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Full Length Research Paper

The effect of land management practices on soil physical and chemical properties in Gojeb Sub-river Basin of Dedo District, Southwest Ethiopia

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This study was undertaken to evaluate the effect of cultivation, fallow and woody land with and without soil bund on soil physical and chemical properties in Gojeb river basin of Dedo district. Landscape of the basin was divided in to three slope positions as upper (25 to 35%), middle (15 to 25%) and lower (5 to 15%). From each slope position, purposely three land use types (cultivated, fallow and woody) lands conserved with and without soil bund were selected. Accordingly, a total of 54 composited soil samples, from 3 slope positions x 3 land use types x 3 replications x 2 conservation system (with and without soil bund) were considered to collect soil sample for soil physical and chemical properties analysis. For both composited and core sampled soil sample collection systematic random sampling techniques were conducted through considering similarity of slope gradient, soil types and land use cover. Analysis of variance (ANOVA) and mean separation was carried out by Turkey test using R-version 3.2.2 (2015). Additionally, Pearson's correlation analysis was done by using Statistical Package for Social Sciences (SPSS version 20).The result showed that soil bulk density and sand fraction decreased from upper to lower slope position. In contrast, total soil porosity, gravimetric soil moisture content, fraction of clay and silt were increased from upper to lower slope position. With respect to land use soil porosity, gravimetric soil moisture content, clay and silt proportion of woody land >fallow land> cultivated land. However soil bulk density and sand fraction highest in the cultivated land than fallow and woody land. Similarly, for all land uses conserved with soil bund has highest gravimetric soil moisture content, soil porosity, clay and silt fraction than similar land uses not conserved with soil bund. Soil chemical parameters [pH, EC, Av.P, OM, OC, TN, CEC,[exchangeable cations (K, Ca and Mg), exchangeable sodium percentage (ESP) and percent base saturation (PBS)] were significantly increased from upper to lower slope position while exchangeable sodium was not significantly increased. All soil chemical parameters, mean value of woody and fallow land were highest than cultivated land. Similarly, land uses conserved with soil bund has highest mean value than land uses without soil bund. The result of Pearson's correlation matrix also confirmed that several soil phyisical and chemical parameters have a positive relationship, particularly soil organic matter/organic carbon was strongly correlated with cation exchangeable capacity and clay content. In conclusion, the result affirmed that soil physicochemical property of the study area was strongly influenced by land use and conservation difference in addition to topographic position variation. Therefore, to conserve soil resources it needs highest attention of policy makers as well as land use planners to concentrate their efforts on land management/conservation strategies based on land use system and slope variation.

Key words: Land use types, soil bund, soil properties, slope positions, soil parameters.

INTRODUCTION

Degraded lands are the center of much attention as global demands for food, feed and fuel continue to increase at unprecedented rates, while the agricultural land base needed for production is shrinking in many parts of the words (Food and agriculture organization of the united nations (FAO), 2005, Gelfand et al., 2013, Lambin and Meyfroidt, 2011). It is also a major concern in Ethiopia, because of its devastating consequences on economic growth and food security status of the people who are both highly dependent on natural resources (Girma, 2001).The major cause of land degradation are cultivation on steep and fragile soils with inadequate investment on soil conservation, erratic and erosive rainfall patterns, declining use of fallow, limited recycling of dung and crop residues to the soil, rapid population increment, deforestation, low vegetative cover and unbalanced crop and livestock production (Belay 2003, Hurni 1988, Leonard, 2003; Lulseged and Paul, 2006).

Changes in land use and soil management practice can have a marked effect on soil organic matter. Several studies in the past have shown poor soil management, deforestation, topography and continuous cultivation of virgin tropical soils often lead to depletion of nutrients and high soil erosion rate (Nigussie and Fekadu, 2003; Seibert et al., 2007; Tilhun, 2015). Land-use practices affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations in the rooting zone. Although, its consequences vary, land conversion frequently leads to nutrient losses when it disrupts surface and mineral horizons (for example, by mechanical disturbance) and reduces inputs of organic matter (Semahugne, 2008). Sustainable use of soil resource has been an increasing concern to decision and policy makers (Tesfahunegn, 2014).

The complex inter-linkages between poverty and population growth is another dimension to the land degradation problems. In recent years, rapid population growth has brought several changes: farm holdings have become smaller due to constraints in land availability; holdings are more fragmented; farmers cultivate fragile margins on steep slopes previously held in pasture and woodlots. Reduced fallow period coupled with longer cultivation periods on slopping lands without suitable land amendments to replenish lost nutrients has thus led to widespread degradation of land. The consequences of more intensive farming and farming on steep slopes are declining fertility and increasing the high incidence of soil loss due to erosion (Shiferaw and Holden, 1998). All the above mentioned attributes aggravates soil degradation of southwest Ethiopia, especially gojeb river basin of Dedo district in the Jimma zone. The problem is particularly serious because of densely population coupled with rugged and rolling topography, making the area vulnerable to soil degradation. In addition, land fragmentation and having small farm size per household in the study area has forced the farmers to conduct continuous cultivation which reduced fallow period. Similarly, many farmers subjected to continuous cultivation of steeply slope lands without any adequate soil fertility amendments and soil and water conservation measures. Given this state of conditions, evaluating land management practice is very important and relevant to formulate policy options and support systems that could accelerate sustainable agricultural development. Therefore, the objective of this study was to evaluate the influence of different land use systems with and without soil bund on selected soil physical and chemical property in the Gojeb sub-river basin of dedo district, South western Ethiopia.

METHODOLOGY

Description of the study area

The study area is located in the Jimma zone which is 335 kms South-West of Addis Ababa. The minimum temperature is 11.8°C and the maximum temperature is 28°C. The annual rainfall averages about 1500 mm. The season is divided into three: the main rainy season (June to September), cool dry season (October to February) and short rainy season (March to May). The seasonal distribution of rainfall is 17.2% in cool dry season, 56.3% in the rainy season and 26.2% in short rains. The mean relative humidity is 68% (Belay and Aynalem, 2009).

Geological surveys indicated that the district is under the tertiary volcanic of maqdala. It consists of alkali olivine basalt and tuffs. The major soils categories of dedo district are Orthic Acrisols and Orthic Vetisols; Orthic Acrisols (80%) and Orthic Vertisols (20%). Orthic Acrisols cover the largest part of the zone except in the Gojeb River Valley. Vertisols do confine the southern portion of the district particularly in the Gojeb River Valley (OFED, 2001).

Land-use pattern and crop production

The district hasa total area of 1140km^2. 49.1% of the district land is under cultivation while, 23.9, 13.9 and 13.1% is occupied by forest, woodland and grassland respectively. Major types of crops produced include maize, teff, sorghum, wheat horse beans and Oilseeds (OFED, 2001).

Soil sampling framework

Soil sampling was conducted after classifying the catchment in to

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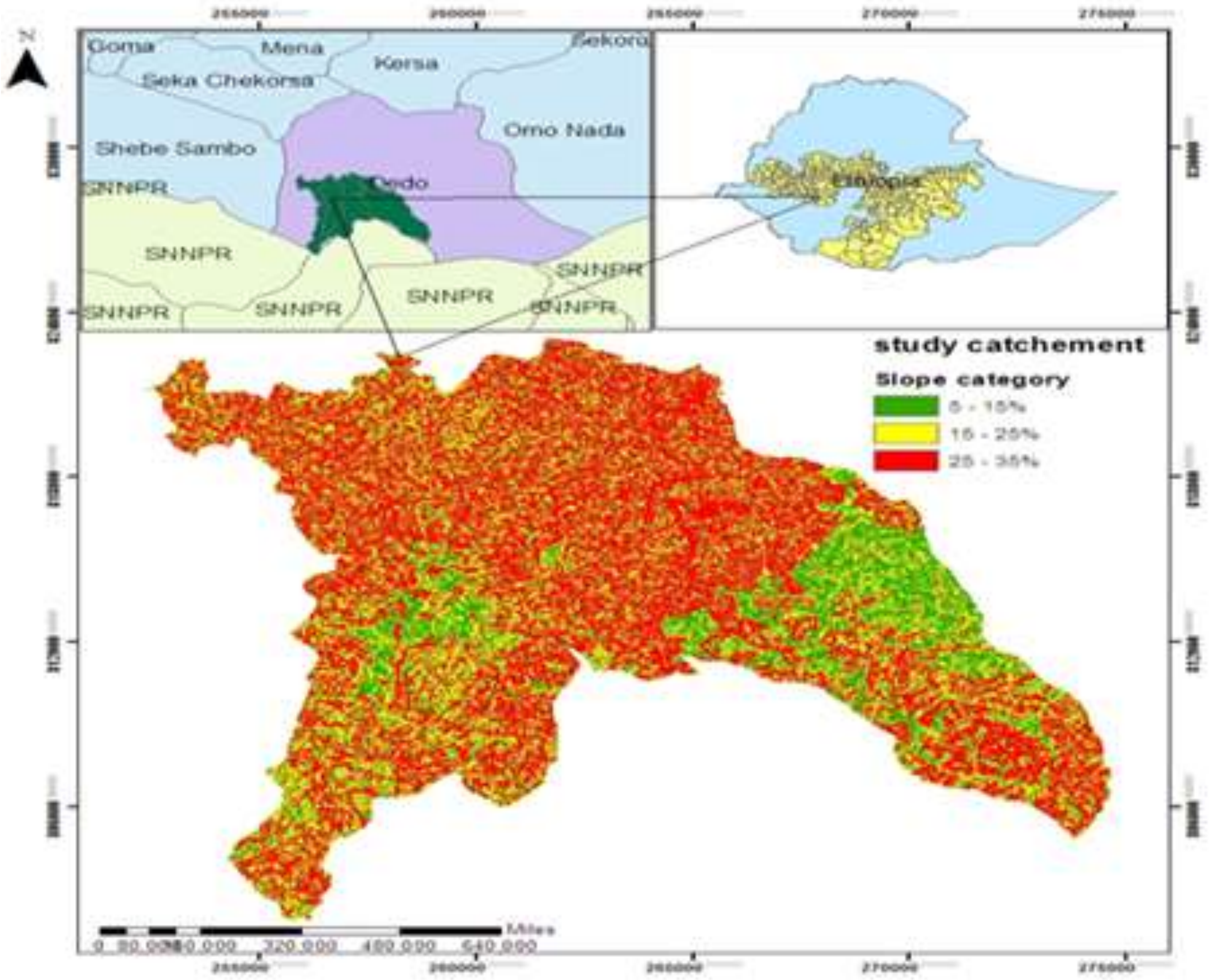

Figure 1. Map of the study area.

upper slope position (25 to 35%), Middle slope position (15 to 25%) and lower slope position (5 to 15%) (Figure 1). From each slope category, three land uses namely cultivated, fallow and woody lands with and without soil bund were purposely selected. To reduce error due to variation of soil type and topographical differentiation, similar soil types and slope gradient across the slope was considered. In each land use types 20 x 20 meter plot was formed to consider four corners and one at the center of X designed rectangular plot for soil sampling. Accordingly, 27 soil samples were collected from 3 land uses from each slope categories with 3 replication for both conserved and none conserved with soil bund. Consequently, a total of 54 soil samples from the two farming system were collected from 0 to 40 cm soil depth.

Sampling preparation and laboratory analysis

The samples collected were air dried, mixed well and passed through a 2 mm sieve for soil selected physicochemical analysis. Undisturbed core samples collected from each land use types were used for soil physical parameters such as soil bulk density, total porosity, soil gravimetric moisture content.

Soil bulk density: This was determined as the ratio of oven dry soil mass to its volume (Blake and Hartge, 1986).

Soil gravimetric: This moisture content was calculated as the ratio of weight of wet soil to weight of oven dry soil.

Total porosity: This was calculated using bulk density and particle density as described in Hao et *al.* (2008).

Texture: This was estimated using Hydrometer method (Gee and Bauder, 1986.) after destroying organic matter by adding hydrogen peroxide (H_2O_2) and dispersing the soil through adding sodium hexametaphosphate $(NaPo_3)_6$.

Soil pH and electrical conductivity (EC): These parameters were measured from soil suspension solution prepared with 1:2.5(w/v) soil water ratios using pH meter and EC meter respectively.

Organic matter content: This was determined following the Walkey and Black (1934).

Total nitrogen: This was determined following the Kjeldahl (1992) procedure.

Table 1. The effect of slope position and different land uses with and without soil bund on soil physical properties.

Land use	Soil Physical property					
	BD (g/cc)	Por (%)	Soil moisture (%)	Sand (%)	Silt (%)	Clay (%)
Cultivation	1.38^{b}	47.54^{a}	26.02^{b}	65.11^{a}	20.89^{c}	14.00^{c}
Fallow	1.55^{a}	55.67^{b}	32.30^{a}	46.33^{b}	31.22^{b}	22.44^{b}
Woody	1.27^{c}	58.17^{a}	31.11^{a}	28.72^{c}	36.67^{a}	34.61^{a}
	Different Land Use types assisted with soil bund and without soil bund					
Co	$1.56a^{b}$	$46.02a^{b}$	$25.18a^{a}$	$64.78a^{a}$	$20.33a^{c}$	$13.89a^{c}$
CSB	$1.54a^{a}$	$49.06a^{a}$	$26.85a^{a}$	$65.44a^{a}$	$21.44a^{c}$	$14.11a^{c}$
F0	$1.42a^{a}$	$53.66a^{a}$	$31.42a^{a}$	$46.89a^{b}$	$30.89a^{b}$	$22.22a^{b}$
FSB	$1.34a^{a}$	$56.07a^{b}$	$33.18a^{a}$	$45.78a^{b}$	$31.56a^{b}$	$22.67a^{b}$
w0	$1.28a^{b}$	$57.69a^{a}$	$29.90a^{a}$	$28.44a^{c}$	$35.00a^{a}$	$33.56a^{a}$
WSB	$1.26a^{b}$	$60.27a^{a}$	$32.32a^{a}$	$29.00a^{c}$	$38.33a^{a}$	$35.67a^{a}$

Co- cultivated land without soil bund, CSB-cultivated land with soil bund, Fo-fallow land without soil bund, FSB-fallow land with soil bund, Wo-woody land without soil bund and WSB-woody land with soil bund. Mean values followed by different letters in the subscript is for conservation difference within similar land uses and letters in the superscript for different land uses of similar conservation practices are statistically different at P ≤0.05.

Available phosphorous: This was extracted using (Brady NC, Weil RR (2002).

Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K and Na): These were determined after leaching soil by ammonium acetate (1N NH_4OAc) at pH 7.0.

Exchangeable Ca and Mg in the extracts: These were measured using atomic absorption spectrophotometer.

Na and K: These were analyzed by flame photometer (Chapman, 1965).

Cation exchange capacity: This was estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965).

Percent base saturation (PBS): This was calculated as the ratio of sum of the base forming cations (Ca, Mg, K and Na) to CEC of the soil and multiplied by 100.

Statistical analysis

Analysis of variance (ANOVA) was conducted. When ANOVA showed significant differences ($P<0.05$) among the various land use types and soil conservation difference for each parameter, a mean separation method were employed by using Tukey test by using R-version 3.2.2 (2015). Additionally, descriptive statistics by Microsoft office excel and Pearson's correlation analysis was done by using Statistical Package for Social Sciences (SPSS).

RESULT AND DISCUSSION

Soil Physical properties

Soil physical properties were significantly influenced by different land use types. Results revealed that soil bulk density (BD), gravimetric soil moisture content, soil porosity and proportion of sand, silt and clay contents were significantly different under different land use types. Land use associated with soil bund had lower soil bulk density than land uses without soil bund. For all land use types and conservation practices the mean soil bulk density increased from lower slope to upper slope position (Table 2). This might be due to the trampling effect and increased soil erosion in the upper slope position. Livestock grazing intensity and soil erosion vulnerability in the study area was very high in the upper slope as compared with middle and lower slope position. Similarly, mean value of bulk density was high in the cultivated and fallow land. This could be attributed to continuous cultivation and trampling effect of livestock since fallow and cultivated land in the study area were used for intensive livestock grazing during the dry season. The findings are in agreement with (Lemenih et al., 2005 and Selassie, 2005) who reported progressive increase in bulk density due to deforestation and continuous cultivation in the top plow layers because of the decline in the soil organic matter content and compaction from the tillage. The high bulk density in the cultivated and grazing land is the result of continuous shallow depth cultivation and excessive dry season livestock trampling. The variation soil bulk density could be also due to the absence of soil bund which removes soil organic matter and weakens the natural stability of soil aggregates making it susceptible to erosion. Soil bulk density of cultivated, fallow and woody grazing land without soil bund had increased bulk density than land uses with soil bund. Soil condition in the woody land was more desirable than in cultivated because of the percentage of vegetation. Plant litter and low grazing

Table 2. Mean difference of soil physical properties among different slope position and land uses with and without soil bund.

Lower slope position						
land use	**Bd**	**SOM**	**POR**	**Sand**	**Silt**	**Clay**
Co	$1.53a^{a}$	$29.23b^{a}$	$52.17a^{b}$	$60.00a^{a}$	$23.67c^{a}$	$16.33c^{a}$
Fo	$1.50a^{a}$	$38.83a^{a}$	$53.34a^{b}$	$43.33b^{b}$	$32.33b^{a}$	$24.33b^{a}$
Wo	$1.36a^{a}$	$29.21b^{a}$	$58.60a^{b}$	$18.33c^{c}$	$41.00a^{a}$	$40.67a^{a}$
Csb	$1.29a^{b}$	$24.24a^{a}$	$61.34a^{a}$	$59.00a^{c}$	$24.33b^{a}$	$16.67c^{a}$
Fsb	$1.22a^{b}$	$29.86a^{b}$	$63.85a^{a}$	$43.67b^{a}$	$32.33a^{a}$	$24.00b^{a}$
Wsb	$1.14a^{b}$	$31.41a^{a}$	$66.99a^{a}$	$19.00c^{c}$	$36.33a^{a}$	$44.67a^{a}$
Middle slope position						
Co	$1.55a^{a}$	$19.83a^{a}$	$42.69b^{b}$	$63.00a^{a}$	$22.33c^{a}$	$14.67c^{a}$
f0	$1.52a^{a}$	$24.43a^{b}$	$41.52b^{b}$	$46.00b^{b}$	$31.00b^{a}$	$23.00b^{ab}$
Wo	$1.42b^{a}$	$32.38a^{b}$	$52.24a^{b}$	$28.33c^{b}$	$37.33b^{a}$	$34.33a^{b}$
Csb	$1.34a^{b}$	$23.09b^{a}$	$54.81b^{a}$	$65.33a^{b}$	$21.67c^{ab}$	$13.00c^{a}$
Fsb	$1.29a^{b}$	$37.91ab^{a}$	$61.26a^{a}$	$46.67b^{a}$	$31.00b^{a}$	$22.33b^{a}$
Wsb	$1.23b^{b}$	$42.05a^{a}$	$63.65a^{a}$	$28.67c^{b}$	$36.00a^{a}$	$35.33a^{b}$
Upper slope position						
Co	$1.61a^{a}$	$26.49a^{a}$	$42.03a^{b}$	$71.33a^{b}$	$19.00c^{b}$	$9.67c^{b}$
Fo	$1.60a^{a}$	$31.01a^{ab}$	$43.64a^{b}$	$51.33b^{a}$	$29.33b^{a}$	$19.33b^{b}$
Wo	$1.49b^{a}$	$34.40a^{a}$	$47.95a^{b}$	$38.67c^{a}$	$35.67a^{b}$	$25.67a^{c}$
Csb	$1.49a^{b}$	$23.92a^{a}$	$50.13a^{a}$	$68.00a^{a}$	$18.33b^{b}$	$13.67c^{a}$
Fsb	$1.41a^{b}$	$31.77a^{a}$	$50.19a^{a}$	$47.00b^{a}$	$31.33a^{a}$	$21.67b^{a}$
Wsb	$1.22b^{b}$	$25.70a^{b}$	$52.07a^{a}$	$39.67c^{a}$	$33.33a^{a}$	$27.00a^{c}$

Co- cultivated land without soil bund, CSB-cultivated land with soil bund, Fo-fallow land without soil bund, FSB-fallow land with soil bund, Wo-woody land without soil bund and WSB-woody land with soil bund. Mean values followed by different letters in the subscript is for conservation difference within similar land uses and letters in the superscript for different land uses of similar conservation practices are statistically different at P ≤0.05.

intensity in the woody land might have resulted in increased soil water which improves soil structure, and subsequently increased organic matter. In contrast, soil total porosity was significantly decreased in all slope positions for both conserved and none conserved land with soil bund. This might be due to soil bulk density and soil total porosity which is inversely related. As soil bulk density increase, soil total porosity decrease and vice-versa. The result of Pearson's correlation matrix result also indicated that soil bulk density and soil total porosity were negatively correlated at correlation coefficient -0.42 and p-value 0.001 (Table 6). All land uses assisted with soil bund has relatively highest soil total porosity (Table 1). This could be due to the presence of soil bund which improves soil organic matter which enhances soil total porosity.

Gravimetric soil moisture content was significantly different due to land use types. Significantly high soil moisture continent was recorded in the woody and fallow land. However, there was no significant variation due to conservation differences. Land use treated with soil bund had higher soil moisture content than land uses without soil bund. This could be attributed to the contribution of constructed soil bund which conserves soil water in addition to the improved vegetation cover in the fallow and woody land. With respect to slope position, soil moisture content also increased from upper to lower slope position almost for all land use types and conservation practices (Table 2). This could be due to slope gradient of upper slope position which has poor water holding capacity which accelerates soil erosion due to high velocity of runoff.

The mean values of soil texture of three land uses (woody, fallow and cultivated land) with soil bund was significantly different in comparison to adjacently located similar land use types without soil bund. Cultivated land had significantly high sand proportion and low silt and clay fraction (Table1). In contrast, woody and fallow lands had lowest mean value of sand fraction and high silt and clay fraction. However, because of the conservation differences, there was no significant variation. This might be due to soil texture which is not easily changed as a result of conservation difference within short period of time. However, there was slight variation of sand, silt and

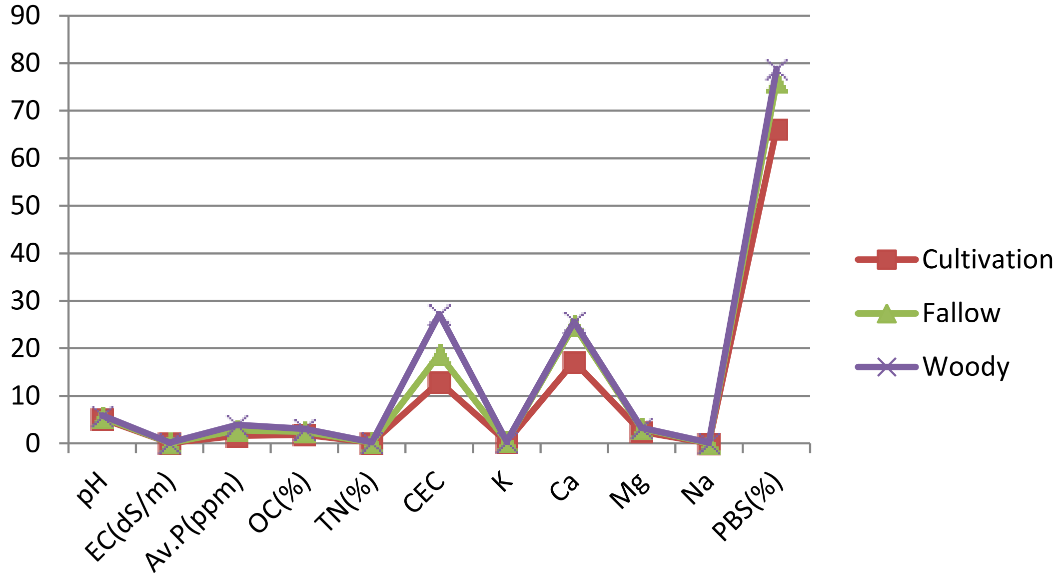

Figure 2. Trend of soil chemical properties under different land use types.

clay fraction between land uses with and without soil bund. (Jamala and Oke, 2013) also reported that soil texture is intrinsic soil property, but intensive cultivation could contribute to the variations in particle size distribution at the surface horizon of cultivated and natural fallow land. Regarding slope position, sand fraction of cultivated land increased from lower to upper slope position whereas silt and clay fraction decreased from lower to upper slope position (Table 2). This could be attributed to less addition of organic matter coupled with high erosion rate which diminishes clay fraction of the soil in the upper slope. Pearson's correlation matrix confirmed there was strongly positive relationship between clay content and soil organic matter (Table 6 and Figure 2).

Soil chemical properties

Soil pH and electrical conductivity

Soil pH and EC value was significantly affected by land uses ($p \leq 0.05$). Lowest mean pH and EC value were observed in the cultivated land while the highest pH and EC value were recorded in the woody and fallow lands (Figure 3). The reason for lowest pH value in the cultivated land might be attributed to the excessive removal of basic cations. The results are in lined with Selassie et al., 2015 who observed that washing away of solutes and basic cations lowers pH value in the Zikre watershed North West Ethiopia. Nevertheless, pH and EC value were not significantly different due to conservation difference. However, for both conserved and non-conserved scenarios, the mean pH and EC value of woody land>fallow land>cultivated land (Table 3). The mean value of pH and EC of cultivated lands with and without soil bund were significantly lowest in all slope categories (Table 4).The lowest value of soil pH value in the cultivated land could be due to high microbial oxidation which produces organic acid, soil erosion processes as well as basic cations depletion might have been more aggravated in the cultivated land and, the application of inorganic fertilizer which also lowed the pH value in the cultivated land. The result agree with (Habitamu, 2014) who stated that, H^+ released by nitrification of NH_4^+ from chemical fertilizer lowers the pH value of cultivated land as compared with non-cultivated land. With respect to conservation difference, that is cultivated, fallow and woody land treated with soil bund showed highest pH value than the same land use types without soil bund. This could be due to reduced soil erosion in the land uses with soil bund which results in improving and restoring of organic matter. (Wolka et al., 2011) also stated that soil and water conservation with soil bund reduces surface runoff and soil loss, retain water that enhances crop growth and contributes to soil organic carbon input. High mean variation of electrical conductivity was observed between woody and cultivated land with and without soil bund (Table 4). Cultivated land with and without soil bund had lowest EC in all slope positions. Apparently, for all land use and both conserved and none conserved lands mean EC value decreased from lower to upper slope position. Soluble cations and anions always move downward with surface runoff and accumulated suspended clay towards lower slope might have caused an increase in EC at the lower might have

Table 3. The effect of slope position and different land uses with and without soil bund on soil chemical properties.

Land Use	pH	EC(dS/m)	Av.P (ppm)	OC (%)	TN (%)	CEC	K	Ca	Mg	Na	PBS (%)
								(cmol kg^{-1})			
Cultivation	5.19^{c}	0.10^{c}	1.60^{c}	1.86^{c}	0.16^{c}	12.99^{c}	0.29^{c}	17.19^{b}	2.46^{b}	0.060^{b}	66.16^{b}
Fallow	5.52^{b}	0.12^{b}	2.74^{b}	2.49^{b}	0.21^{b}	18.75^{b}	0.44^{b}	24.83^{a}	3.17^{a}	0.056^{b}	76.05^{a}
Woody	5.84555 5.85^{a}	0.16827 0.17^{a}	3.90277 3.90^{a}	3.05388 3.05^{a}	0.26333 0.26^{a}	27.1622 27.16^{a}	0.400.4 0.47^{a}	25.571125.57^{a}	3.295553.30^{a}	0.14055 0.140^{a}	78.7885 78.79^{a}

Table 4. The effect of different land uses with and without soil bund on soil physical property.

Slope	pH	EC(dS/m)	Av.P(ppm)	OC (%)	TN (%)	CEC	K	Ca	Mg	Na	PBS
								(cmol Kg^{-1})			
C0	5.23a^{c}	0.10a^{b}	1.33a^{c}	1.75a^{c}	0.15a^{c}	12.56a^{c}	0.30a^{b}	16.97a^{b}	2.47a^{a}	0.06a^{b}	61.14b^{c}
CSB	5.76a^{c}	0.10a^{b}	1.87a^{c}	1.98a^{c}	0.17a^{c}	13.44a^{c}	0.28a^{b}	17.42a^{b}	2.45a^{a}	0.07a^{b}	68.13a^{c}
F0	5.54a^{b}	0.11a^{b}	2.51a^{b}	2.45a^{b}	0.21a^{b}	18.23a^{b}	0.45a^{a}	24.67a^{a}	3.13a^{a}	0.06a^{b}	71.17b^{b}
FSB	5.75a^{b}	0.12a^{b}	2.98a^{b}	2.52a^{b}	0.22a^{b}	19.27a^{b}	0.43a^{a}	24.98a^{a}	2.81a^{a}	0.06a^{b}	75.93a^{b}
w0	5.71a^{a}	0.16a^{a}	3.52b^{a}	2.96a^{a}	0.26a^{a}	25.97a^{a}	0.46a^{a}	24.70a^{a}	3.47a^{a}	0.13a^{a}	81.64a^{a}
WSB	6.94a^{a}	0.18a^{a}	4.29a^{a}	3.15a^{a}	0.27a^{a}	29.13a^{a}	0.49a^{a}	26.48a^{a}	3.53a^{a}	0.15a^{a}	83.98a^{a}

Co- cultivated land without soil bund, CSB-cultivated land with soil bund, Fo-fallow land without soil bund, FSB-fallow land with soil bund, Wo-woody land without soil bund and WSB-woody land with soil bund. Mean values followed by different letters in the subscript is for conservation difference within similar land uses and letters in the superscript for different land uses of similar conservation practices are statistically different at P ≤0.05.

caused an increase in EC at the lower slope position than upper slope position.

Available phosphorous (P)

The result affirmed that available Phosphors were significantly affected by land use types (Table 3). The average mean values of available Phosphors were 1.60, 2.74 and 3.90 (ppm) for cultivated, fallow and woody lands respectively. Cultivated land had significantly lower available phosphors. This could happen due to high erosion, low organic and inorganic fertilizer application and crop residue removal in the cultivated land as compared with other land use types (Bezabih et al., 2014; Yitbarek et al., 2013; Jamala and Oke 2013; Bucsi and Centeri 2007). The average available phosphors of woody land>fallow land>cultivated land (Table 4) for both was conserved with and without soil bund in all slope positions. Similarly, for all land uses high mean values of available Phosphors were recorded in the land use with soil bund. The average value of available Phosphors decreased from lower to upper slope position for all land uses and both conserved and none conserved land uses (Table 5).

Organic Carbon (OC) and Total Nitrogen (TN)

Organic carbon and total nitrogen also showed variation due to land uses and conservation difference. The average means value of organic carbon and total nitrogen of cultivated land<fallow land>woody land. This could be due to soil erosion processes and different anthropogenic activities like land fragmentation and grazing

Table 5. Mean difference of soil chemical properties among different slope position and land uses with and without soil bund on soil

Land use	pH	EC	Oc	TN	P	CEC	K	Ca	Mg	Na	PBS
Lower slope position											
co	5.07b^{a}	0.102bc^{a}	2.10c^{a}	0.18c^{a}	1.96c^{a}	14.38c^{a}	0.37b^{a}	14.72b^{a}	1.59c^{b}	0.08a^{a}	68.44b^{a}
fo	5.47a^{a}	0.12b^{a}	2.62b^{a}	0.23b^{a}	2.87b^{a}	20.61b^{a}	0.58a^{a}	21.30a^{a}	2.62b^{b}	0.06a^{a}	83.07a^{a}
wo	5.67a^{a}	0.18a^{b}	3.21a^{b}	0.28a^{b}	3.79a^{b}	29.35a^{b}	0.60a^{a}	18.93a^{a}	3.15a^{a}	0.11a^{ac}	84.6a^{a}
csb	4.95c^{a}	0.11b^{a}	2.20c^{a}	0.19c^{a}	2.02c^{a}	15.01c^{a}	0.28b^{a}	16.23b^{a}	2.55b^{c}	0.08b^{a}	85.86b^{a}
fsb	5.45b^{a}	0.12b^{a}	2.67b^{a}	0.23b^{a}	2.98b^{a}	21.24b^{a}	0.51a^{a}	21.78a^{a}	2.64b^{b}	0.06b^{a}	91.36a^{a}
wsb	5.64a^{b}	0.22a^{a}	3.49a^{a}	0.30a^{a}	5.05a^{a}	35.31a^{a}	0.56a^{a}	20.63a^{a}	2.92a^{b}	0.26a^{a}	91.37a^{a}
Middle slope position											
co	5.23b^{a}	0.096b^{a}	1.91c^{a}	0.17c^{a}	1.40c^{a}	12.99c^{a}	0.27a^{a}	19.61c^{b}	2.80b^{a}	0.05b^{a}	59.13b^{b}
fo	5.52b^{a}	0.114b^{a}	2.43b^{a}	0.21b^{a}	2.47b^{b}	18.06b^{a}	0.45a^{a}	30.21b^{a}	4.17a^{a}	0.05b^{a}	70.97a^{b}
wo	5.85a^{a}	0.15a^{a}	2.93a^{a}	0.25a^{a}	3.68a^{a}	26.23a^{b}	0.43a^{a}	35.45a^{b}	4.1a^{a}	0.21a^{a}	74.32a^{b}
csb	5.17c^{a}	0.11c^{a}	2.03c^{a}	0.17c^{a}	1.88c^{a}	13.74c^{a}	0.23b^{a}	25.06c^{a}	1.59c^{b}	0.07a^{a}	75.96b^{b}
fsb	5.50ab^{a}	0.12ac^{a}	2.52b^{a}	0.22b^{a}	3.69b^{a}	19.52b^{a}	0.33a^{b}	32.24b^{a}	2.05b^{b}	0.06a^{a}	79.50a^{b}
wsb	5.73a^{b}	0.17a^{a}	3.09a^{a}	0.27a^{a}	4.40a^{a}	28.28a^{a}	0.42a^{a}	39.15a^{a}	2.77a^{b}	0.10a^{b}	82.14a^{b}
Upper slope position											
c0	5.39bc^{a}	0.087c^{a}	1.23c^{b}	0.11c^{b}	0.64c^{b}	10.30c^{a}	0.26b^{b}	16.57b^{b}	3.02b^{a}	0.05a^{a}	39.67b^{c}
fo	5.61b^{a}	0.11bc^{a}	2.29b^{a}	0.20b^{a}	2.19b^{a}	16.02b^{a}	0.36a^{b}	23.43a^{b}	3.81a^{a}	0.06a^{a}	54.48a^{c}
wo	6.28a^{a}	0.14a^{b}	2.74a^{a}	0.24a^{a}	3.08a^{a}	22.35a^{a}	0.34a^{b}	25.09a^{b}	3.11b^{a}	0.08a^{c}	61.61a^{c}
csb	5.33b^{a}	0.09c^{a}	1.72c^{a}	0.15c^{a}	1.70c^{a}	11.56c^{a}	0.35c^{a}	20.96b^{a}	3.20b^{a}	0.05a^{a}	65.456b^{c}
fsb	5.55b^{a}	0.11bc^{a}	2.38b^{a}	0.21b^{a}	2.27b^{a}	17.04b^{a}	0.44b^{a}	35.00a^{a}	3.75a^{a}	0.05a^{a}	71.43a^{c}
wsb	5.88a^{a}	0.15a^{a}	2.87a^{a}	0.25a^{a}	3.41a^{a}	23.79a^{a}	0.50a^{a}	34.19a^{a}	3.69a^{a}	0.09a^{b}	71.57a^{c}

Co- cultivated land without soil bund, CSB-cultivated land with soil bund, Fo-fallow land without soil bund, FSB-fallow land with soil bund, Wo-woody land without soil bund and WSB-woody land with soil bund. Mean values followed by different letters in the subscript is for land uses of similar conservation practices in each slope category and letters in the superscript is for similar land uses and conservation practices within different slope position are statistically different at P ≤0.05.

intensity which is very high in the cultivated land. (Khan et al., 2013) also observed low soil organic matter in the cultivated land. Soil erosion and low organic matter addition could also reduce soil clay content in the cultivated land. Level soil bund and topographic features coupled with parent material and climatic conditions have the greatest effect on amount of carbonate in soils (Wolka et al., 2011; Alijani and Sarmadian, 2014). In contrast, highest mean values were recorded in the woody land (Table 5). The second highest mean value was in the fallow land with and without soil bund (Table 4).This could be attributed to good nutrient management in the woody and fallow land while the lowest mean value in the cultivated land might be due to low addition of organic matter and rapid mineralization coupled with poor nutrient management. Similar results were found by (Jamala and Oke, 2013; Birhanu A., Enyey A. 2014)who noted poor organic matter and total nitrogen in the cultivate land is due to poor nutrient management. There was a linear relationship between Organic carbon and clay content of the soil (Figure 4). Presence of soil bund and trees in the woody land might have reduced soil loss which could increase soil organic carbon and total nitrogen. (Selassie and Ayanna 2013) also noted that, presence of vegetation accords soil adequate cover thereby reduces soil loss.

CEC and exchangeable cations

Cation exchange capacity (CEC) and exchangeable cations (K,Ca, Mg and Na) were significantly different due to land uses (p≤0.05).Conservation practices did not show any variation. Cation exchange capacity (CEC), exchangeable K, Ca, Mg and Na significantly increased from cultivated to fallow and woody land in all slope positions (Figure 3). Mean value of cation exchange capacity (CEC) and exchangeable cations (K, Mg,Ca and Na) of woody land conserved and none conserved with soil bund were more than fallow land with and without soil bund which were also more than cultivated land with and without soil bund (Table 4). This is because the cultivated land of the study area had less organic matter, continuous cultivation, removal of crop residue coupled

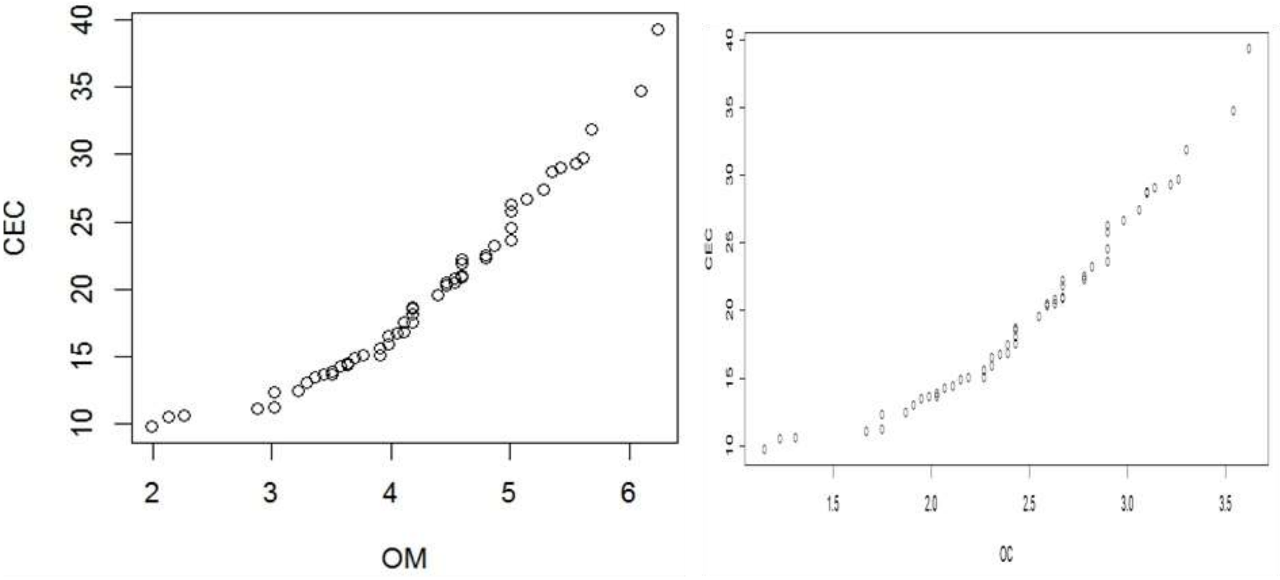

Figure 3. The linear relationship beteween CEC(cation exchange capacity) with OM (organic matter) & OC(organic carbon).

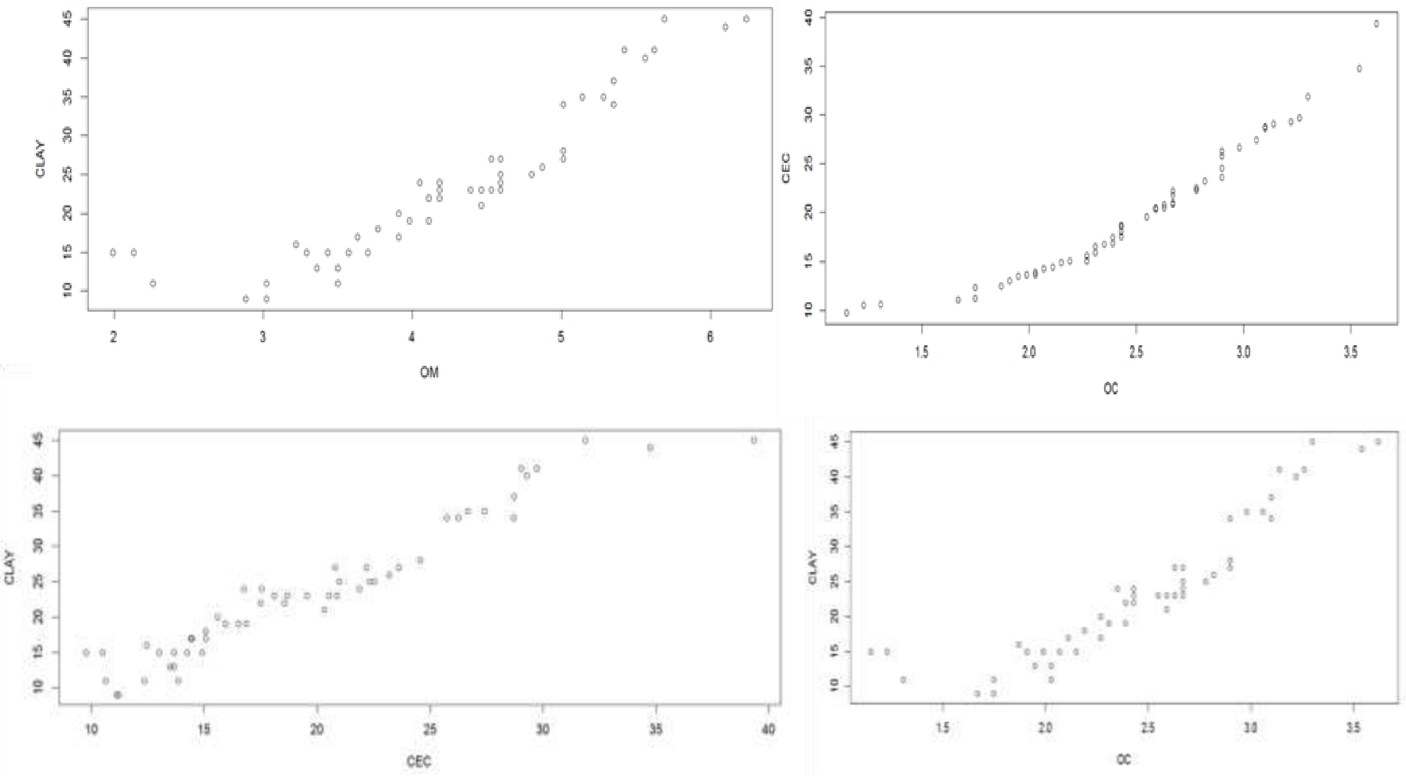

Figure 4. The linear relationship between clay with OM, OC, CEC and OC with CEC.

with severe soil erosion and landslides whereas vegetation cover in the woody land and prolonged fallow period assisted with soil conservation practice might have reduced soil erosion and leaching of exchangeable cations. The result of Pearson's correlation matrix and scatter plot graph confirms that cation exchange

Table 6. Pearson's correlation matrix of soil physical and chemical properties.

Soil properties		pH	EC	OC	TN	P	CEC	K	Ca	Mg	Na	ESP	BD	Porosity	Gav.som	Clay
pH	CC	1														
	Sig. (P-value)	.														
EC	CC	0.78**	1													
	Sig. (P-value)	0.00	0.00													
OC	CC	0.78**	0.83**	1												
	Sig. (P-value)	0.00	0.00	.												
TN	CC	0.78**	0.71**	0.80**	1											
	Sig. (P-value)	0.00	0.00	0.00	.											
P	CC	0.75**	0.96**	0.954*	0.95**	1										
	Sig. (P-value)	0.00	0.00	0.00	0.00	.										
CEC	CC	0.78**	1.00**	0.99**	0.87**	0.976**	1									
	Sig. (P-value)	0.00	0.00	0.00	0.00	0.00	.									
K	CC	00.81**	0.92**	0.82**	0.92**	0.87**	0.84**	1								
	Sig. (P-value)	0.00	0.00	0.00	0.00	0.00	0.00	.								
Ca	CC	00.45**	0.66**	0.66**	0.66**	0.57**	0.66**	0.69**	1							
	Sig. (P-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.							
Mg	CC	00.63**	0.38**	0.39**	0.39**	0.34**	0.39**	0.56**	0.37**	1						
	Sig. (P-value)	0.00	0.002	0.002	0.002	0.007	0.002	0.00	0.003	.						
Na	CC	0.49**	0.23*	0.23*	0.23*	0.15	0.23*	0.42**	0.25*	0.70**	1					
	Sig. (P-value)	0.00	0.048	0.047	0.047	0.137	0.049	0.001	0.034	0.00	.					
BD	CC	00.07	0.35**	0.34**	0.34**	0.36**	0.35**	0.2	0.02	-0.40**	-0.31*	0.82**	1			
	Sig. (P-value)	0.316	0.004	0.005	0.005	0.004	0.005	0.071	0.448	0.001	0.012	0.00	.			
Porosity	CC	0.03	-0.33**	-0.32**	-0.32**	-0.31*	-0.33**	-0.21	-0.18	0.30*	0.24*	-0.26*	-0.42**	1		
	Sig. (P-value)	0.403	0.008	0.009	0.009	0.012	0.008	0.061	0.098	0.013	0.044	0.031	0.001	.		
Clay	CC	0.27*	0.34**	0.34**	0.34**	0.39**	0.35**	0.28*	0.16	-0.1	-0.32*	0.08	0.19	-0.1	0.05	1
	Sig. (P-value)	0.026	0.006	0.007	0.007	0.002	0.007	0.049	0.123	0.241	0.01	0.284	0.081	0.237	0.37	.

**. Correlation coefficient (CC) is significant at the 0.01 level.*. Correlation coefficient (CC) is significant at the 0.05 level. Sig. (P-value) is significant level at the 0.01 and 0.05 level.

capacity (CEC) and organic matter were strongly related with correlation coefficient of 0.99 at (p<0.001) (Table 6 and Figure 3). (Tilhum G, 2015) argued that the declining fallow period or continuous cultivation, limited nutrient recycling of dung and crop residue in the soil, low use of chemical fertilizer and soil erosion contributed to depletion of CEC exchangeable cations. There is also slight mean increment of CEC and exchangeable cations from non-conserved land to conserved land with soil bund.

Percent base saturation (PBS)

Percent base saturation was also significantly increased from cultivated to woody land and from none conserved land to conserved lands with soil bund. (Habitum A, 2014) is in the opinion that the high percent base saturation in the surface layers of forest lands might be due to relatively high organic matter and clay contents (soil colloidal sites and storehouse of exchangeable bases) in the subsurface layer of forest land compared to the surface layers of cultivated and grazing lands. However, PBS decreased from lower to upper slope position for all land uses and conservation practices. Based on the result (Table 4) the highest mean value was recorded in the woody.

CONCLUSION AND RECOMMENDATION

Several soil physical-chemical properties were significantly varied among land uses in association with and without soil bund under different slope category. The result revealed low soil porosity, gravimetric soil moisture content, clay and silt proportion in the cultivated land with and without soil bund as compared with woody and fallow land with and without soil bund in all slope categories. However, soil bulk density and sand fraction was highest in the cultivated land than fallow and woody land. Similarly, Soil chemical parameters [pH, EC, Av.P, OM, OC, TN, CEC, exchangeable (K, Ca, Mg and Na)] and percent base saturation were significantly influenced by land use types. Conversely, conservation practices did not show any significant differences but all parameters showed slight mean variation because of absence and presence of soil bund. Cultivated land with and without soil bund were poor in soil chemical parameters as compared with woody and fallow lands with and without soil bund. There is also strong correlation between different parameters like cation exchange capacity (CEC with fraction of clay content and soil organic matter. In summary, soil physical-chemical property of the study area was strongly influenced by land use and conservation difference in addition to topographic variation. Consequently, to conserve soil resources, it needs highest attention of policy makers as well as land use planners to concentrate their efforts on land management strategies based on land use system and slope differentiation of the region. Therefore, reducing intensive cultivation and integrated use of inorganic and organic fertilizers could replenish the degraded soil physical-chemical property of the study area. It is also recommended that controlled grazing, increased fallow period, avoiding deforestation and using multipurpose agro forestry tree should be more practiced in the study area. Governmental and non-governmental organizations should work to introduce conservation technologies which have received little attention on the farmers of the study area. Integrated soil and water conservation practice should be promoted in the study area. Landscapes with steeply slopes should be strictly prevented from cultivation.

Conflict of Interests

The authors have not declared any conflict of interests.

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Soil thermal parameters assessment by direct method and mathematical models

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Soil thermal parameters are mainly inputs for models of soil heat flux. Mathematical models are important tool for predicting the soil heat and water transfer, depending on some fundamentals of soil physical properties. Soil moisture is one of the soil physical properties that have a great effect on thermal parameters. The aim of the work is to describe the behavior of soil thermal parameters under different values of soil moisture, and is to investigate the effect of some fundamentals of soil physical properties on thermal parameters. We could describe the relationship between thermal diffusivity and soil moisture by ∩ shaped curve using a quadratic equation and evaluate the efficiency of this equation, statistically. Experimental thermal diffusivity (K_{exp}) by direct method and mathematical models were measured. Mathematical models were Chung and Horton model (1987) (K_{cal-2}), the model of Arkhangel'skaya (2004) (K_{cal-3}) and the suggested quadratic equation (K_{cal-1}). Efficiency of the quadratic equation and mathematical models were estimated using the correlation coefficient (R^2), Root Mean Square Error (RMSE), and the Nash-Sutcliffe Efficiency (NSE). The values of R^2, RMSR and NSE for the quadratic equation were 0.978, 0.24 and 0.95, respectively, for sod-podzolic soil under the study. The quadratic equation is a simple and faster equation for forecasting soil thermal diffusivity.

Key words: Soil thermal parameters, thermal diffusivity, thermal conductivity, soil heat capacity, soil moisture, soil bulk density, organic matter, quadratic equation and mathematical models.

INTRODUCTION

Soil thermal parameters are playing an important role in many, chemical, biological, physical and environmental processes such as the dew, soil aeration, crop growth (Timlin et al., 2002), soil CO_2 production (Buchner et al., 2008; Bauer et al., 2012), ecosystem carbon sequestration (Ju et al., 2006), and subsurface soil water evaporation (Sakai et al., 2011). Usually, the soil heat transport simulations are based on estimates of the soil thermal conductivity and soil thermal diffusivity as a function of the soil water content. Moreover, (Votrubova et al., 2012) noted that the simulated soil thermal conditions are strongly affected by the root water uptake approximation. Several authors have suggested models to estimate soil thermal parameters as a function of soil moisture: (Chung and Horton, 1987) estimated the thermal conductivity as a function of soil moisture; also

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(Evett et al., 2012) described the thermal conductivity as a function of soil moisture and soil bulk density. On the other hand, (Tikhonravova and Khitrov, 2003) suggested a polynomial equation to estimate soil thermal diffusivity as a function of soil moisture as:

$K=K_0+a_1\theta+a_2\theta^2+a_3\theta^5$

where K_0, a_1, a_2 and a_3 are the parameters of the equation. Moreover, (Arkhangel'skaya, 2004) proposed another kind of equation a lognormal equation dependence on thermal diffusivity from water content. (Arkhangel'skaya et al., 2015) described the relationship between thermal diffusivity and water content by S-shaped curve. The vertical one dimensional flux density of heat (JH (W m^{-2})) in soil is given by Fourier's la,

$$q =- \lambda \frac{dT}{dZ}$$

where λ is soil thermal conductivity (J m^{-1} s^{-1} $^{o}C^{-1}$), T is temperature in ^{o}C and z is soil depth.
λ could be considered as the apparent soil thermal conductivity, as latent heat transfer cannot be separated from conduction in moist soils.

$\lambda = \lambda^* + D_{vapor}\ L$

λ* is the instantaneous thermal conductivity, D is the thermal vapor diffusivity; L is the latent heat of vaporization (2.449 MJ/kg or 585 cal/g).

Combining the heat flux equation with the equation for conservation of heat energy results in a general expression for soil heat flow, where soil temperature may vary in time and space. The continuity equation of heat in the soil refers that the variation of temperature in time is the result of the additions and losses of energy. This equation is suggested by (Carlslaw and Jaeger, 1964; Nerpin and Chudnovsky, 1975; Kondo and Saigusa, 1994).

$$\rho s\ cs\ \frac{\partial T}{\partial t} = - \frac{\partial q}{\partial z} \qquad Cv\ \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\ \left(\lambda\ \frac{\partial T}{\partial z}\right)$$

The theoretical investigation (Shein and Karpachevskyi, 2007) indicates that the variation of temperature in time is the result of the thermal diffusivity, K (cm^2/sec), and the changes of temperature through depth (Z cm) by classical equation:

$$\frac{\partial T}{\partial t} = K \frac{\partial^2 T}{\partial z^2}$$

The thermal diffusivity K is the ratio between the thermal conductivity *λ* (J m^{-1} sec^{-1}°C^{-1}) and the volumetric heat capacity Cv, (that is, $K=\frac{\lambda}{cv}$). Where Cv (J g^{-1} °C^{-1}) is the volumetric heat capacity $Cv=\rho s\ Cs$, where *ρs* is the apparent density of the soil (Mg/m^3), and Cs is the specific heat of the soil. If the soil is homogeneous, then the soil's volumetric heat capacity Cv and thermal conductivity λ are constant with depth. The objective of the current work is therefore to describe the relationships between thermal parameters and some fundamentals of soil physical properties. A second objective was to evaluate the efficiency of suggested quadratic equation. To achieve this objective, the thermal diffusivity was measured by direct method under different soil moisture content levels, then the results were compared with those estimated by mathematical models, so that we could determine which is the best model could be used to forecast thermal diffusivity.

MATERIALS AND METHODS

This study was carried out on sod-podzolic soils of the Moscow region, Zelenograd field laboratory of Soil Science Institute named by V.V.Dokuchaev. Disturbed and undisturbed soil samples were collected from profile layers according to their difference in morphological features. Undisturbed soil samples were taken by metallic cylinders of 5 cm high and 5 cm inner diameter. Particle Size Distribution was estimated using Laser Diffraction method by Analysette-22 according to (Eshel et al., 2004). Organic matter was measured using Express analyser AN-7529. Soil bulk density (ρ_b) was determined by core method according to (Klute and Dirksen, 1986). Soil particle density (ρ_s) was determined by pycnometer according to (Blake and Hartge, 1986). Total porosity (n) was calculated using the obtained values of particle and bulk density according to (Klute and Dirksen, 1986).

Experimental thermal diffusivity (Kexp)

One method for measuring thermal diffusivity K directly in the laboratory is based on placing a heat source, having a constant temperature in contact with the surface of a soil column having constant cross-sectional area and insulated sides. Soil thermal diffusivity (Kexp) was measured in the laboratory by the direct method using Kondratieff method at different values of soil moisture according to (Shein and Karpachevsky, 2007). The levels of soil moisture θv were 0.02, 0.1, 0.2, 0.35, 0.4, 0.5, and 0.55, cm^3/cm^3.

Mathematical models

Three models Chung and Horton model (1987) (Kcal-2), the model of Arkhangel'skaya (2004) (Kcal-3), and the proposed quadratic equation (Kcal-1) were used to estimate thermal diffusivity as shown in Table 1. The parameters of Chung and Horton model (1987) *b*1, *b*2, and *b*3 were estimated by fitting the curve, and calculating the thermal diffusivity by indirect method through calculating volumetric heat capacity. They calculated the thermal conductivity using the equation:

$\lambda_0\,(\theta) = b_1+b_2\theta+b_3\theta^{\,0.5}$

Where, *b*1, *b*2, and *b*3 are empirical parameters. Volumetric heat capacity Cv was determined by using the formula:

Table 1. Different methods used to estimate thermal diffusivity.

Thermal diffusivity	Model	Method	Parameter
(K_{exp})	In Lab	Kondratieff methods	
(K_{cal-2})	$\lambda_0(\theta)=b_1+b_2\theta+b_3\theta^{0.5}$ $K(\theta)=\frac{\lambda(\theta)}{cv}$	Chung and Horton (1987)	b_1, b_2 and b_3
(K_{cal-3})	$K = K_0 + a\exp\left[-0.5\left(\frac{\ln\left(\frac{w}{w_0}\right)}{b}\right)^2\right]$	Arkhangel'skaya (2004) Lognormal equation	K_0,a,w,w_0 and b
(K_{cal-1})	$K(\theta)=b_1+b_2\theta-b_3\theta^2$	Quadratic equation	b_1, b_2 and b_3

$$Cv = 1.94\,(1 - n - \phi) + 4.189\theta v + 2.5\,\phi \quad (\mathrm{M\,J\,m^{-3o}C^{-1}})$$

Where: Cv is soil heat capacity, n is the soil porosity; ϕ is the volume fraction of soil organic matter and θv is the volumetric water content. 2) The parameters of model Arkhangel'skaya (2004), K_0, a, w_0, and b were determined from curve fitting of thermal diffusivity and soil moisture.

$$K = K_0 + a\exp\left[-0.5\left(\frac{\ln\left(\frac{w}{w_0}\right)}{b}\right)^2\right]$$

where W is water content, K is the corresponding thermal diffusivity; K_0, a, w_0, and b are parameters of the curve. K_0 is thermal diffusivity of dry soil, w_0 is the water content corresponding to the maximum thermal diffusivity. 3) The new suggest quadratic interpolation equation was to estimate thermal diffusivity K (θ) as a function of soil moisture.

$$K(\theta) = b_1+b_2\theta-b_3\theta^2$$

The parameters of equation b_1, b_2 and b_3 are *b*3 were estimated by fitting the curve.

Statistical analysis

Efficiency of the quadratic equation and mathematical models were determined using the correlation coefficient (R^2), Root Mean Square Error (RMSE), and the Nash-Sutcliffe Efficiency (NSE) according to Nash and Sutcliffe (1970).

$$RMSE=\sqrt{\frac{\sum_N (Ym-Yc)^2}{N}}$$

NSE is defined as:

$$NSE=1-\left[\frac{\sum_N (Ym-Yc)^2}{\sum_N (Ym-Yavg)^2}\right]$$

where Ym is the measured value of K, Yc is the corresponding calculated value of K and Yavg when referring to average of the measured values of K. Modeling efficiencies (NSE) range is from (−∞ to 1), where NSE = 1 corresponds to a perfect match between calculated values and measured data and, NSE = 0 indicates that the model predictions are as accurate as the mean of the measured data, whereas an efficiency <0 ($-\infty < NSE < 0$) occurs when the model simulations are worse than the measured mean. Software tools were Microsoft Excel, MATLAB, and SPSS program for the Statistical analysis.

RESULTS AND DISCUSSION

Effect of soil moisture on thermal parameters

Effect of soil moisture on thermal diffusivity

Figure 1, shows that thermal diffusivity at first increased rapidly with increasing water content to reach the maximum, then decreased at a slower rate. The maximum value of (K_{exp}) was 9(cm^2/h) at θv=0.4 cm^3/cm^3, while the minimum value of (K_{exp}) was 4.37(cm^2/h) at θv=0.02cm^3/cm^3. This result agreed with (Arkhangel'skaya et al., 2015) who found out that the maximum thermal diffusivity is observed at a water content of 0.3 to 0.4 cm^3/cm^3. The reason water content increase thermal contact between soil particles and replaces the air, is that it has lower thermal conductivity than water and increases the specific heat between soil partials. But the thermal diffusivity increases more rapidly than the volumetric heat capacity, as a result, there is a decrease in thermal diffusivity. We could describe the represented data in Figure 1 by ∩ shaped curve using a quadratic interpolation equation.

$$K(\theta) = b_1+b_2\theta-b_3\theta^2$$

where b_1, b_2 and b_3 are the experimental approximated parameters that have an effect on thermal diffusivity; θ is a fraction of volume soil moisture. This description differs from (Arkhangel'skaya, 2004; Arkhangel'skaya et al., 2015) that described the relationship between thermal diffusivity and water content by S - shaped curves with a long gently sloped segment in the region of volumetric water content below 0.15 cm^3/cm^3, and the region of pronounced increase of thermal diffusivity in the water

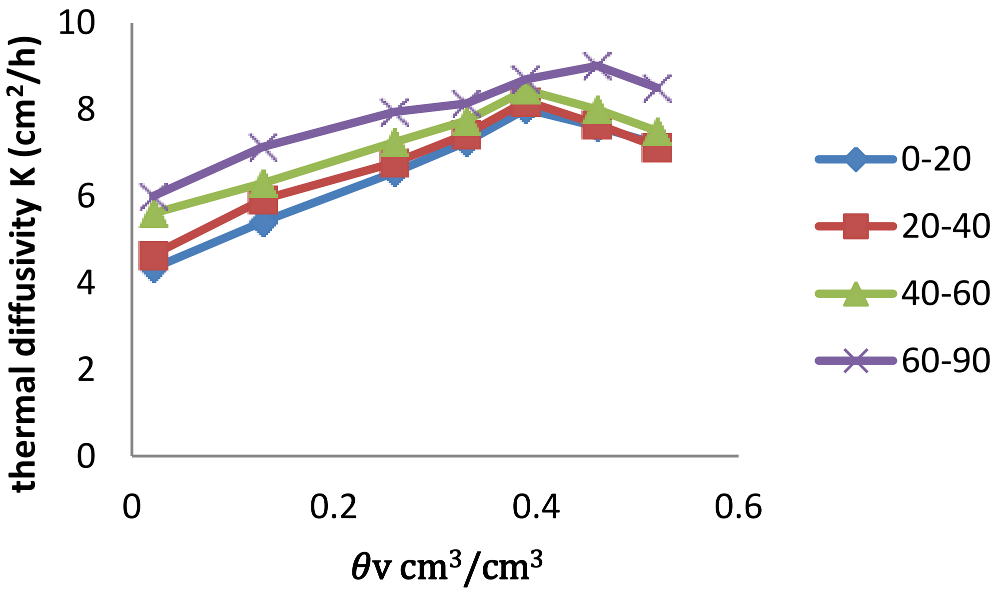

Figure 1. Effect of soil moisture on thermal diffusivity.

content has the range from 0.15 to 0.30 to 0.35 cm^3/cm^3.

Effect of soil moisture on thermal conductivity and heat capacity

Figure 2 introduces the relationship between soil moisture and each of thermal conductivity and soil heat capacity. The minimum value of λ=4.76 (J $cm^{-1}h^{-1}$ $^0c^{-1}$) was at θv=0.02 cm^3/cm^3 at soil depth (0-20) cm, while the maximum value of λ= 28.50 (J $cm^{-1}h^{-1}$ $^0c^{-1}$) was at θv=0.55 cm^3/cm^3 at soil depth (60 to 90) cm .The thermal conductivity and soil heat capacity increase by increasing soil moisture. Soil heat capacity CV increases linearly with water content, thermal conductivity λ increases more rapidly than Cv at low water contents. This result agreed with (Evett et al., 2012; Oladunjoye and Sanuade, 2012), they found that thermal conductivity and soil heat capacity is based on and increased with increasing soil moisture.

Relationship between thermal parameters and organic matter under different values of soil moisture

Figure 3, shows that the highest values of thermal diffusivity and thermal conductivity were at the lowest value of organic matter 0.2%, while the lowest values of thermal diffusivity and thermal conductivity were at the highest value of organic matter 1.29%. The reason of that organic matter leads to increase macro pores and soil porosity, due to decreasing contact points between soil particles sequence decrease, thermal diffusivity and thermal conductivity, this result agreed with (Oladunjoye and Sanuade, 2012). There were insignificant negative correlations between organic matter and each of thermal diffusivity and thermal conductivity, were -0.831 and -0.914, respectively.

Relationship between thermal parameters and soil bulk density under different values of soil water content

Figure 4 shows that the highest values of thermal diffusivity and thermal conductivity were at the highest value of soil bulk density 1.38 Mg/m^3, while the lowest values of thermal diffusivity and thermal conductivity were at the lowest value of soil bulk density 1.18 Mg/m3.The reason of that with depth, increase soil bulk density, where soil particles are better conductors of heat than water, leads to increase conduction of heat between soil particles and increasing thermal parameters, this result agreed with Arkhangel'skaya et al (2015) and Oladunjoye and Sanuade (2012).

Efficiency of the models

Table 2 shows that the calculated values of K obtained from three models were compared to the corresponding measured value of (K_{exp}) by direct method. The results observed that the best model could be used to estimate soil thermal diffusivity as a function of soil moisture which was the quadratic equation (K_{cal-1}), then Arkhangel'skaya model (K_{cal-3}) and the model of Chung and Horton (K_{cal-2}),

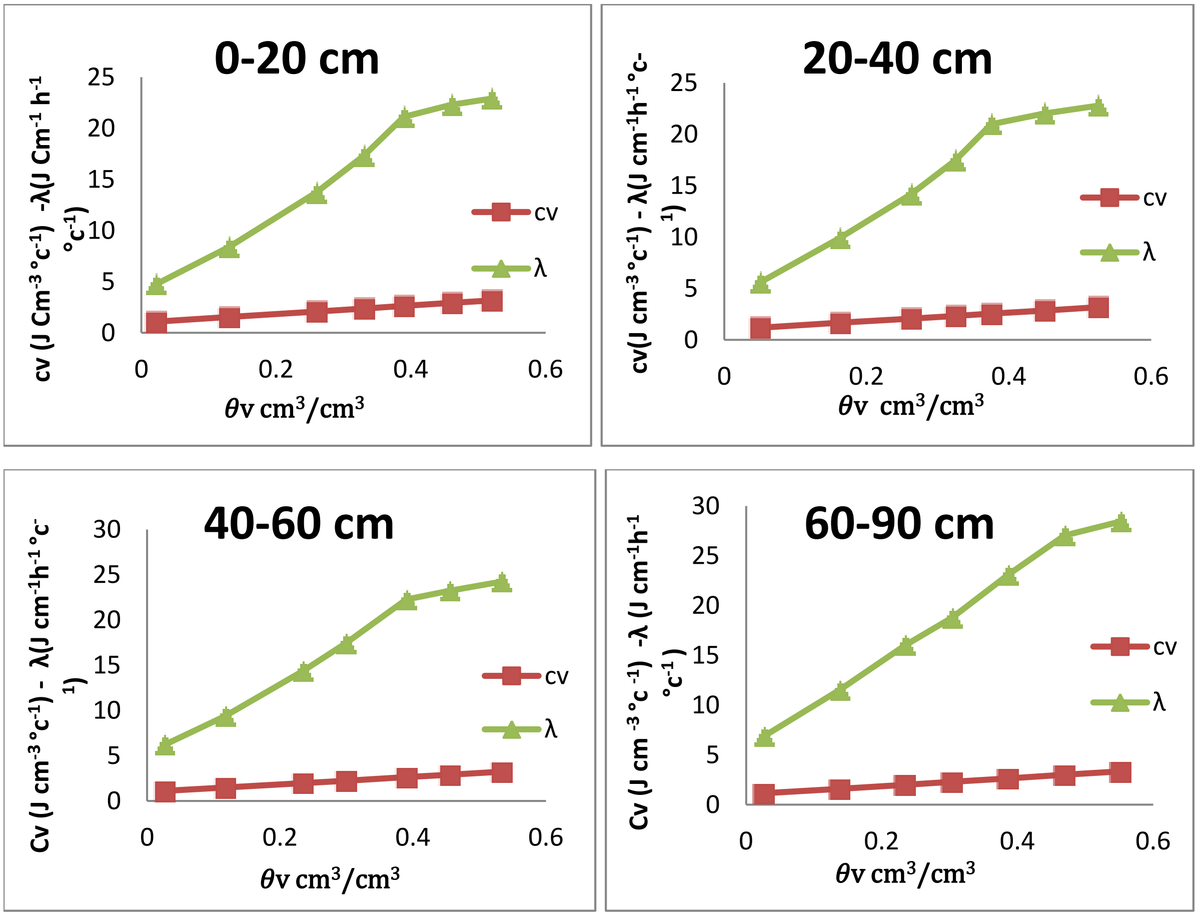

Figure 2. Effect of soil moisture (θv) on soil heat capacity C_v (J .cm^{-3} °C $^{-1}$) and thermal conductivity λ (J.cm^{-1}.h^{-1} °C $^{-1}$).

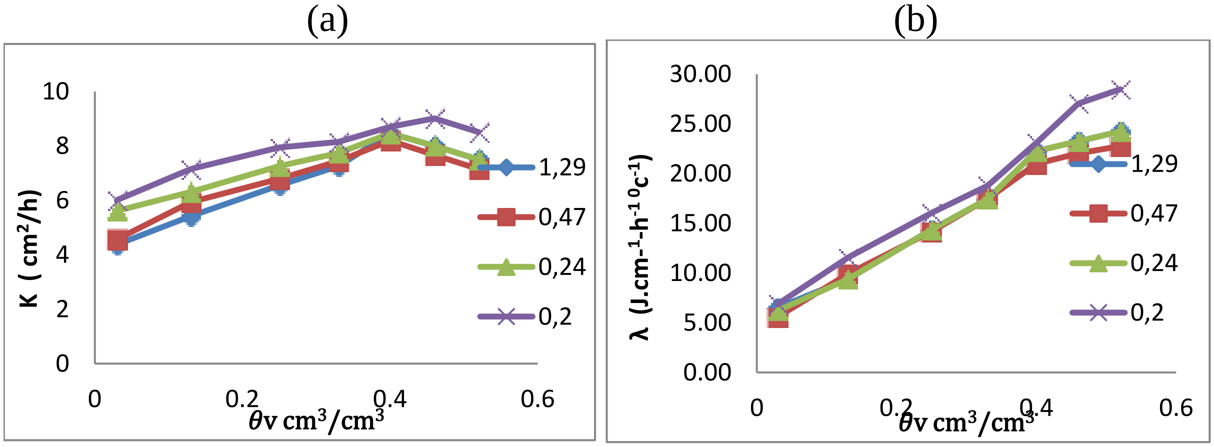

Figure 3. A- Effect of organic matter on thermal diffusivity (K) and b- an effect of organic matter on thermal conductivity (λ) under different values of soil moisture.

for sod-podzolic soil under the study. (K_{cal-1}) had the highest values of R^2 which was 0.978 and NSE was 0.95, but had the lowest value of RMSE was 0.24. While R^2 of (K_{cal-3}) was 0.931, NSE was 0.82 and RMSE was 0.49. On the other hand (K_{cal-2}) had the lowest values of R^2 and NSE, which were 0.896 and 0.78, respectively. While the

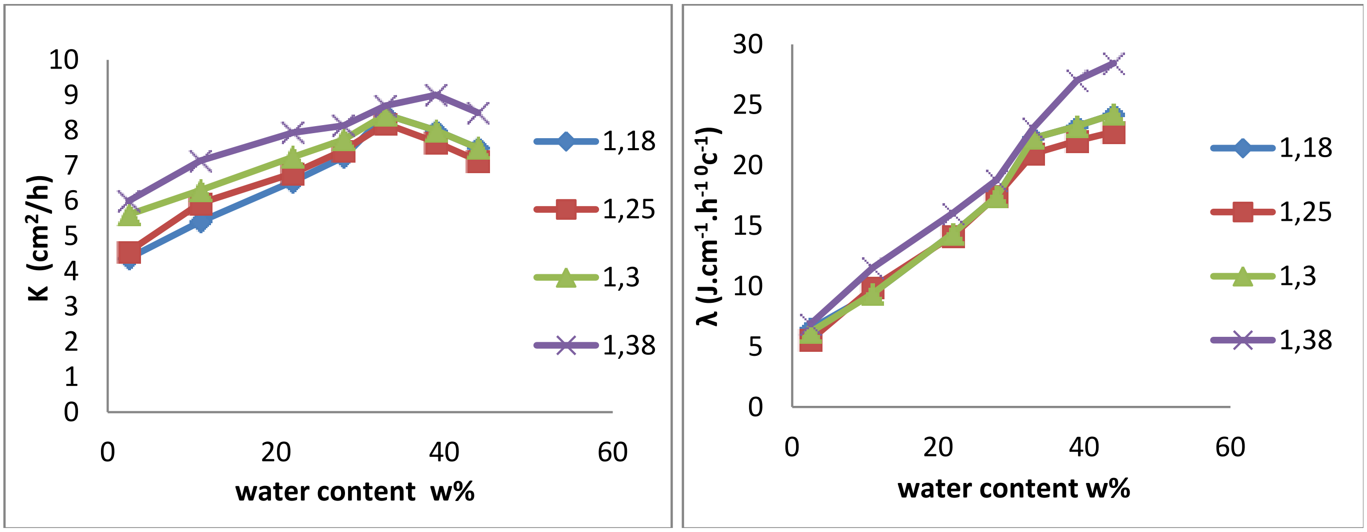

Figure 4. A-Relationship between soil bulk density and thermal diffusivity (K) and b-the relationship between soil bulk density and thermal conductivity(λ) under different values of water contents.

Table 2. Statistical parameters (R2), (RMSE) and (NSE).

Methods	R^2				RMSE	NSE
	(K_{exp})	(K_{cal-1})	(K_{cal-2})	K($_{cal-3}$)		
(K_{exp})	1	0.978	0.896	0.931		
(K_{cal-1})	0.978	1	0.937	0.900	0.24	0.95
(K_{cal-2})	0.896	0.937	1	0.807	0.54	0.78
(K_{cal-3})	0.931	0.900	0.807	1	0.49	0.82

(K_{exp}) Thermal diffusivity experimental,(K_{cal-1})Quadratic equation,(K_{cal-2})Chung and Horton 1987 and (K_{cal-3}) Arkhangel'skaya (2004).

highest value of RMSE was 0.54. Moreover, Figure 5 shows that the quadratic equation was the best descripttion for the graphical representation of the experiment data, for sod-podzolic soil under the study. The model of Arkhangel'skaya (2004) and Arkhangel'skaya et al. (2015) described the relationship between thermal diffusivity and water content by S -shaped curve. But this description differs from ours as we described thermal diffusivity by ∩ shaped curve that described represented data from experimental thermal diffusivity. While the model of Chung and Horton (1987) was the less efficiency because of it estimated thermal diffusivity by indirect method, through estimated thermal conductivity as a function of soil moisture.

Conclusion

Soil physical properties are soil moisture, soil bulk density, particle size distribution and organic matter, which have a great effect on thermal parameters. Thermal diffusivity at first, increased rapidly with increasing water content then decreased at a slower rate. All thermal parameters increased with increasing clay content and soil bulk density (soil depth), while decreased with increasing organic matter and soil porosity. We could describe the relationship between thermal diffusivity and soil moisture by ∩ shaped curve using a quadratic equation. The quadratic equation (Kcal-1) was more efficient than the model of (Arkhangel'skaya, 2004) (Kcal-3) and model of (Chung and Horton, 1987) (Kca-2), for calculating thermal diffusivity as a function of soil moisture. The quadratic equation is a simple and faster equation for forecasting soil thermal diffusivity, for sod-podzolic soil under study. However, it requires more experiments in variant types of soils.

Conflict of Interests

The authors have not declared any conflict of interests.

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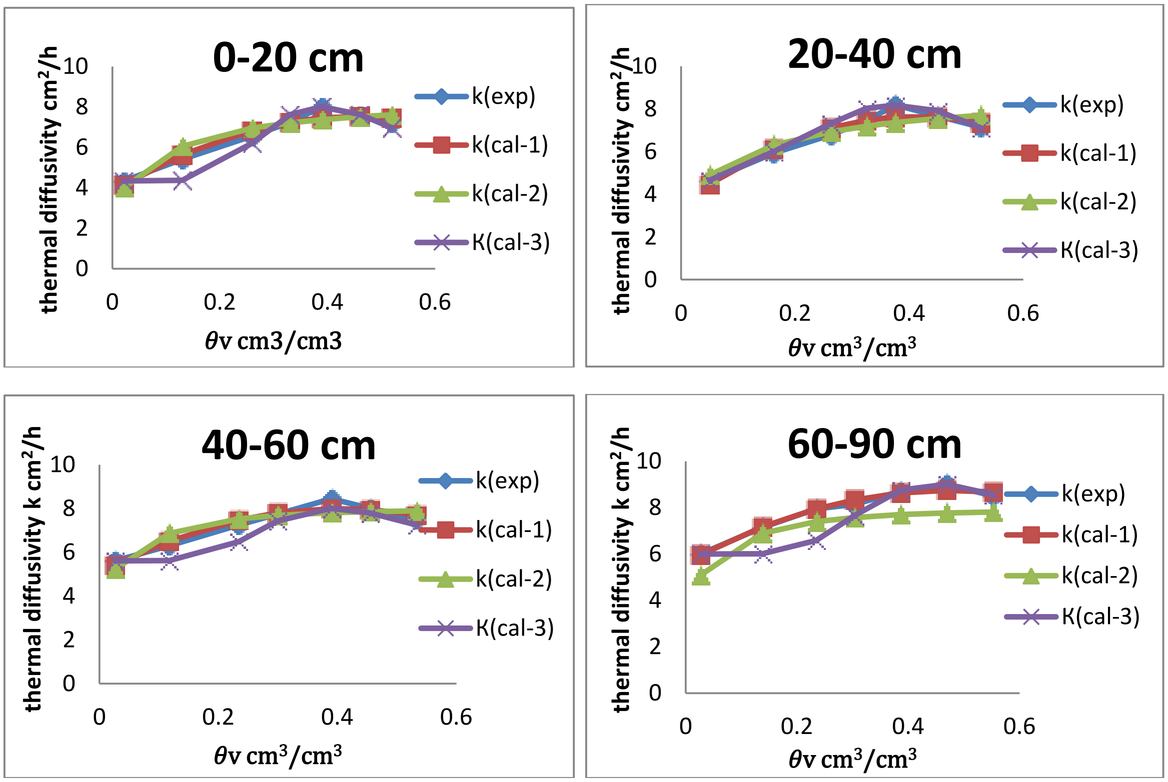

Figure 5. Values of calculated and experimental thermal diffusivity at different values of soil moisture.

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