Water and Soil Management and Modeling

Online ISSN: 2783 - 2546

University of Mohaghegh Ardabili

Influence of land use and management practices on soil physicochemical properties across slope gradients

Awoke Abebaw [1], Walle Jemberu[2], Mekonnen Getahun[3], Wasihun Mengiste[4]* Aweke Endalew[5]

[1] MSc in Soil Science, Department of Natural Resources Management, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia
[2] PhD in Soil Conservation , Department of Natural Resources Management, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia
[3] PhD in Soil Science, Amhara Design and Supervision Works Enterprise, Bahir Dar, Ethiopia
[4] Assistant Professor, Department of Soil Resource and Watershed Management, College of Agriculture and Natural Resources, Gambella University, Gambella, Ethiopia
[5] MSc in Soil Science, Department of Soil Resource and Watershed Management, College of Agriculture and Natural Resources, Gambella University, Gambella, Ethiopia

Abstract

The decline in soil fertility is being intensified by both human activities and natural phenomena. Therefore, in order to address the concerns of the agricultural revolution and sustainable land productivity. It is crucial to examine the influence of land use and land management practices on soil properties across various slope gradients. The research aimed to examine how different land use and management techniques influence selected physicochemical properties of the soil across various slope classes. The study employed an experimental design that included three types of land use and two slope classes, with samples collected from managed and unmanaged areas. Finally, 36 samples were obtained at a depth of 0-20 cm. Three-way ANOVA was used for statistical analysis. The results revealed that most soil physicochemical properties were significantly ($P < 0.05$) influenced by land use type management practice and slope gradient. Forest land exhibited the highest values for clay (44.25%), TP (59.03%), pH (5.73), OM (5.03%), TN (0.16%), and Av. P (12.19 ppm), CEC (31.60 cmol(+) kg-1) and exchangeable bases: Ca^{2+} (8.94 cmol(+) kg-1), Mg^{2+} (3.10 cmol(+) kg-1), K^+ (0.62 cmol(+) kg-1) and Na^+ (0.61 cmol(+) kg-1). In contrast, cultivated land showed the highest sand content (33.42%) and bulk density (1.25 g cm-3), while grazing land recorded the highest silt content (31.67%). Managed areas recorded the highest values for clay (43.11%), TP (57.57%), pH (5.65), OM (4.35%), TN (0.15%), and Av. P (11.14 ppm), CEC (29.25 cmol(+) kg-1) and exchangeable bases: Ca^{2+} (8.37 cmol(+) kg-1), Mg^{2+} (2.48 cmol(+) kg-1), K^+ (0.59 cmol(+) kg-1) and Na^+ (0.52 cmol(+) kg-1) compared to unmanaged areas. With respect to slope gradient, it was generally noted that most of the studied soil properties increased with decreasing slope gradient. Generally, the sources of variations in the soils' physicochemical properties were land use type, management practice, and slope. Therefore, there is a need for appropriate and integrated land management techniques, such as agroforestry, contour plowing, terracing, conservation tillage, mulching, crop rotation, cover cropping, controlled grazing, reforestation, and the use of organic amendments, which aim to improve the physicochemical properties of soils to the different land use and slope classes in Burat Watershed.

Keywords: Land use change; Integrated land management; Soil fertility; Topography; Sustainable land productivity

Article Type: Research Article

*Corresponding Author, E-mail: wasihunmengiste@gmu.edu.et

Citation: Abebaw, A., Jemberu, W., Getahun, M., Mengiste, W., & Endalew, A. (2025). Influence of land use and management practices on soil physicochemical properties across slope Gradients. Water and Soil Management and Modeling, 5(4), 15-27.
doi: 10.22098/mmws.2025.18301.1674
Received: 08 September 2025, Received in revised form: 16 October 2025, Accepted: 27 October 2025, Published online: 07 November 2025
Water and Soil Management and Modeling, Year 2025, Vol. 5, No. 4, pp. 15-27.
Publisher: University of Mohaghegh Ardabili

1. Introduction

Soil serves as the basic resource for almost all land uses and only resource that underpins sustainable agriculture (Corato et al., 2024). It provides essential nutrients for plant growth (Warke & Wakgari, 2024), regulates water infiltration and storage, supports biodiversity (Hailu et al., 2021), and plays a crucial role in carbon sequestration (Xalxo et al., 2025). The sustainable productivity of the soil is governed by its physical, chemical, and biological properties quality level (Kiflu & Beyene, 2013). The speed of soil fertility degradation varies with different natural and manmade factors like land use type, climatic conditions, slope gradient, land management techniques, etc. (Lal, 2001).

The degradation of soil quality has emerged as a significant and pervasive threat in Ethiopia, undermining agricultural productivity, food security, and the livelihoods of millions of smallholder farmers (Kahsay et al., 2025). This degradation is primarily driven by a combination of factors, including unsustainable land use practices, climate change, deforestation, and overgrazing (Huang et al., 2024). The conversion of forest and grassland into cultivated areas, often without adequate soil conservation measures, leads to increased soil erosion, nutrient depletion, and a reduction in soil organic matter (SOM), all of which contribute to declining soil fertility and reduced crop yields (Assefa et al., 2020). Research indicates that inappropriate land use systems and practices can further accelerate the depletion of vital soil characteristics, leading to a decline in agricultural potential and increased vulnerability to environmental stresses (Dixit et al., 2024; Kiflu & Beyene, 2013). In the Ethiopian highlands, where rugged terrain and intensive agriculture are common, soil erosion rates are among the highest in the world, resulting in significant economic losses and environmental damage (Kahsay et al., 2025).

Recent studies in Ethiopia have shown that land management practices significantly improve soil properties compared to unmanaged areas. For instance, in the Ojoje sub-watershed of the Southern Ethiopian Highlands, integrated agricultural land management practices over 5 to 10 years increased soil organic carbon, total nitrogen, available phosphorus, sulfur, boron, and cation exchange capacity, with the most significant improvements observed in areas treated for 10 years (Abera & Wana, 2023). Similarly, in the East Shewa Zone, the adoption of soil and water conservation (SWC) technologies, including soil bunds and mulching, significantly enhanced soil moisture content and maize yield (Jelde et al., 2024). Similarly, research in the Korekore Watershed indicated that areas under soil and water conservation measures had improved soil fertility and crop productivity compared to unmanaged lands (Fantahun et al., 2024). These findings underscore the importance of implementing sustainable land management practices to enhance soil quality and agricultural productivity in Ethiopia.

Slope position plays a significant role in shaping soil properties through its effect on water movement, erosion, and sediment deposition (Amare et al., 2024). Steep slopes are highly vulnerable to surface runoff, which limits water infiltration and accelerates soil erosion, often leaving behind shallow and less productive soils (Deng et al., 2020). Because of their exposure to gravity, rainfall, and wind, these areas tend to lose soil material more quickly than gentler terrains (Balasubramanian, 2017; Wu et al., 2024). As a result, upper slope soils generally contain less organic matter and have lower water-holding capacity, reducing their fertility and limiting the range of vegetation they can support (Schoonover & Crim, 2015). Without appropriate management, these landscapes face significant agricultural challenges, as the continuous loss of topsoil can degrade soil quality and diminish crop yields over time (Selassie et al., 2015). In comparison, gentler slopes and flat terrains slow surface water movement, which enhances infiltration and moisture storage (Amare et al., 2024). Such conditions encourage the formation of deeper soils and improve fertility through the accumulation of organic matter and deposited sediments (Amare et al., 2024). At the foot-slopes, material transported from higher elevations, including nutrients and organic matter, is deposited, creating soils that are typically richer in moisture and fertility (Luo et al., 2024). Furthermore, soils in these lower slope positions are generally less exposed to erosion, allowing for the development of stable, nutrient-enriched layers that support higher productivity (Seifu et al., 2021).

The Burat watershed was suitable for crop production, homestead, tree plantation, and livestock grazing. However, increasing population pressure, steep slope gradients, and intensive cultivation have led to smaller landholdings per household and placing enormous stress on the available agricultural land. This situation brought disturbance to the ecosystem, particularly in the soil. Due to this, the area has been exposed to soil erosion, excess rills, and some gullies that might decline crop and forage productivity. Furthermore, poor soil management practices, coupled with steep slopes, high rainfall, continuous cultivation with low external inputs, and overgrazing, have made the watershed highly vulnerable to nutrient depletion and land degradation, thereby threatening the livelihoods of local farmers. As a result, soil fertility has declined, and agricultural productivity remains low. Despite these challenges, the extent, causes, and impacts of soil fertility decline under different land use types, management practices, and slope gradients have not received sufficient research attention in the Burat watershed. Knowledge-based soil and land resource management is therefore essential for sustaining productivity and ensuring long-term environmental stability. Hence, this study was undertaken to evaluate the influence of land use and management practices on selected soil properties across slope gradients in the Burat sub-watershed.

2. Materials and Methods

2.1. Description of the study area

This research was conducted in the Burat watershed, which is situated in Dera District in the South Gondar zone, which is in northwestern Ethiopia (Figure 1). It is located nearly 33 Kilometers to the Northeast of Bahir Dar and 602 kilometers to the Northwest direction from Addis Ababa. Geographically, it lies between latitudes 11°45′50″ N and 11°46′1″ N and longitudes 37°32′41″ and 37°34′52″, covering around 670 hectares of land (Figure 1). The elevation recorded in this region varies from 1882 meters to 1995 m.a.s.l. (Figure 1).

The study watershed is characterized by gentle to slightly steep slope topography (0 to 44%). According to Bahir Dar meteorological station records from 2010 to 2019, between the years 2010 and 2019, the average annual rainfall was 1845.83 mm (Table 3). It has a single rainy season, which usually starts in May and ends in October, with July and August receiving the highest rainfall. The average minimum and maximum temperatures recorded annually were 10.7 °C and 25°C, respectively (Figure 3).

The study area encompasses various land use types, such as cultivated land, bushland, grazing land, forest land, bare land, and settlement. A subsistence mixed farming system is practiced within the watershed. Finger millet (Eleusine coracana), Teff (Eragrostis teff), Barley (Hordeum vulgare), Bread wheat (Triticum aestivum), and Maize (Zea mays) crops are grown with rain-fed. The (FAO, 2005) states that Nitosols are the most common soil type in the study area.

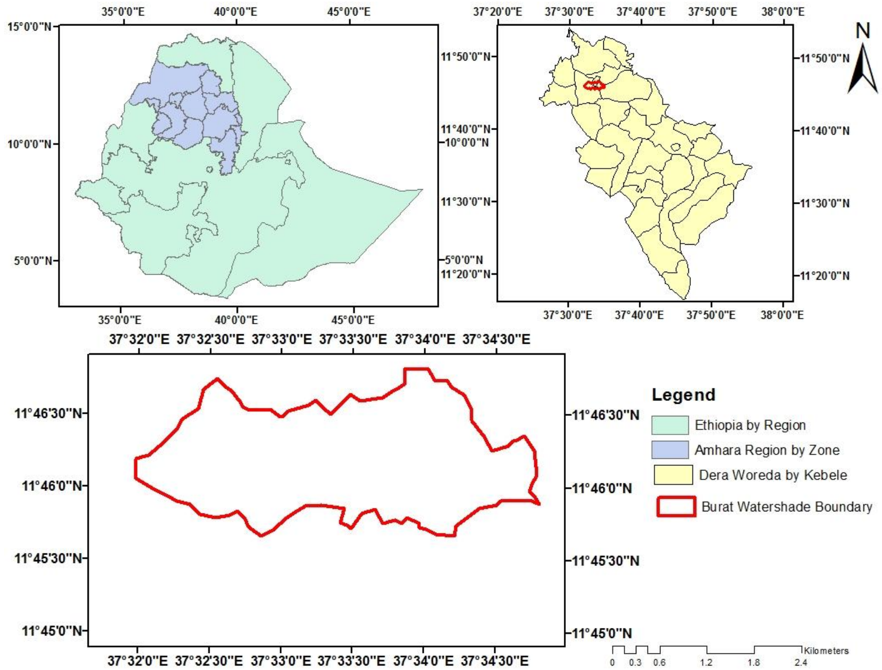

Figure 1. Geographical location of the study area

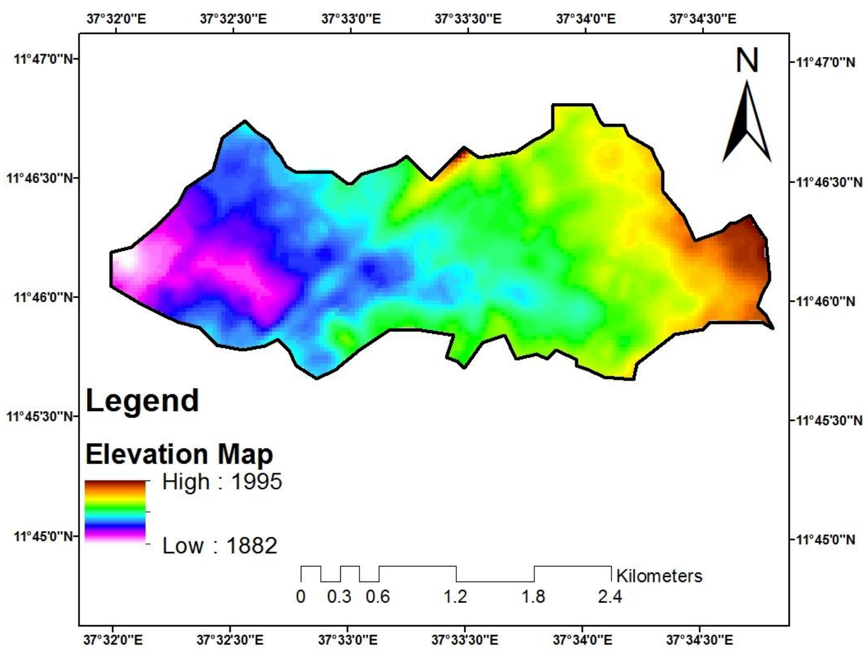

Figure 2 Altitude map of the area

2.2. Experimental design and soil sampling:

Following a preliminary survey, three major types of land uses (grazing land, forest land, and cultivated land) that dominate in the watershed were chosen with two slope gradients in both managed (soil bund) and unmanaged areas. Soil sampling sites were selected by stratifying the watershed according to the dominant land use types, slope gradients, and management practices. After site selection, twelve representative locations were established for each land use type (calculated as 2 management practices × 2 slope gradients × 3 replications).

Composite soil samples were taken using a sampling auger from each 10m x 10m plot at a depth of 0-20 cm. Accordingly, a total of 36 sampling plots (3 land uses x 2 management practices x 2 slope gradients x 3 replication) were maintained for laboratory analysis. Additionally, 36 undisturbed soil core samples were obtained to ascertain BD across all plots, also in triplicate. Finally, samples were thoroughly labeled, packed, and delivered to the soil laboratory for preparation and analysis.

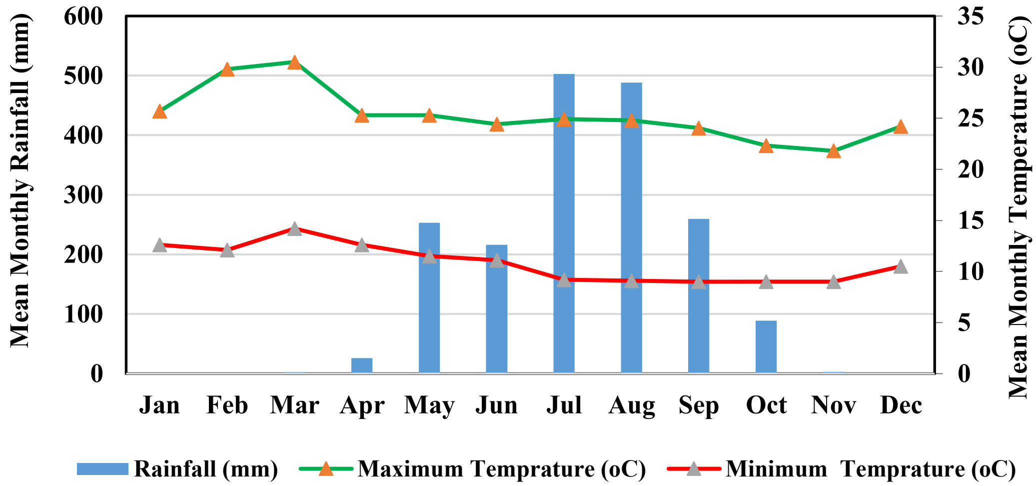

Figure 3. Annual average rainfall (mm) and mean minimum and maximum temperatures in the study area

2.3. Laboratory analysis

For the examination of selected soil physicochemical parameters, the samples were air-dried, ground, and sifted via a 2 mm mesh. The Bouyoucos hydrometer technique (Bouyoucos, 1962) was employed to measure the particle size distribution. Soil bulk density (BD) was measured using core samples that were oven-dried at 105 °C for 24 hours (Black, 1965) and calculated according to Equation 1. Total porosity (TP) was then determined using Equation 2 (Brady & Weil, 2008). The pH of the soil was measured in a 1:2.5 soil-to-water suspension using a pH meter (van Reeuwijk, 1995). The wet oxidation technique was used to ascertain the amount of organic carbon (Walkley & Black, 1934). The Kjeldahl digestion, distillation, and titration process (Bremner & Mulvaney, 1982) was used to determine TN, whereas the Olsen extraction procedure (Olsen, 1954) was used to assess the amount of available P (Assuming that the particle density of soil is 2.65 g/cm³) (Brady & Weil, 2008).

$\text{BD (g cm}^{-3}) = \dfrac{Mass\ of\ oven-dry\ soil}{Total\ volume\ of\ soil}$	(1)
$\text{TP (\%)} = \left(1 - \dfrac{Bulk\ density}{Particle\ density}\right) X100$	(2)

The exchangeable elements Ca and Mg were measured using an atomic absorption spectrometer (AAS), and the measurements of potassium (K) or sodium (Na) were obtained using a flame photometer (Rowell, 1994). The CEC of the samples was tested by using a 1 M ammonium-acetate 134 solution with pH 7 as the washout solution (Chapman, 1965).

2.4. Statistical analysis

Analysis of variance (ANOVA) was performed using analysis software (SAS) version 9.0 to examine statistical differences among various soil parameters across different land uses, management practices, and slope gradients. Least Significant Differences (LSD) was used to separate means for soil parameters that revealed significant differences ($P < 0.05$).

3. Result and Discussion

3.1. Effect of land use types, slope, and land management practices on selected soil physical properties

3.1.1. Particle size distribution

The sand and clay fraction was significantly ($P < 0.01$) varied among land use, management practice, and slope (Table 1). The highest (33.42%) sand fraction was observed in cultivated land, and the lowest (26.92%) was in forest land (Table 1). Moreover, the lowest (35.67%) and the highest (44.25%) clay fractions were noted in cultivated land and forest land, respectively (Table 1). This is probably attributed that clay particles were more easily exposed to erosion than sand particles in free grazing and cultivated land (due to soil aggregate disturbance during plowing), rather than forest land. These results correspond with the results of (Abate & Kibret, 2016; Assefa et al., 2020).

The higher silt and sand fractions were recorded in unmanaged areas, while the higher clay fraction was shown in the managed areas (Table 1). This trend may be attributed to soil erosion, which carries away the finer soil particles in unmanaged regions. Similar conclusions were noted by Gadana et al. (2020) and Mohammed et al. (2020), who find the highest sand fraction in unmanaged areas and higher clay content in managed areas in various parts of Ethiopia. Conversely, Table 1 showed an increase in sand and a decrease in clay fractions with an increase in slope gradient. The reason for this outcome can be explained by the loss of finer particles from the upper slopes and their subsequent deposition in lower areas coarser-textured classes dominated on the upper slopes. The higher clay content and lower sand content observed in the soils at the lower slopes may result from the transport of finer particles from the upper slopes, where they accumulate in the lower areas (Endalew et al., 2025). This finding is consistent with (Mohammed et al., 2020; Mulugeta Aytenew, 2015) who reported that a lower slope typically exhibits a higher clay fraction and lower sand fraction.

3.1.2. Bulk density (BD)

Soil BD revealed a significant ($P < 0.01$) effect in land use type, management practice, and slope gradient (Table 1). The highest (1.25 g cm-3) BD was reported in cultivated land, and the lowest (1.09 g cm-3) was recorded in forest land (Table 1). The lower BD recorded in forest land may be attributed to the higher organic matter content found in these soils. Whereas the higher BD in cultivated soils is likely a result of compaction caused by regular farming practices and the reduced organic matter content (Abate & Kibret, 2016; Tufa et al., 2019; Yitbarek, 2013). BD was higher in the soils of the unmanaged area (Table 1). This could be due to the relatively lower SOM content, topsoil erosion, and higher compaction effect due to the absence of land cover and overgrazing, in agreement with different authors (Gadana et al., 2020). Regarding slope, it increases with an increase in slope gradient (Table 1). The reason could be attributed to the parallel decrease in SOM content with an increase in slope gradient in consent with the findings of (Gadana et al., 2020; Mohammed et al., 2020; Mulugeta Aytenew, 2015).

Table 1. The effects of land use type, slope gradient, and land management practice on selected soil physical properties

Land use, management, and slope	Particle size distribution (%)			Textural class	BD (g cm $^{-3}$)	TP (%)
	Sand	Silt	Clay			
Land uses						
Grazing land	30.83^{b}	31.67	37.50^{b}	Clay loam	1.20^{a}	54.72^{b}
Cultivated land	33.42^{a}	30.92	35.67^{b}	Clay loam	1.25^{a}	52.89^{b}
Forest land	26.92^{c}	28.83	44.25^{a}	Clay	1.09^{b}	59.03^{a}
MSD(0.05)	2.51	NS	2.25		0.05	1.95
P- Value	0.00**	0.07^{ns}	0.00**		0.00**	
Management						
Unmanaged	31.67^{a}	33.16^{a}	35.17^{b}	Clay loam	1.23^{a}	53.52^{b}
Managed	29.11^{b}	27.77^{b}	43.11^{a}	Clay	1.12^{b}	57.57^{a}
MSD (0.05)	1.70	2.31	1.52		0.05	1.32
P- Value	0.04**	0.00**	0.00**	0.00**	0.00**	0.00**
Slope						
Lower (2-5%)	29.06^{b}	30.00	40.94^{a}	Clay	1.15^{b}	56.39^{a}
Higher (5-10%)	31.72^{a}	30.94	37.33^{b}	Clay loam	1.20^{a}	54.70^{b}
MSD(0.05)	1.70	NS	1.52		0.04	1.32
P- Value	0.05**	NS	0.00**		0.02*	0.02**
CV	9.50	12.79	10.83		5.48	4.39

Mean values within a column followed by the different letters are significantly different from each other at **P < 0.01 and *P < 0.05. NS = Not significant

3.1.3. Total Porosity (TP)

Total porosity showed a reverse trend to bulk density and also exhibited highly significant differences ($P < 0.01$) among land use types, management practices, and slope gradients (Table 1). It was highest in forest land (59.03%) and lowest in cultivated land (52.89%) (Table 1). The highest TP under forest land could be due to increased accumulation of organic matter, higher biological activity, and improved soil structure. Conversely, the lower TP in cultivated soils reflects compaction and structure degradation caused by continuous cultivation and reduced organic matter. Similar findings by Assefa et al. (2020) reported higher TP in the forest land compared to other land uses. Additionally, Kebebew et al. (2022) and Asmare et al. (2023) observed that TP was highest in forest land and lowest in cultivated land.

Managed areas showed higher TP (57.57%) than unmanaged areas (53.52%) (Table 1). This may be due to the presence of soil bunds that reduce erosion, promote moisture retention, and enhance organic matter buildup, thereby improving soil pore and soil structure. Variations in TP can also be influenced by bulk density, clay content, organic matter, and cultivation intensity. Lower BD, together with higher clay and OM content, likely contributes to the higher TP observed on managed areas (Gadana et al, 2020). In agreement with this, Assefa et al. (2020) reported higher TP on managed land compared to unmanaged land, with even treated cultivated land showing higher TP than untreated forest land. This highlights the impact of management practices on soil porosity. Regarding slope gradient, TP was higher on the lower slope (56.39%) than on the upper slope (54.70%) (Table 1). In the Burat watershed, TP generally increases as slope decreases. This pattern is likely due to the accumulation of clay particles and organic matter washed down from upper slopes, while the lower porosity on steeper slopes may result from greater erosion, runoff, and soil compaction. In consent with this finding, Mulugeta Aytenew (2015) and Assefa et al. (2020) reported that soils at lower slope positions had higher TP compared to soils at upper slope positions.

3.2. Effect of land use types, slope, and land management practices on selected soil chemical properties

3.2.1. Soil pH (H_2O)

Soil pH (H2O) was significantly ($P < 0.01$) influenced by all factors, such as land use type, slope, and management practice (Table 2). The forest land has the highest (5.73) soil pH, while cultivated land recorded the lowest (5.20) soil pH (Table 2). Therefore, soil pH in the studied areas ranges from moderately acidic to strongly acidic, according to the classification by Tadesse et al. (1991). The lowest soil pH recorded in cultivated land may result from the removal of exchangeable bases during crop harvest, erosion, the presence of Al3+ and H+ in the solution, and improper use of ammonium-based fertilizers. Correspondingly, Selassie et al. . (2015) found the lowest and highest soil pH values in crop land and forest land, respectively. The lower mean soil pH was observed in unmanaged areas (Table 2). The low soil pH in these unmanaged areas could be a result of the leaching of basic cations caused by erosion. This finding aligns with the results of (Mohammed et al., 2020), which indicated the lowest soil pH in unconserved plots. Similar to the above authors (Gadana et al., 2020; Selassie et al., 2015) also showed the same scenario. A clear trend of decreasing soil pH was noted with increasing slope gradients. This phenomenon can be explained by the accumulation of basic cations in lower slope areas, which are transported from upper slopes through erosion processes (Endalew et al., 2025). This observation is supported by findings from Abate & Kibret (2016) and Mulugeta Aytenew (2015), who reported similar patterns in their studies.

3.2.2. Soil organic matter (SOM)

Land use, management practice, and slope gradient had a significant ($P < 0.01$) impact on SOM (Table 2). The highest SOM (5.03%) was found in forest land, while the lowest SOM (3.27%) was observed in cultivated land (Table

2). This difference is due to the contribution of fallen plant materials in forest land, which helps increase SOM and reduces soil erosion risk. Conversely, the lowest SOM in cultivated land could be related to the removal of SOM through oxidation because of intensive cultivation, low application of external inputs, and its removal with harvested plant biomass. These findings are consistent with those of Abate & Kibret (2016) and Assefa et al. (2020), which indicated soil organic matter (SOM) was lowest in cultivated areas and highest in forested regions. Soils of the managed areas had higher SOM (Table 2). This could be due to the influence of management practices applied and the accumulation of OM. This aligns with the research conducted by Gadana et al. (2020) and Selassie et al. (2015). Besides, SOM increases as the slope gradient decreases (Table 2). This accumulation in the lower slope might be due to its transportation to the lowest slope from the upper landscape by runoff and erosion (Mulugeta Aytenew, 2015).

3.2.3. Total nitrogen (TN)

Total nitrogen (TN) varied significantly ($P < 0.01$) by land use, management practice, and slope gradient (Table 2). Correspondingly, the highest TN (0.16%) was recorded in forest land, while cultivated land showed the lowest TN (0.11%) (Table 2). Based on the ratings from (Tadesse et al., 1991), TN ranges from low to medium levels. The higher TN content in forest areas is likely due to major organic matter accumulation from the decomposition of fallen plant materials. In contrast, the lower TN in cultivated land can be attributed to factors such as soil erosion, the rapid mineralization of SOM, continuous cultivation without external inputs, and the complete removal of crop residues. This finding concurs with the results of (Fetene & Amera, 2018; Gadana et al., 2020; Selassie et al., 2015), which emphasized the lowest TN in cultivated land and the highest in forest land.

Managed area showed higher TN across all land use types (Table 2). This may be related to the accumulation of OM, reduction of runoff off and soil loss. This finding is supported by Wolka et al. (2011), who reported higher TN in managed areas. Similarly, (Belayneh et al., 2019; Gadana et al., 2020; Mohammed et al., 2020) also reported higher TN in conserved areas. Across different slope gradients, TN levels increased in lower slopes compared to upper slopes across all land uses (Table 2). This trend may be attributed to the accumulation of SOM due to runoff in the lower slope gradient. In line with this result, Mulugeta Aytenew (2015) reported the highest TN in the gentle slope at Dawja Watershed, Amhara Region. Similarly, Gadana et al. (2020) and Mohammed et al. (2020) noted higher TN in lower slope gradients in different parts of Ethiopia.

Table 2. Effects of land use, slope, and management practice on selected soil chemical properties.

Treatment	pH (H_2O)	OM	TN	Av. P	Exchangeable bases (cmol$_{(+)}$ kg^{-1})				CEC
					Ex.Ca	Ex. Mg	Ex. K	Ex. Na	
Land uses									
Grazing land	5.43^b	3.41^b	0.14^b	9.10^b	7.12^b	1.83^b	0.47^b	0.38^b	25.98^b
Cultivated land	5.20^c	3.27^b	0.11^c	8.16^b	6.25^c	1.47^b	0.36^b	0.35^b	23.44^c
Forest land	5.73^a	5.03^a	0.16^a	12.19^a	8.94^a	3.10^a	0.62^a	0.61^a	31.60^a
LSD(0.05)	0.12	0.47	0.013	1.66	0.71	0.45	0.07	0.05	2.48
P-value	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**
Management									
Unmanaged	5.26^b	3.46^b	0.12^b	8.50^b	6.51^b	1.78^b	0.38^b	0.37^b	24.77^b
Managed	5.65^a	4.35^a	0.15^a	11.14^a	8.37^a	2.48^a	0.59^a	0.52^a	29.25^a
LSD(0.05)	0.1	0.32	0.01	1.12	0.48	0.30	0.05	0.04	1.67
P-value	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.09^{ns}	0.00**	0.00**
Slope gradients									
2-5%	5.57^a	4.12^a	0.15^a	11.02^a	8.32^a	2.51^a	0.59^a	0.52^a	28.46^a
5-10%	5.33^b	3.69^b	0.12^b	8.60^b	6.55^b	1.75^b	0.38^b	0.38^b	25.55^b
LSD(0.05)	0.1	0.31	0.01	1.12	0.48	0.30	0.05	0.03	1.67
P-value	0.00**	0.01**	0.00**	0.00**	0.00**	0.00**	0.00**	0.03**	0.01**
CV	3.55	15.69	11.84	19.94	13.52	25.55	25.68	21.11	9.36

Mean values within a column followed by the different letters are significantly different from each other at **P < 0.01 and *P < 0.05. NS = Not significant

3.2.4. Available phosphorus (AP)

ANOVA analysis indicated that Available Phosphorus (AP) was significantly influenced (P < 0.01) by land use, management practices, and slope gradient (Table 2). The AP was found to be highest (12.19 ppm) in forest land and lowest (8.16 ppm) in cultivated land (Table 2). According to Olsen (1954), the AP content in the study area is considered very low (<15 ppm). The increase in AP content in natural forests can be attributed to the higher organic matter levels found in forest soils. The lower AP levels in cultivated land could result from intensive farming, minimal application of external inputs, and erosion and fixation of phosphate anions by aluminum. This finding is consistent with the result reported by Assefa et al. (2020), who also noted lower AP levels in cultivated areas. AP was higher in managed areas across all types of land use (Table 2). These could be attributes due to OM accumulation and low soil erosion as compared to unmanaged areas. Similarly, Selassie et al. (2015) and Endalew et al. (2025) report higher AP in managed areas. Regarding slope, AP decreases with an increase in slope gradient (Table 2). This could be attributed to the removal of AP from higher slopes and its deposition in lower slopes. Likewise, (Gadana et al., 2020) reported higher AP values in lower slope gradients.

3.2.5. Exchangeable bases (Ca, Mg, K, Na)

Exchangeable bases were significantly (P < 0.01) influenced by land use, management practice, and slope gradient (Table 2). The highest values for exchangeable bases were found in forest land, while the lowest were found in agricultural land (Table 2). This difference may be related to the higher pH, clay, and soil organic matter (SOM) content in forest land, and the relatively lower levels in cultivated land, as indicated by Anteneh & Mohammed (2020). Soils of the managed areas showed higher exchangeable bases than unmanaged (Table 2). This might be due to SOM and clay accumulation in the conserved area. The lower content of exchangeable bases in unmanaged areas may be due to leaching and higher rates of soil erosion compared to managed fields (Gadana et al., 2020). There was a noticeable decrease in exchangeable bases as the slope gradient increased (Table 2). This finding is supported by (Gadana et al., 2020; Yimer, 2017), which reported that higher levels of exchangeable bases were present in lower slopes, likely due to runoff and erosion transporting materials from higher elevations to lower gradients. According to the FAO (2006) rating, the contents of Ca, Mg, and Na were categorized as medium across all types of land use, while K was high in forest land and medium in other land uses.

3.2.6. Cation exchange capacity (CEC)

The result of AVOVA showed that Land use, management practice, and slope all influenced CEC in a significant (P < 0.01) way (Table 2). The highest CEC measured was 31.60 cmol(+) kg-1 in forest land, while the lowest value recorded was 23.44 cmol(+) kg-1 in cultivated land (Table 2). The low CEC in cultivated land may be due to the depletion of organic matter from continuous cultivation, disturbances from high soil erosion, and the removal of crop residues (Fetene & Amera, 2018). Managed areas recorded higher CEC values (Table 2). This could be due to low soil erosion, high SOM, and clay fraction in managed areas (G. Selassie & Ayanna, 2013; Selassie et al., 2015). Besides, (Mohammed et al., 2020) also reported higher CEC in managed areas. Regarding slope gradient, CEC showed an increasing trend with decreases in slope gradients (Table 2). This pattern could be due to the removal of clay particles and SOM from the upper slopes by runoff, which are then deposited on the lower slopes. This result is consistent with the observation of Rezaei et al. (2015), who reported that CEC is higher in lower slope gradients compared to other gradients. Consequently, the distribution of CEC across different slope gradients reflects the trends of clay and organic matter distribution, indicating that CEC is influenced by both soil organic matter content and clay levels (Bayle et al., 2023; Molla et al., 2022; Mulugeta Aytenew, 2015). The CEC of the examined soils was classified as medium to high according to Hazelton and Murphy (2007).

4. Conclusion

The soils of the Burat watershed in northwestern Ethiopia have displayed significant variation in selected physicochemical properties based on land use types, slope classes, and management practices. The findings of this study indicated that soil quality in cultivated areas was lower compared to the soils in adjacent forest and grazing lands. Specifically, the average values for clay fraction, organic matter, total nitrogen, phosphorus, exchangeable bases, and cation exchange capacity were higher in forest soils and lower in those that are cultivated. Soil fertility parameters were consistently higher in managed areas and in lower slope positions, underscoring the positive role of conservation practices, organic matter inputs, and careful slope management, while poor cultivation practices and unmanaged steep slopes accelerated degradation. Nevertheless, this study was limited to one watershed, surface soils (0–20 cm), and a single point in time, without considering seasonal variations, deeper soil horizons, or biological indicators, which restricts the broader applicability of the results. To combat soil degradation, the adoption of organic amendments such as compost, manure, and crop residues, along with afforestation, agroforestry, terracing, and slope-appropriate cultivation methods, is strongly encouraged. In addition, strengthening farmer education and awareness on sustainable land management practices is essential to enhance implementation and long-term effectiveness. Future research should cover diverse watersheds, include long-term and deeper soil assessments, and integrate biological indicators for a fuller picture of soil health. Evaluating the socio-economic feasibility of conservation practices is also essential to ensure sustainable adoption and resilience in agriculture.

Author Contributions:
Awoke Abebaw: Conceptualization, methodology, formal analysis and investigation, visualization, resources, writing-original draft preparation.
Wale Jemberu: Conceptualization, supervision, formal analysis, and investigation.
Getahun Mekonen: Conceptualization, supervision, formal analysis, and investigation
Wasihun Mengiste: Conceptualization, methodology, formal analysis, and investigation, manuscript editing**.**
Awoke Endalew: Conceptualization, methodology, formal analysis, and investigation, manuscript editing**.**

Conflicts of interest

The authors of this article declared no conflict of interest regarding the authorship or publication of this article.

Data availability statement:

All data generated or analyzed during this study are included in this published article.

References

Abate, N., & Kibret, K. (2016). Effects of Land Use , Soil Depth and Topography on Soil Physicochemical Properties along the Toposequence at the Wadla Delanta Massif , Northcentral Highlands of Ethiopia. 5(2): 57–71. doi: 10.5539/ep.v5n2p57

Abera, A., & Wana, D. (2023). Effect of agricultural land management practices on the selected soil quality indictors: empirical evidences from the south Ethiopian highlands. Environmental Systems Research 12(1): 2. doi: 10.1186/s40068-023-00282-y

Amare, H., Admase, H., & Ewunetu, T. (2024). Influence of land-use types and topographic slopes on the physico-chemical characteristics of soils in Northwestern Ethiopia. Frontiers in Soil Science, 4 1463315. doi: 10.3389/fsoil.2024.1463315

Anteneh, M., & Mohammed, W. (2020). Effects of land cover changes and slope gradient on soil quality in the Gumara watershed, Lake Tana basin of North – West Ethiopia. Modeling Earth Systems and Environment 6(1): 85–97. doi: 10.1007/s40808-019-00660-5

Asmare, T. K., Abayneh, B., Yigzaw, M., & Birhan, T. A. (2023). The effect of land use type on selected soil physicochemical properties in Shihatig watershed, Dabat district, Northwest Ethiopia. Heliyon, 9(5), e16038. doi: 10.1016/j.heliyon.2023.e16038

Assefa, F., Elias, E., Soromessa, T., & Ayele, G. T. (2020). Effect of changes in land-use management practices on soil physicochemical properties in Kabe Watershed, Ethiopia. Air, Soil and Water Research 13 1178622120939587. doi: 10.1177/1178622120939587

Balasubramanian, A. (2017). Soil erosion– causes and effects. Centre for Advanced Studies in Earth Science University of Mysore, Mysore. https://www.researchgate.net/profile/A-Balasubramanian/publication/314500264_Soil_Erosion-_Causes_and_Effects/links/58c2c729a6fdcce648de2bec/Soil-Erosion-Causes-and-Effects.pdf

Bayle, D., Feyissa, S., & Tamiru, S. (2023). Effects of land use and slope position on selected soil physicochemical properties in Tekorsh Sub-Watershed, East Gojjam Zone, Ethiopia. Open Agriculture 8(1): 20220147. doi: 10.1515/opag-2022-0147

Belayneh, M., Yirgu, T., & Tsegaye, D. (2019). Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, Upper Blue Nile Basin, Ethiopia. Ecological Processes 8(1): 1–14. doi: 10.1186/s13717-019-0188-2

Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., & Clark, F. E. (1965). Methods of Soıl Analysıs. Part I. pp. 1572 American Society of Agronomy. Inc. Publisher, Madison, Winconsin, USA.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils 1. Agronomy Journal 54(5): 464–465.

Brady, N.C. and Weil, R.R. (2008). The nature and properties of soils. Upper Saddle River, NJ: Prentice Hall. Vol. 13, pp. 662–710.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen-total. In 'Methods of soil analysis. Part 2. Chemical and microbiological properties'.(Eds AL Page, RH Miller, DR Keeney) pp. 595–624. Soil Science Society of America: Madison, WI, USA.

Chapman, H. D. (1965). Cation-exchange capacity. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties 9 891–901.

Corato, U., Viola, E., Keswani, C., & Minkina, T. (2024). Impact of the sustainable agricultural practices for governing soil health from the perspective of a rising agri-based circular bioeconomy. Applied Soil Ecology 194 105199. doi: 10.1016/j.apsoil.2023.105199

Deng, L., Sun, T., Fei, K., Zhang, L., Fan, X., Wu, Y., & Ni, L. (2020). Effects of erosion degree, rainfall intensity and slope gradient on runoff and sediment yield for the bare soils from the weathered granite slopes of SE China. Geomorphology 352 106997. doi: 10.1016/j.geomorph.2019.106997

Dixit, M., Ghoshal, D., Lal Meena, A., Ghasal, P. C., Rai, A. K., Choudhary, J., & Dutta, D. (2024). Changes in soil microbial diversity under present land degradation scenario. Total Environment Advances, 10, 200104. doi: 10.1016/j.teadva.2024.200104

Endalew, A., Feyisa, T., & Molla, E. (2025). Effect of slope position and aspect on selected soil physicochemical properties of Mesk watershed, northwestern Ethiopia. Ethiopian Journal of Science & Technology, 18(1), 27–42. doi: 10.4314/ejst.v18i1.2

Fantahun, A., Lemma, T. M., Tesfay, F., & Getahun, Y. S. (2024). Impact of Soil and Water Conservation Measures on Soil Physicochemical Characteristics and Crop Productivity: Evidence From Korekore Watershed in the Central Highlands of Ethiopia. The Scientific World Journal 2024(1): 2679180. doi: 10.1155/tswj/2679180

FAO (Food and Agriculture Organization). (2006). Plant nutrition for food security: a guide for integrated nutrient management. FAO, fertilizer and plant nutrition bulletin No. 16, FAO, Rome.

Fetene, E. M., & Amera, M. Y. (2018). The effects of land use types and soil depth on soil properties of Agedit watershed, Northwest Ethiopia. Ethiopian Journal of

Science and Technology 11(1): 39–56. doi: 10.4314/ejst.v11i1.4

Food and Agriculture Organization of the United+ Nations. (2005). Soil Map of the World. Revised Legend. World Soil Resources Report 60.

G. Selassie, Y., & Ayanna, G. (2013). Effects of Different Land Use Systems on Selected Physico-Chemical Properties of Soils in Northwestern Ethiopia. Journal of Agricultural Science 5(4): 112–120. doi: 10.5539/jas.v5n4p112

Gadana, D. B., Sharma, P. D., & Selfeko, D. T. (2020). Effect of soil management practices and slope on soil fertility of cultivated lands in mawula watershed, loma district, southern Ethiopia. Advances in Agriculture 2020 1–13. doi: 10.1155/2020/8866230

Hailu, L., Tesfaye, G., Fikirie, K., & Debebe, Y. (2021). Effect of land-use practices on species diversity and selected soil property in Somodo Watershed South-Western Ethiopia. PLOS ONE 16(5): e0252305. doi: 10.1371/journal.pone.0252305

Hazelton, P.A. and Murphy, B.W. (2007) Interpreting Soil Test Results: What Do All the Numbers Mean? CSIRO Publishing, Australia, 1-152. doi: 10.1071/9780643094680

Huang, X., Ibrahim, M. M., Luo, Y., Jiang, L., Chen, J., & Hou, E. (2024). Land use change alters soil organic carbon: constrained global patterns and predictors. Earth's Future 12(5): e2023EF004254. doi: 10.1029/2023EF004254

Kahsay, A., Haile, M., Gebresamuel, G., & Mohammed, M. (2025). Impact of land use changes on soil physical quality in southeastern Tigray, Ethiopia. South African Journal of Plant and Soil 42(1–3): 43–53. doi: 10.1080/02571862.2025.2538216

Kebebew, S., Bedadi, B., Erkossa, T., Yimer, F., & Wogi, L. (2022). Effect of Different Land-Use Types on Soil Properties in Cheha District, South-Central Ethiopia. Sustainability, 14(3), 1323. doi: 10.3390/su14031323

Kiflu, A., & Beyene, S. (2013). Effects of different land use systems on selected soil properties in South Ethiopia. 4(5): 100–107. doi: 10.5897/JSSEM12.20

Lal, R. (2001). Soil degradation by erosion. Land Degradation & Development 12(6): 519–539. doi: 10.1002/ldr.472

Luo, B., Li, J., Tang, J., Wei, C., & Zhong, S. (2024). Microtopography effects on pedogenesis in the mudstone-derived soils of the hilly mountainous regions. Scientific Reports 14(1): 11998. doi: 10.1038/s41598-024-62540-y

Mohammed, M., Takele, G., & Kibret, K. (2020). Effects of physical soil and water conservation structures and slope gradients on soil physicochemical properties in West Oromia, Ethiopia. International Journal of Soil Science 15(1): 1–7. doi: 10.3923/ijss.2020.1.7

Molla, E., Getnet, K., & Mekonnen, M. (2022). Land use change and its effect on selected soil properties in the northwest highlands of Ethiopia. Heliyon 8(8). doi: 10.1016/j.heliyon.2022.e10157

Mulugeta Aytenew. (2015). Effect of Slope Gradient on Selected Soil Physicochemical Properties of Dawja Watershed in Enebse Sar Midir District , Amhara National Regional State. American Journal of Scientific and Industrial Research September 2015 74–81. doi: 10.5251/ajsir.2015.6.4.74.81

Olsen, S. R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (Issue 939). US Department of Agriculture.

Rezaei, H., Jafarzadeh, A. A., Alijanpour, A., Shahbazi, F., & Kamran, K. V. (2015). Effect of Slope Position on Soil Properties and Types Along an Elevation Gradient of Arasbaran Forest , Iran. 5(6): 449–456. doi: 10.18517/ijaseit.5.6.589

Rowell, D. L. (1994). Laboratory methods for studying mineralization. Soil Science: Methods and Applications. Longman Scientific and Technical, Longman Group UK Ltd., Longman House, London, England.

Schoonover, J. E., & Crim, J. F. (2015). An Introduction to Soil Concepts and the Role of Soils in Watershed Management. Journal of Contemporary Water Research & Education

154(1): 21–47. doi: 10.1111/j.1936-704X.2015.03186.x

Seifu, W., Elias, E., Gebresamuel, G., & Khanal, S. (2021). Impact of land use type and altitudinal gradient on topsoil organic carbon and nitrogen stocks in the semi-arid watershed of northern Ethiopia. Heliyon 7(4): e06770. doi: 10.1016/j.heliyon.2021.e06770

Selassie, Y. G., Anemut, F., & Addisu, S. (2015). The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia. Environmental Systems Research 4(1): 0–6. doi: 10.1186/s40068-015-0027-0

Tadesse, T., Haque, I., & Aduayi, E. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant Science Division Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Tufa, M., Melese, A., & Tena, W. (2019). Effects of land use types on selected soil physical and chemical properties: The case of Kuyu district, Ethiopia. Eurasian Journal of Soil Science 8(2): 94–109. doi: 10.18393/ejss.510744

van Reeuwijk, L. P. (1995). Procedures for soil analysis, (5th Ed.), Technical Paper 9, (Wageningen: ISRIC, FAO).

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37(1): 29–38.

Warke, A., & Wakgari, T. (2024). A Review on the Impact of Soil Acidification on Plant Nutrient Availability, Crop Productivity, and Management Options in the Ethiopian Highlands. Agriculture, Forestry and Fisheries 13(2): 31–45. doi: 10.11648/j.aff.20241302.13

Wolka, K., Moges, A., & Yimer, F. (2011). Effects of level soil bunds and stone bunds on soil properties and its implications for crop production: the case of Bokole watershed, Dawuro zone, Southern Ethiopia. Agricultural Sciences 2(03): 357. doi: 10.4236/as.2011.23047

Wu, Y., Jia, G., Yu, X., Rao, H., Peng, X., Wang, Y., Wang, Y and Wang, X. (2024). Response of soil nutrients and erodibility to slope aspect in the northern agro-pastoral ecotone, China. Soil 10(1): 61–75. doi: 10.5194/soil-10-61-2024

Xalxo, A., Verma, L. P., Jayasree, B., Jiya, P. K., Gawde, N., Suryawanshi, A., Ashraf, F., Jatin, Yadav, R., & Kokale, S. (2025). The Role of Soil in Carbon Sequestration: Implications for Climate Change Mitigation. International Journal of Environment and Climate Change 15(6): 86–97. doi: 10.9734/ijecc/2025/v15i64875

Yimer, F. (2017). Effect of Landscape Positions on Soil Properties in an Agricultural Land A Transect Study in the Main Rift Valley Area of Ethiopia. Journal of Science & Development 5(1): 2017. https://journals.hu.edu.et/hu-journals/index.php/agvs/article/view/105

Yitbarek, T. (2013). Impacts of Land Use on Selected Physicochemical Properties of Soils of Abobo Area, Western Ethiopia. Agriculture, Forestry and Fisheries 2(5): 177. doi: 10.11648/j.aff.20130205.11