organic matter; CEC, cation exchange capacity; CM, coarse material; HC, hydraulic conductivity; CI, crusting index; PAWC, plant-available water content; PR, penetration resistance.

Table 6. Descriptive statistics of some soil properties in topsoil (0–0.3 m) of study area (n = 142).

The soil textural components, coarse material, soil organic matter, and Cd were highly variable in topsoil, and P, B, hydraulic conductivity (Ks), and some micronutrients (e.g., boron) were highly varied in subsoil. On the other hand, wheat yield showed low variation with a relatively normal distribution as indicated by moderate skewness and low kurtosis values (**Table 6**). This was attributed to fertilizer applications for a long time. In contrast to subsoil, where most of the variables were slight to moderately skewed, the majority of the variables were highly skewed in topsoil, which may be attributed to the existence of many irregular slopes with erosion and/or depression localities. Extreme values are likely to occur at these localities. Soil loss, SOM content, and concentrations of P, K, B, Zn, Mn, CM, and crusting index were noticeable among these variables. All these variables are known to control yield in wheat [22]. However, wheat yield interestingly showed low variation with a relatively normal distribution as indicated by moderate skewness and low kurtosis values. In contrast to subsoil, where most of the soil variables were slight to moderately skewed, the majority of the variables were highly skewed in topsoil. The variables Mn, P, K, B, Zn, and soil loss exhibited a considerably constant distribution in topsoil, as suggested by kurtosis values (**Table 6**). Therefore, this low variation in wheat yield may be attributed to the application of fertilizers in the study area.

The P level was low (<10 mg kg^{-1}) in 94% of the study area and was medium to high (>10 mg kg^{-1}) in only 6% of the study area. By contrast, the K content was adequate in both soil depths in most of the study area. Combined with highly variable and skewed distribution of SOM, the low P content of the majority of soil indicated that P and N fertilizers application should be site specific.

Microelement contents of the study soils were classified based on procedures [50]. Calculations showed that B and Zn contents were low due to parent material and that Cu, Mn, Fe, and Cd contents were adequate. Boron content was lower than 0.5 mg kg^{-1} in 85.5% of the cultivated areas and 82.9% of the grassland areas, and Zn was lower than 0.5 mg kg^{-1} in 99.7% of the entire study area. Both B and Zn are essential microelements in wheat production. This indicates that the use of B and Zn additive fertilizers is necessary. Also, the highly variable and skewed distribution of these elements should be considered in fertilizer application [22].

3.3. Factor analysis

The evaluation of soil degradation is difficult because of the diversity and complexity of soil-degrading processes. Interrelations between the variables frequently obscure the evaluation of each soil-degrading process' contribution. Factor analysis is frequently used to reduce the number of variables in a dataset, and so we used factor analysis to identify the key variables of soil degradation in the study area.

All the studied soil properties namely EC, pH, P, K, SOM, CEC, B, Zn, Cu, Fe, Mn, Cd, sand, clay, silt, coarse material, hydraulic conductivity, soil erodibility (K) factor, crusting index, runoff, PAWC, soil loss, penetration resistance, and wheat yield were subjected to factor analysis (see **Table 7**).

Topsoil: The 24 variables were considered for the factor analysis of topsoils and grouped in nine factors accounting for 71.2% of the total variance (**Table 8**).

The variables clay, sand, and erodibility were loaded in Factor 1 and this factor was named as "erodibility factor". The "erodibility factor" accounted for 14.7% of the total variation. We found a negative correlation between clay content and soil erodibility. This was attributed to the effect of clay on soil aggregate strength, which decreases soil erodibility. Likewise, when we compared soil loss in clayey and sandy clay soils, clay soil was more resistant to erosion because of its stronger aggregates.

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Variable	Mean	SD	Min	Max	CV	Skewness	Kurtosis
#EC, mmhos cm^{-1}	0.62	0.14	0.30	0.94	22.22	0.01	0.43
pH	7.55	0.42	6.37	8.30	5.50	0.61	0.39
#SOM, %	1.12	0.45	0.14	2.32	40.68	0.06	0.37
P, mg kg^{-1}	2.79	3.33	0.40	22.40	119.33	3.22	12.68
K, mg kg^{-1}	171.71	69.43	33.75	461.92	40.43	0.93	2.10
B, mg kg^{-1}	0.19	0.22	0.00	1.48	112.34	3.21	13.06
Zn, mg kg^{-1}	0.12	0.04	0.03	0.32	37.40	1.04	2.76
Cu, mg kg^{-1}	1.73	0.82	0.17	3.83	47.53	0.57	0.45
Fe, mg kg^{-1}	8.70	3.85	2.57	20.50	44.28	0.60	0.02
Mn, mg kg^{-1}	11.05	6.43	3.01	35.90	58.18	1.16	1.31
Cd, mg kg^{-1}	0.04	0.02	0.00	0.12	57.17	0.03	0.05
#CEC, cmol kg^{-1}	36.36	9.38	19.19	66.86	25.81	0.42	0.02
Sand, %	45.17	9.01	26.72	76.39	19.94	0.50	0.63
Clay, %	32.82	8.56	10.73	53.39	26.08	0.10	0.48
Silt, %	22.01	3.50	12.88	30.19	15.88	0.31	0.12
#CM, %	18.45	10.34	2.18	49.84	56.05	0.81	0.06
#HC, cm h^{-1}	45.17	9.01	26.72	76.39	19.94	0.50	0.63
#PR, KPa	2579.60	332.00	1590.00	3522.00	12.87	0.40	0.64

#SD, standard deviation; CV, coefficient of variation; EC, electrical conductivity; SOM, soil organic matter; CEC, cation exchange capacity; CM, coarse material; HC, hydraulic conductivity; PR, penetration resistance.

Table 7. Descriptive statistics of some soil properties in subsoil (0.3–0.6 cm) of study area (*n* = 115).

The K factor of 10 measurements of surface soil in the Hornos area in Spain was calculated and compared with three aspects of aggregate stability [51]. A significant correlation was found between the K factor and the percentage of particles <100 μm, which is accepted as a measure of the vulnerability of soil to erosion by overland flow.

The variables Fe, Cu, and pH were loaded in Factor 2, which were named as "soil fertility" factor. The soil fertility factor described 10.74% of the total variation and had a positive correlation with the two micronutrients (Cu and Fe). However, there was a negative relationship between soil pH and these nutrients. A research result [52] showed that the increased clay and iron (Fe) contents resulted in decreased soya bean emergence and soil strength. The eroded soils had lower infiltration rates and higher clay dispersion.

Properties Cu, EC, and CEC were loaded in Factor 3, and it was named as "soil chemistry factor". The soil chemistry factor described 9.89% of the total variation. Positive correlation occurred between Cu and CEC and between Cu and EC. Factor 4 was named as "soil-crusting factor" that included SOM and CI and described 8.37% of the total variation.

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
Clay, %	0.95	−0.02	0.14	−0.06	−0.02	−0.09	0.10	0.01	−0.01
K Factor, t ha h ha^{-1} MJ^{-1} mm^{-1}	−0.88	0.15	0.12	0.00	0.03	−0.15	0.14	−0.15	0.04
Sand, %	−0.76	−0.08	−0.35	−0.06	0.08	0.24	−0.33	−0.02	0.03
Silt, %	−0.48	0.19	0.40	0.24	−0.11	−0.29	0.44	0.01	−0.04
Fe, mg kg^{-1}	0.11	−0.84	0.10	0.16	−0.15	−0.17	−0.09	−0.11	−0.11
pH	−0.06	0.81	0.09	−0.09	0.05	0.13	−0.21	−0.15	−0.08
Cu, mg kg^{-1}	−0.00	−0.59	0.52	−0.06	−0.20	−0.12	−0.25	0.08	−0.13
#CEC, cmol kg^{-1}	−0.05	−0.14	0.87	0.00	0.05	0.07	−0.04	−0.03	−0.00
#EC, mmhos cm^{-1}	0.40	0.43	0.64	0.23	−0.06	−0.03	−0.08	0.03	0.05
#SOM, %	0.13	−0.06	0.10	0.93	−0.03	−0.01	0.13	0.16	0.00
#CI, dimensionless	−0.19	−0.10	−0.04	0.92	−0.01	0.10	−0.02	0.14	0.01
Soil loss, Mg ha^{-1}	0.01	0.04	−0.05	−0.05	0.88	0.13	0.01	0.12	−0.08
Runoff, dimensionless	−0.09	0.18	0.07	0.02	0.78	−0.16	−0.17	−0.19	0.17
#HC, cm h^{-1}	0.06	0.21	0.21	−0.04	−0.04	0.71	−0.05	−0.10	0.06
#CM, %	−0.19	0.14	−0.23	0.09	0.05	0.68	0.00	0.04	−0.13
B, mg kg^{-1}	0.28	−0.15	0.05	0.15	−0.01	0.36	0.13	−0.10	0.31
#PAWC, mm	0.19	−0.11	−0.15	0.14	−0.11	0.00	0.77	−0.03	−0.02
Mn, mg kg^{-1}	0.12	−0.03	−0.14	0.24	−0.00	−0.06	−0.39	−0.17	−0.32
P, mg kg^{-1}	0.01	−0.14	0.06	0.14	0.08	0.06	0.02	0.83	−0.02
K, mg kg^{-1}	0.06	0.44	0.08	0.28	−0.17	−0.23	−0.21	0.58	0.07
Zn, mg kg^{-1}	0.25	0.01	−0.11	0.05	−0.08	−0.14	0.14	0.35	−0.10
#PR, kPa	0.07	−0.04	−0.13	0.07	−0.01	−0.18	0.09	−0.06	0.74
WY, Mg ha^{-1}	0.18	−0.22	−0.10	0.04	−0.04	−0.23	0.26	0.06	−0.61
Cd, mg kg^{-1}	−0.10	0.03	0.41	−0.21	0.25	0.07	0.26	0.17	0.42
Variance, %	14.57	10.74	9.89	8.37	6.46	6.31	5.73	4.63	4.46
Cumulative variance	14.57	25.31	35.20	43.57	50.03	56.34	62.07	66.70	71.16

#CEC, cation exchange capacity; EC, electrical conductivity; SOM, soil organic matter; CI, crusting index; CM, coarse material; HC, hydraulic conductivity; PAWC, plant-available water content; PR, penetration resistance; WY, wheat yield.

Table 8. Factor analysis for topsoil in study area.

Factor 5, "soil erosion factor", which includes soil loss and runoff, described 6.46% of the total variation. As expected, there was a positive correlation between soil loss and runoff. Factor analysis was applied to predict erosion in an area intensively cultivated with sugarcane near the city of Piracicaba, São Paulo [53]. The researchers revealed that soil erosion was influenced by slope length and steepness (LS) factor (topographic) more than by the K factor (soil erodibility).

Factor 6 was named as "soil conductivity factor", which included the hydraulic conductivity and coarse material content and described 6.31% of the total variation (**Table 8**). We found a strong positive loading for CM (0.68) and HC (0.71). In a study [54], land-use effects on soil compaction considering the saturated hydraulic conductivity (Ks) in a field continuously growing corn and a hayfield both having clay soil in Canada were evaluated. The Ks-values for hayfield-growing soils were approximately 10 or 100 times greater than for the corn-growing soils of which degradation level for upper B horizons had changed from slight to severe. While there was no difference for B horizons in terms of Ks, their results showed that the corn yield was reduced by about 50% due to severe compaction and low Ks. The Ks-values for the 30–50-cm depth can be a reliable indicator for assessing soil structure degradation.

Factor 7, the plant-available water content or "PAWC factor" described 5.7% of the total variation (**Table 8**). The PAWC is considered the most critical indicator for land degradation, especially for dryland farming regions [46]. In dryland regions, spring and summer months are generally dry, and plant water needs are not met due to low and improper distribution of precipitation. The PAWC is a limiting factor for root depth [47–49]. Precipitation water is stored in the soil, depending on soil depth and water-holding capacity. In cases of infiltration rate lower than rainfall intensity, a portion of rainwater may be lost via surface runoff or ponded on the surface. The amount infiltrating into soil may be stored depending on soil depth or lost via deep percolation or underground lateral flow in sloping layered soils. As a result, the amount of water stored in the soil may be critical in areas where water is the principal growth-limiting factor [47, 48]. Spatial variability of topsoil (0–30 cm) and subsoil (30–60 cm) in the Kazova Plain was investigated by factor analysis [55]. Six of 10 variables for both top and subsoils were loaded in four factors accounting for 94.80 and 92.80% of total variance, respectively. The results showed that the plant-available water content and available phosphorus content (P) were the most important soil properties for soil management and soil fertility studies in the study area.

Macroelements K and P were loaded in Factor 8. Factor 8 was named as "macroelement factor". The loadings showed a high correlation between these two variables. The imbalance of macronutrients (e.g., N, P, K, Ca, Mg, and S) and microelements (e.g., Zn, Cu, Mo, B, and Se) may cause a yield decline in degraded soils. Factor analysis has been used to identify the most sensitive indicators of some soil characteristics for evaluating soil tillage in Vertisol and Entisols in the Bafra province of Turkey [56]. The soil physicochemical properties of Vertisols were grouped in three groups and of Entisols were grouped in two groups. Available water content, field capacity, soil organic matter, wilting point, and $CaCO_3$ were in the first group; bulk density, sand, and carbon were in the second group; and penetration resistance was in the third group for Vertisols. Soil organic matter, available water content, wilting point, field capacity, soil organic matter, sand, and bulk density were in the first group and $CaCO_3$, silt, and penetration resistance were in the second group for Entisols.

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Mn, mg kg^{-1}	0.86	0.05	0.11	−0.11	0.07	0.04	−0.19
pH	−0.82	0.03	−020	−0.01	−0.22	−0.15	0.00
Fe, mg kg^{-1}	0.82	0.17	−0.03	0.32	−0.09	−0.16	−0.08
Clay, %	0.07	0.93	−0.05	0.09	−0.03	0.00	−0.02
Sand, %	−0.08	−0.93	0.09	0.05	−0.19	−0.12	−0.08
#EC, mmhos cm^{-1}	−0.44	0.57	0.04	0.49	0.25	−0.19	−0.10
#HC, cm h^{-1}	−0.24	−0.55	0.54	0.04	0.19	−0.15	−0.07
Zn, mg kg^{-1}	0.34	−0.11	0.75	0.05	0.17	0.20	0.17
P, mg kg^{-1}	0.06	−0.02	0.73	−0.21	−0.29	0.10	0.04
#CM, %	0.14	−0.32	0.45	−0.25	−0.02	−0.33	−0.26
#CEC, cmol kg^{-1}	−0.00	0.02	−0.15	0.86	0.03	−0.05	0.10
Cu, mg kg^{-1}	0.44	0.07	0.00	0.71	−0.37	0.15	0.06
WY, Mg ha^{-1}	0.07	−0.02	− 0.07	−0.03	0.72	−0.09	0.12
Silt, %	0.05	0.19	−0.10	−0.31	0.54	0.29	0.25
#SOM, %	0.07	0.17	0.42	0.10	0.53	0.08	−0.22
K, mg kg^{-1}	−0.05	0.24	0.17	−0.10	−0.12	0.82	−0.06
B, mg kg^{-1}	−0.23	0.31	0.00	−0.18	−0.37	−0.62	0.18
Cd, mg kg^{-1}	−0.04	0.02	0.04	−0.01	0.05	0.08	0.87
#PR, KPa	0.15	−0.02	−0.01	−0.13	−0.07	0.28	−0.58
Variance, %	16.95	16.27	10.96	8.29	7.19	6.88	6.68
Cumulative variance	16.95	33.22	44.18	52.47	59.66	66.54	73.22

#EC, electrical conductivity; HC, hydraulic conductivity; CM, coarse material; CEC, cation exchange capacity; WY, wheat yield; SOM, soil organic matter; PR, penetration resistance.

Table 9. Factor analysis for subsoil in study area.

Finally, wheat yield and penetration resistance were loaded in Factor 9 and it was named as "crop yield factor". The crop yield factor described 4.46% of the total variation. Loadings showed a high negative correlation ($R^2 = -0.735$) between these two variables in the study area. Similar results were found elsewhere, PR reduced wheat and soybean yields [57]. Others [58] showed that PR had a highly adverse effect on wheat spike number. Results of another study [59] showed that PR was a limiting factor of soybean yield due to its adverse effect on field capacity.

In subsoil, 19 variables were grouped in seven factors that accounted for 73.2% of total variance, as shown in **Table 9**. Available Mn content, pH, and available Fe content were loaded in Factor 1, which described 16.9% of the total variation in the studied variables. Factor 1 was named as "microelement factor". The loadings showed a positive relationship among Mn, Cu, and Fe contents and a negative correlation between pH and each of these variables. The variables of clay, sand, EC, and HC were loaded in Factor 2, which described 16.2% of the total variance. Factor 2 was named as "soil physics factor". Hydraulic conductivity had a negative loading, whereas EC and clay had positive loadings in Factor 2, suggesting that contrary to sand, both clay content and EC had a negative effect on HC. Factor 3 described 10.9% of the total variance. The variables Zn and available P were loaded in this factor. Hydraulic conductivity was also loaded in this factor. Factor 4, named "soil chemistry", included CEC, Cu, and EC and described 8.3% of the total variance. Wheat yield, silt, and SOM were loaded in Factor 5, which described 7.2% of the total variance. Factor 5 was named as "yield factor". Available K and B were loaded in Factor 6, and Cd and PR were loaded in Factor 7. Factor 6, describing 6.9% of variance, was named as "soil potassium factor", and Factor 7, describing 6.7% of total variance, was named as "soil cadmium factor".

4. Conclusion

Factor analysis revealed that PR in topsoil had a profound adverse effect on wheat yield, whereas silt and SOM content in subsoil had a positive effect. A moderate positive correlation occurred between PAWC and wheat yield. Therefore, insufficient water-holding capacity, low SOM content, and high PR are the major variables affecting wheat yield in the catchment. These variables can be controlled by management practices such as residue management, crop rotation, and use of organic materials in crop production. Soil loss is one of the major contributors to soil degradation. Our results showed that 89% of the study area is under the influence of surface runoff to some degree. Conservation tillage (CT) can be adapted to decrease the potential of surface runoff in the study area. However, CT should be applied carefully to the areas with high PR, since it can also increase PR.

In combination with crop rotation and variable fertilizer application, these practices can help restore soil productivity in cultivated areas, which cover 95.4 ha of the study area. Forage crops should be used in crop rotation to increase SOM content and decrease PR in the study area. It is likely that increasing SOM and decreasing PR will decrease surface crusting, which would increase water-holding capacity by increased water infiltration into soil and decreases the potential for soil loss through surface runoff. The localities covered by grass and shrubs should be managed properly to avoid further deterioration. This may be accomplished by the application of rotational grazing, which reduces animal trafficking, in turn decreasing PR in grasslands.

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