https://doi.org/10.17221/150/2019-SWR

Available water capacity and organic carbon storage profiles in soils developed from dark brown soil to boggy soil in Changbai Mountains, China

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Citation: Yu D., Hu F., Zhang K., Liu L., Li D. (2021): Available water capacity and organic carbon storage profiles in soils developed from dark brown soil to boggy soil in Changbai Mountains, China. Soil & Water Res., 16: 11–21.

Abstract: The available water capacity (AWC) is the most commonly used parameter for quantifying the amount of soil water that is readily available to plants. Specific AWC and soil organic carbon storage (SOCS) profiles are consequences of the soil development process. Understanding the distributions of AWC and SOCS in soil profiles is crucial for modelling the coupling between carbon and water cycle processes, and for predicting the consequences of global change. In this study, we determined the variations in the AWC and SOCS from the surface to a depth of 100 cm in soils developed from dark brown soil, skeletal dark brown soil, meadow dark brown soil, white starched dark brown soil, meadow soil, and boggy soil in the Changbai Mountains area of China. The AWC and SOCS profiles were calculated for each main soil group/subgroup using only the readily available variables for the soil texture and organic matter with the soil water characteristic equations. The results showed the following. (1) The AWC and SOCS decreased initially and then increased, before decreasing again in soils developed from dark brown soil to boggy soil, where the maximum SOCS occurred in the white starched dark brown soil, and the maximum AWC in the dark brown soil. (2) The SOCS was decreased by deforestation and concomitant soil erosion, but the negative impact of this decrease in the SOCS in the Changbai Mountains area was not caused completely by reductions in AWC. (3) In the soil development process from dark brown soil to boggy soil in response to deforestation, the AWC distribution differed in the profile and even among individual layers, whereas the SOCS was mainly present in the upper layer.

Keywords: couple of carbon and water; deforestation; plant available water; soil formation

The importance of the available water capacity (AWC) as a water retention predictors has been widely recognised in recent decades (Veihmeyer 1927; Hartemink et al. 2001; Rawls et al. 2003). The AWC is important for studying soil humidity, ecological agricultural planning, soil erosion, water retention, crop growth potential evaluation, and simulating global land cover changes due to the effects of economic factors and climate changes (Timlin et al. 2001; Minasny & McBratney 2003; Rawls et al. 2003; Trnka et al. 2016; Xia et al. 2017; García-González et al. 2018). However, human activity has adversely affected the land cover and contributed to soil deterioration (Yang et al. 2003; Lepers et al.

Supported by the National Major Science and Technology Projects of China (Grant No. 2018YFC0507201), and Central Public-interest Scientific Institution Basal Research Fund of China(No. GYZX190308).

Dandan Yu and Feilong Hu contributed equally to this work.

https://doi.org/10.17221/150/2019-SWR

2005; Esayas 2010), thereby decreasing the AWC and fertilizer use efficiency, and causing reductions in soil productivity (Oldeman et al. 1991; Sims et al. 1998; Islam & Weil 2000; Trnka et al. 2016; Rodolfo et al. 2017). Decreases in AWC are attributed to changes in the characteristic of the water-holding capacity of the pores and reductions in the depth (thickness) of the rooting zone (Claudio & Gilmo 1989; Testi et al. 2005). Therefore, AWC reductions could be used to predict changes in water retention due to soil deterioration caused by erosion (Pimentel et al. 1995; Trnka et al. 2016).

In the outer area of the Changbai Mountains in Northeastern China, the primary forests have been replaced by secondary forests after massive deforestations caused by the construction of the Middle East railway in 1882 and the founding of the People's Republic of China (Research Institute of Forestry 1986). Due to coupling among the changes in vegetation on the terrain, parent material, micro-climate, and hydrology, the development of soil within the same horizontal band has been highly complex, and various main soil groups/subgroups have formed, which are closely related to edaphic succession (Research Institute of Forestry 1986). However, no information is available regarding the AWC distribution in each main soil group/subgroup in the Changbai Mountains area.

Studies have shown that the AWC is a function of the soil organic matter content (Dharumarajan et al. 2013). In particular, the abundance of AWC affects and is affected by changes in the soil organic matter content due to climate change and management practices (Minasny & McBratney 2017). In addition, the structure-forming effect of organic matter affects the water retention capacity when the water content is close to the wilting point to a smaller extent compared with that when it is close to the field capacity (Rawls et al. 2003). Furthermore, the effect of the soil organic carbon content on the AWC depends on the proportion of textural components and the amount of organic carbon in the soil (Pachepsky & Rawls 2004; Zemánek 2011). When the carbon content is low, an increase in the carbon content leads to an increase in the AWC in coarse soils but a decrease in fine-textured soils. However, when the carbon content is high, an increase in the carbon content leads to a decrease in the AWC in soils with all different textures (Rawls et al. 2003; Pachepsky and Rawls 2004; Jones et al. 2009). In general, it has been assumed that the changes in the soil organic carbon contents are linear for short periods of time, such as 2–5 years (Hassink et al. 1997; Alliaume et al. 2013). However, soils form slowly, and it takes hundreds of years to form 1 cm of topsoil. Therefore, we assume that there is a threshold that constrains assessments of the effect of the soil organic carbon content on the AWC.

However, previous studies failed to consider the effects of feedback from carbon accumulation on the AWC in the soil profile at depths ranging from 0 to 100 cm. Thus, in the present study, we directly compared the AWC and organic carbon content profiles during the soil development process in order to assess the current regional AWC and organic carbon storage levels and to simulate the vegetation cover under the influence of human activity and climate change. In particular, we compared the AWC and organic carbon storage profiles in soils that developed from dark brown soil to boggy soil in the Changbai Mountains area of China. As for methods for the estimation of the AWC, a lot of pedo-transfer functions (PTFs) that based on soil properties are used to develop mathematical relationships for the estimation of soil water characteristic curve (Rawls et al. 1982; Vereecken et al. 1989; Batjes 1996; Zhou et al. 2005; Nemes et al. 2006; Bayat et al. 2013; Ghanbarian et al. 2015; Wang et al. 2017). Thereinto, the PTFs in Rosetta program allow the estimation of parameters of van Genuchten equation for describing SWCC using limited (textural classes only) to more extended (texture, bulk density, and one or two water retention points) input data (Schaap et al. 2001; Li et al. 2016). Additionally, the Rosetta program offers a user-friendly graphical interface and combines the PTFs with a simple database management structure to facilitate parameter estimates and data management (Schaap et al. 2001). In the view of the better performance of the Rosetta program in predicting AWC (Pachepsky et al. 2015; Li et al. 2016; Qing & Shaohui 2018), hence it was adopted in this study. Our results may facilitate evaluations of the effects of regional carbon sequestration on the soil hydraulic properties. The main aims of this study were as follows.

(1) To quantify the AWC and organic carbon content profiles in soils that developed from dark brown soil to boggy soil in response to deforestation.

(2) To evaluate the relationship between the AWC and soil organic carbon storage (SOCS), and to determine the threshold for assessing the effect of the latter on the former in soils that developed from dark brown soil to boggy soil.

https://doi.org/10.17221/150/2019-SWR

MATERIAL AND METHODS

Site description. This study was conducted in the Changbai Mountains forest region of northeast China. The region has a temperate humid climate with long-term average annual precipitation of 787.3 mm. Most of the precipitation occurs during the summer months. The mean annual temperature is 4.2 °C. The zonal soil in the Changbai Mountains forest region comprises dark brown soil under broad-leaved and Korean pine mixed forests (Research Institute of Forestry 1986). However, it has been shown that various degrees of damage have occurred in the broad-leaved and Korean pine mixed forests due to human activity, and thus the soil development process in this region has been highly complex (Research Institute of Forestry 1986). In the broad-leaved and Korean pine mixed forest zone, the main soil groups/subgroups are dark brown soil (DBS), skeletal dark brown soil (SDBS), meadow dark brown soil (MDBS), white starched dark brown soil (WSDBS), meadow soil (MS), and boggy soil (BS). The relationships among the main soil groups/subgroups during pedogenesis are shown in Figure 1. The basic characteristics of the study sites are shown in Table 1.

Soil sampling and analysis. In order to quantify the AWC in soils that developed from DBS to BS in the Changbai Mountains area, six typical soil profiles were extracted from the comprehensive survey data reported by the State Forestry Bureau survey planning and Design Institute for 1962–1963 (Research Institute of Forestry 1986). The selected soil series had a broad range of intrinsic physical and chemical properties. An overview of the properties of this subset of soils is presented in Table 2. The particle sizes defined by the Food and Agriculture Organization of the United Nations (clay < 0.002 mm < silt < 0.02 mm < sand < 2 mm) (Commission for Integrated Survey of Natural Resources 1990), organic matter contents and depths of the basic soil units were collected. A standard depth of 0–100 cm was used in this study because it corresponds to the effective rooting depth of most annual crops (Doorenbos & Kassam 1979). Three soil particle size and the organic matter percentages weighed by depth were "homogenised" at a depth of 100 cm.

The soil physical properties (textural characterisation, bulk density, and organic carbon content) at all depths in the soil profile with a depth of weight coefficient were integrated into the assessment of the AWC and soil organic carbon at depths of 0–20, 20–40, 40–60, 60–80, and 80–100 cm. We used the PTFs in the Rosetta program to predict the parameters for the soil water characteristic curve (Schaap et al. 2001). The Rosetta program can be downloaded from the US Salinity Laboratory's website (http://

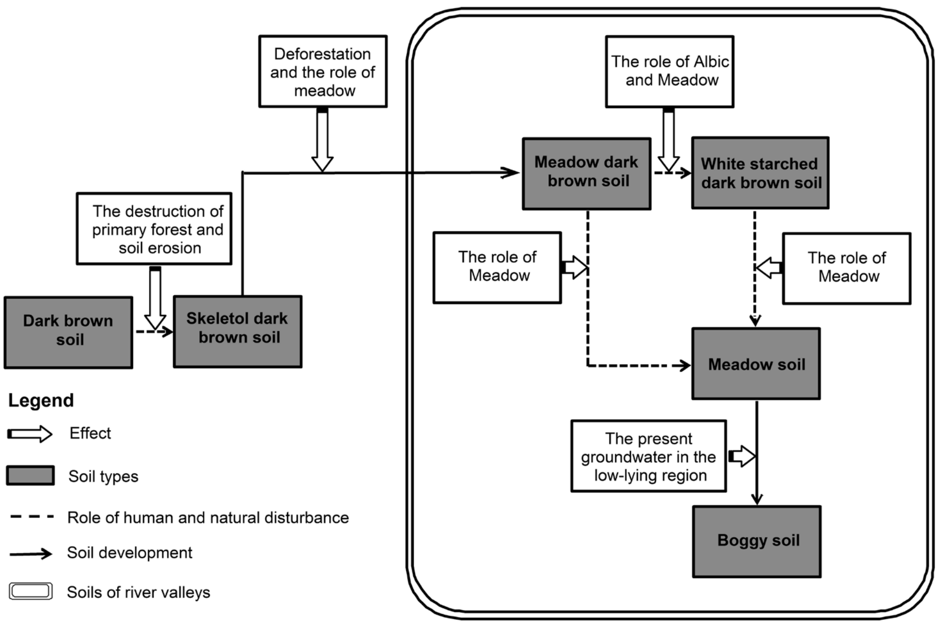

Figure 1. Soil development from dark brown soil to boggy soil in the Changbai Mountains area (Research Institute of Forestry 1986)

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Table 1. Basic characteristics of the study sites

Site	Elevation (m a.s.l.)	Soil types	Parent material	Vegetation compositions
Peony peak, DunHua, Jilin	720	dark brown soil	original heavy gravelly sandy loam	*Carpinus cordata*, oak, Korean pine
Peony peak, DunHua, Jilin	720	skeletol dark brown soil	residual heavy gravel gravel soil	*Lespedeza*, Mongolian oak
Basaltic lava tableland in the north slope of Changbai Mountain in FuSong, Jilin	890	meadow dark brown soil	quaternary fluviolacustrine sedimentary heavy clay	*Acer pseudosieboldianum*, linden, Mongolian oak, Korean pine
Basaltic lava tableland in the north slope of Changbai Mountain in Fu Song, Jilin	780	white starched dark brown soil	with quaternary lacustrine alluvial gravel facies sedimentary clay	shrub meadow: the burns of Osmundaceae *Sorbaria sorbifolia*, *Ulmus propinqua*, *Fraxinus mandshurica*, Korean pine forest
Basaltic lava tableland in the north slope of Changbai Mountain in Fu Song, Jilin	760	meadow soil	impact of pebble light loam	Alpine meadows

Source: Research Institute of Forestry (1986)

www.ussl.ars.usda.gov/) and it provides a user-friendly graphical interface that allows access to the PTFs. Using the Rosetta program, the relevant parameters (i.e., θ_s, θ_r, α, n, K_s, K_o, and L) in the van Genuchten soil water characteristic curve model can be obtained by inputting the particle size percentage and bulk density (Schaap et al. 2001; Li et al. 2016). The parameters comprising θ_s and θ_r are the residual and saturated water contents (in cm^3/cm^3), respectively, α (> 0, in cm^{-1}) is related to the inverse of the air entry suction, and n (> 1, in cm^{-1}) is a measure of the pore size distribution (van Genuchten 1980). The parameter K_s is the saturated hydraulic conductivity (cm/day), K_o is a fitted matching point at saturation (cm/day), and L is an empirical parameter that is normally assumed to be 0.5 (Mualem 1976). The water content at field capacity (F_c, cm^3/cm^3) and wilting point (W_p, cm^3/cm^3) were calculated according to the formula for the van Genuchten soil water characteristic curve. The difference between F_c and W_p is generally considered to be the capacity of available water in a certain layer of soil, i.e., the maximum available water content (AWC, cm^3/cm^3).

$$\text{AWC} = F_c - W_p \qquad (1)$$

The soil organic carbon storage (SOCS, t/hm^2) was calculated for each main soil group/subgroup using Equation (2) (Davidson & Janssens 2006), and the organic carbon content (C, % weight) was calculated for each main soil group/subgroup with Equation (3) (Hornsby 1992):

$$\text{SOCS} = \text{C} \times \text{BD} \times \text{T} \times (1 - \text{CF}) \qquad (2)$$

$$\text{C} = \text{OM}/1.732 \qquad (3)$$

where:

C – the organic carbon (% weight),

BD – the bulk density (g/cm^3),

T – the soil layer thickness (cm),

CF – the percentage of coarse fragments (% weight),

OM – the organic matter content of soil (% weight).

SOCS was then calculated for the 0–20, 20–40, 40–60, 60–80, 80–100 cm layers using the data obtained.

Statistical analysis. The relationships between the AWC and SOCS were analysed with Minitab software (Ver. 16, 2010). Graphs were drawn using SigmaPlot software (Ver. 10, 2002, Systat Software Inc.).

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Table 2. Percentages of silt, clay, and organic matter in five soil profile depths, as well as the bulk density and total organic carbon contents for the six main soil groups/subgroups

Soil great soil groups/ subgroups	Depth (cm)	Silt	Clay	Organic matter	Bulk density (g/cm^3)	Total organic carbon (%)
			(%)			
Dark brown soil	0–20	58.87	21.92	11.39	1.10	6.60
	20–40	42.84	27.33	1.65	1.10	0.95
	40–60	42.20	26.46	0.96	1.40	0.56
	60–80	38.62	24.59	0.58	1.40	0.34
	80–100	30.56	18.69			
Skeletol dark brown soil	0–20	40.41	36.36	7.38	1.10	4.26
	20–40	36.37	29.69	1.45	1.28	0.84
	40–60	37.73	25.93	1.17	1.40	0.68
	60–80	8.43	17.09	0.68	1.40	0.39
	80–100	8.43	17.09	0.68	1.40	0.39
Meadow dark brown soil	0–20	55.37	32.12	8.42	1.00	4.89
	20–40	45.75	40.79	0.96	1.38	0.56
	40–60	32.51	61.63	0.72	1.50	0.41
	60–80	26.65	68.17	0.48	1.50	0.28
	80–100	23.64	73.08	0.49	1.50	0.56
White starched dark brown soil	0–20	25.38	9.61	31.98	1.00	18.55
	20–40	31.93	31.51	10.47	1.45	5.54
	40–60	40.46	31.60	2.62	1.50	1.46
	60–80	45.41	35.39	1.18	1.50	0.68
	80–100	38.25	54.25	5.08	1.50	2.95
Meadow soil	0–20	44.07	14.06	10.06	1.21	5.83
	20–40	55.15	14.31	3.71	1.35	2.15
	40–60	44.50	24.38	2.09	1.32	1.21
	60–80	39.94	28.70	1.39	1.30	0.81
	80–100	39.94	28.70	1.17	1.30	0.68
Boggy soil	0–20	28.00	22.00	7.63	0.60	4.43
	20–40	28.90	20.20	1.38	1.25	0.80
	40–60	30.40	18.95	0.78	1.40	0.45
	60–80	33.00	17.00	0.78	1.40	0.45
	80–100	33.00	17.00	0.78	1.40	0.45

RESULTS

Distribution of AWC profiles in different soil types. As shown in Figure 2, the AWC in the 0–100 cm profile differed significantly among soils that developed from DBS to BS in the Changbai Mountains area ($P < 0.05$). On average, the order of decrease in the AWC followed the order of: DBS (17.37×10^{-2} cm^3 per cm^3) > MS (17.33×10^{-2} cm^3/cm^3) > BS (15.69×10^{-2} cm^3/cm^3) > MDBS (15.58×10^{-2} cm^3/cm^3) > WSDBS (14.85×10^{-2} cm^3/cm^3) > SDBS (13.97×10^{-2} cm^3/cm^3). After comparing the AWC in the depths of 0–20 cm, 0–50 cm, and 0–100 cm for each main soil group/subgroup, we found that the maximum AWC values occurred in the surface layer (0–20 cm) in the soils that developed from the DBS to MDBS and the minimum values in the lower layer (50–100 cm). In addition, the highest AWC values occurred in the surface layer (0–20 cm) in the DBS, SDBS, MDBS, WSDBS, and BS profiles, and the minimum values in the middle and lower layers. However, the highest AWC value occurred in the middle layer in the MS profile and the lowest values in the soil surface and lower layer. Thus, there were significant differences in the vertical

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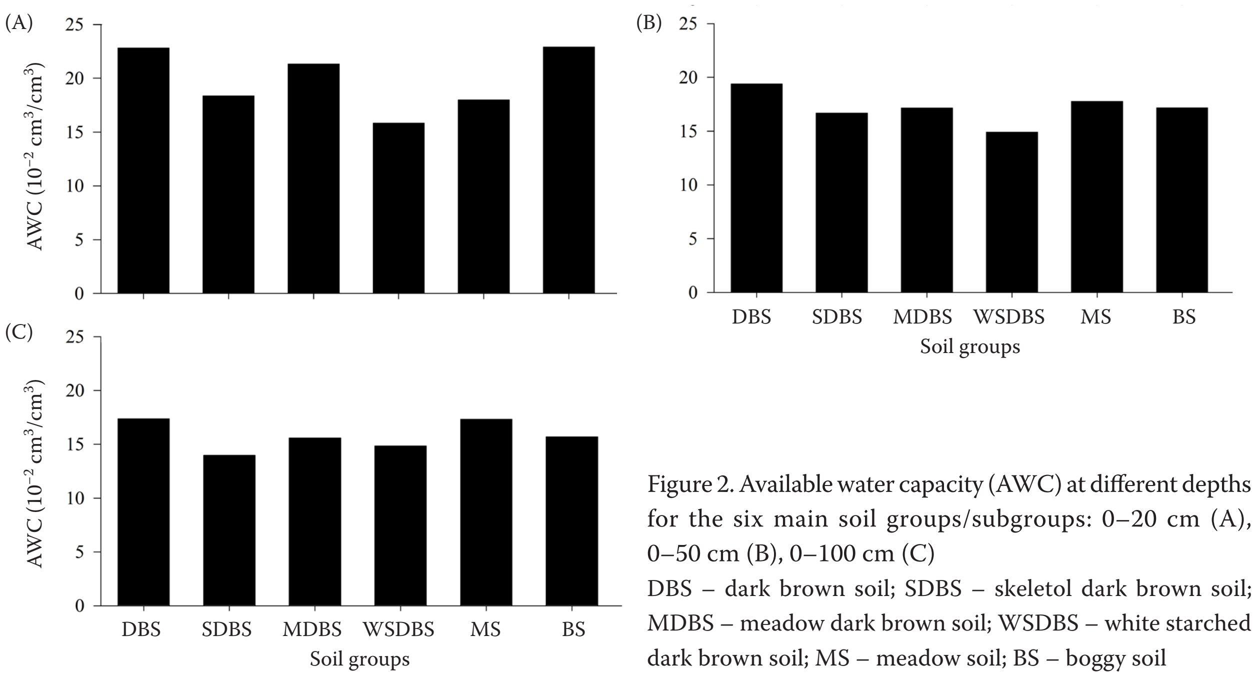

Figure 2. Available water capacity (AWC) at different depths for the six main soil groups/subgroups: 0–20 cm (A), 0–50 cm (B), 0–100 cm (C)
DBS – dark brown soil; SDBS – skeletol dark brown soil; MDBS – meadow dark brown soil; WSDBS – white starched dark brown soil; MS – meadow soil; BS – boggy soil

distribution of the AWC with high values in the upper layer for DBS, SDBS, MDBS, and BS, but almost even distributions in WSDBS and MS (Figure 3).

In general, the difference between the surface layer and other layers was significant in the soils that developed from DBS to BS. The differences in the

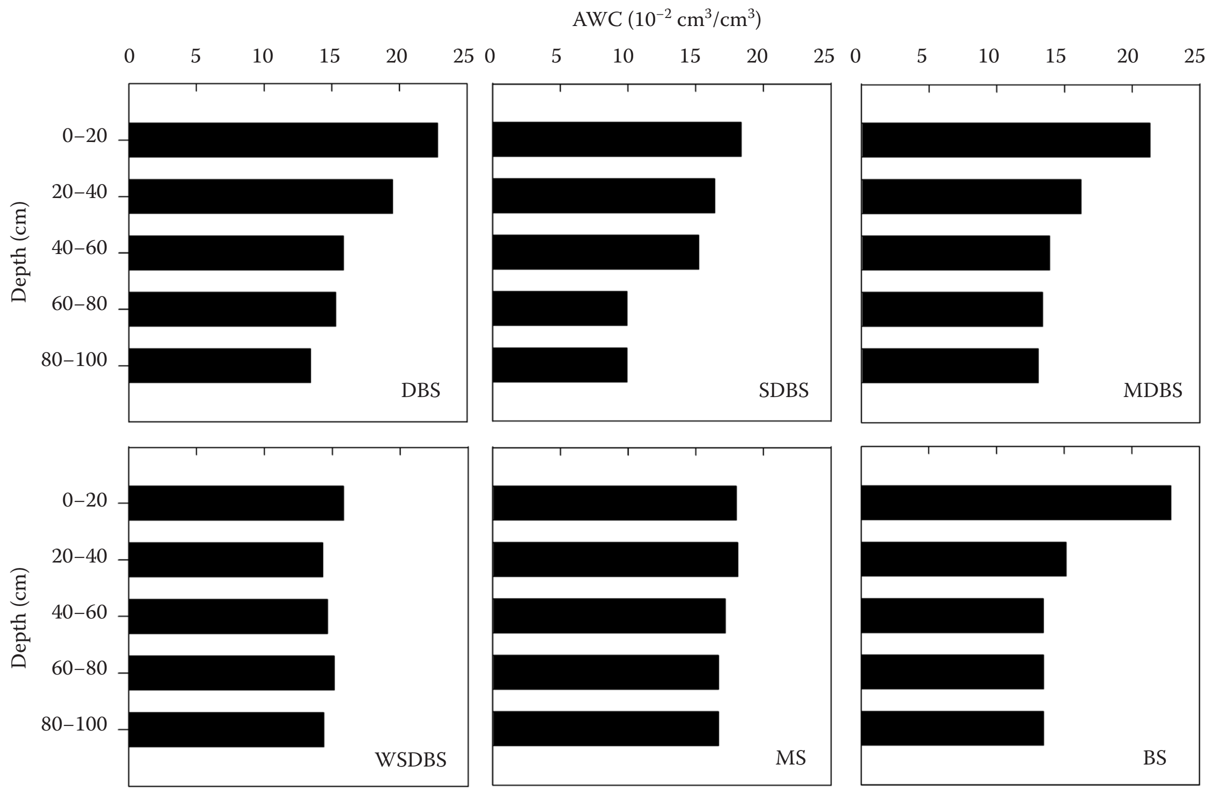

Figure 3. Vertical distributions of available water capacity (AWC) in the soil profiles for the main soil groups/subgroups
DBS – dark brown soil; SDBS – skeletol dark brown soil; MDBS – meadow dark brown soil; WSDBS – white starched dark brown soil; MS – meadow soil; BS – boggy soil

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AWC among the main soil groups/subgroups were presented in the whole profile (Figure 2), but they also differed significantly in the profile distribution and even among the individual layers.

Distribution of SOCS profiles in different soil types. The SOCS profiles in the main soil groups/subgroups are shown in Figure 4. Clearly, the SOCS decreased initially and then increased before decreasing again in the soil development process from DBS to BS. In the 0–100 cm soil profile, the SOCS in the main soil groups/subgroups decreased in the order of WSDBS (807.77 t/hm^2) > DBS (391.14 t/hm^2) > SDBS (350.90 t/hm^2) > MS (309.90 t/hm^2) > MDBS (248.88 t/hm^2) > BS (213.58 t/hm^2) (Figure 4A). The maximum SOCS occurred in the WSDBS. The SOCS contents in DBS, SDBS, MDBS, MS, and BS ranged from 53.11 to 145.34 t/hm^2 in the top 20 cm of the soil profile, but the SOCS content reached 370.97 t/hm^2 in WSDBS (Figure 4B).

The vertical distributions of SOCS were similar in the soil types, where at least 60% of the SOCS occurred in the 0–50 cm depth (Figure 4C). The organic carbon storage tended to decrease from the soil surface to the 100 cm depth in the soils, and the difference between the contents in the surface layer and other layers was significant (Figure 5). Over 80% of the SOCS occurred in the 0–50 cm depth in the MS. The SOCS contents in the 0–20, 20–50 and 50–100 cm soil profiles were higher in WSDBS than the other main soil groups/subgroups. In the soil profiles, the SOCS contents in the soil surface layer ranged from 51.82 to 370.97 t/hm^2, and they accounted for 24.26% and 45.92% of the SOCS in the 100 cm depth (Figures 4B, C). In addition, the SOCS contents in the middle layer (20–50 cm) ranged from 65.45 to 172.69 t/hm^2, and they accounted for 21.38% to 37.50% of that in 100 cm depth. The SOCS contents in the low layer (50–100 cm) ranged from 48.49 to 264.12 t/hm^2, and they accounted for 15.65% to 45.09% of that in the 100 cm depth (Figures 4B, C).

AWC and its relationship with SOCS. As expected, the analysis of the binomial model showed that there was a correlation between the SOCS and AWC as expected (Figure 6; r^2 = 0.4797). SOCS decreased as

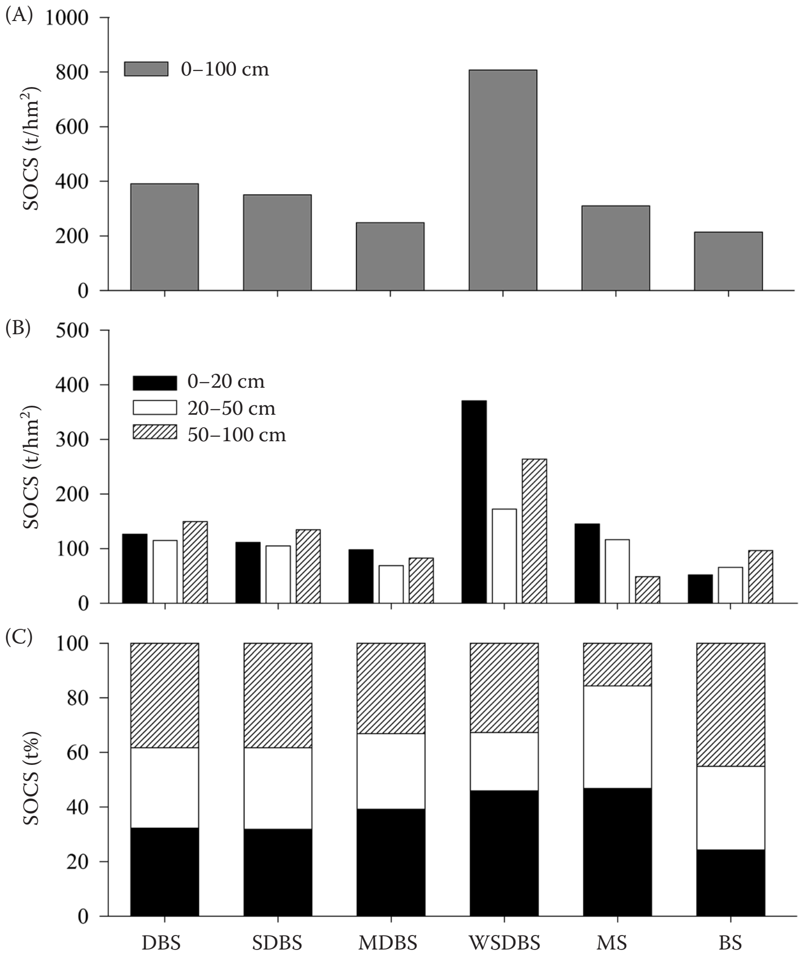

Figure 4. Soil organic carbon storage (SOCS) in the profile depth of 100 cm (A), 0–20, 20–50, and 50–100 cm (B), and percentages of SOCS in the 0–20, 20–50, and 50–100 cm profile depths relative to the 0–100 cm depth (C) for the six main soil groups/subgroups.

DBS – dark brown soil; SDBS – skeletol dark brown soil; MDBS – meadow dark brown soil; WSDBS – white starched dark brown soil; MS – meadow soil; BS – boggy soil

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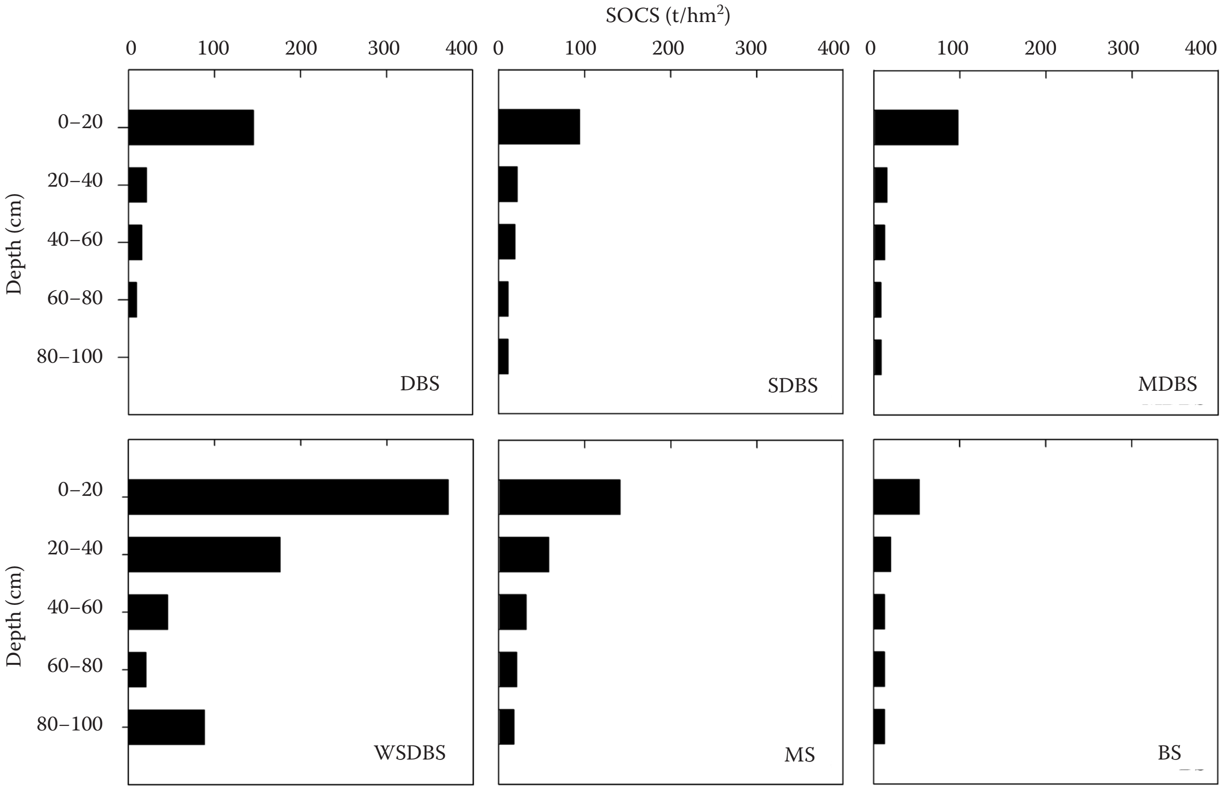

Figure 5. Vertical distributions of soil organic carbon storage (SOCS) in the soil profiles for the main soil groups/subgroups DBS – dark brown soil; SDBS – skeletol dark brown soil; MDBS – meadow dark brown soil; WSDBS – white starched dark brown soil; MS – meadow soil; BS – boggy soil

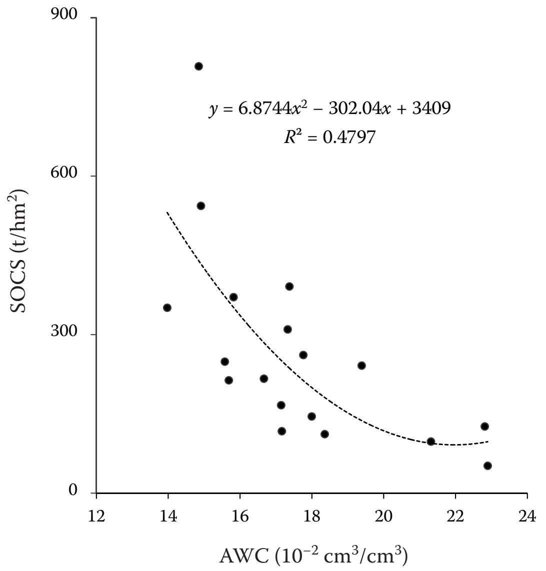

Figure 6. Available water capacity (AWC) and its relationship with soil organic carbon storage (SOCS)

the AWC increased when the AWC value was less than 21.97×10^{-2} cm^3/cm^3, and SOCS increased as AWC increased when the AWC value was more than 21.97×10^{-2} cm^3/cm^3, and thus the threshold for AWC was determined as 21.97×10^{-2} cm^3/cm^3. Thus, the mathematical relationship between the SOCS and AWC at a depth of 100 cm in each soil types formed a concave curve, and the point of inflexion occurred at 21.97×10^{-2} cm^3/cm^3. Thus, statistical analysis showed that the sensitivity of SOCS to any changes in AWC decreased as the AWC value increased (r^2 = 0.4797).

DISCUSSION

Assessment of AWC distribution. During the soil development process from DBS to BS, the AWC decreased initially and then increased, before decreasing again. The maximum AWC value occurred in the DBS (Figure 2). According to previous studies, silt and organic matter are the dominant factors that control the AWC (Salter & Williams 1967; Rivers & Shipp 1972; Hollis et al. 1977; Hudson 1994). In the present study, the characteristics of the vertical distribution of the AWC in the 0–100 cm profile during the soil development process from DBS to BS agreed

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with these previous findings, where the AWC fluctuated greatly in the soil layers other than the 0–20 cm layer (Figure 2). The sampling plots considered in this study represented typical profiles where the primary forest had been replaced by secondary forest after massive deforestations during the construction of the Middle East railway in 1882 and the founding of China (Research Institute of Forestry 1986), where the forest soil was fully exposed to rain and erosion by wind. Frye et al. (1982) reported that the available water-holding capacity of an eroded Maury soil was 4% to 6% lower in the upper 15 cm layer on a volume basis compared with the non-eroded counterpart soil, which they attributed to the higher clay content and lower organic matter content of the eroded soil. Zhou et al. (2005) estimated that the AWC in the soil layer depth of 0–100 cm in a full soil profile in the Changbai Mountains ranged from 17.2% to 21.2%. Our results showed that the AWC in the soil depth profile from 0–100 cm ranged from 13.97% to 17.37% in the Changbai Mountains area. The different results obtained in these two studies may be attributed to variations in the sampling sites selected. The differences between these results also suggest that further direct measurements are desirable in order to make site-specific decisions for soil and water management (Atherton et al. 1999; Jiang et al. 2007).

Assessment of SOCS distribution. The variations in SOCS are mainly determined by the biological activities of vegetation, which are concentrated in the upper layer (Figure 5, Charley & West 1977; Schlesinger & Adrienne 1998). In the present study, the characteristics of the vertical distribution of the SOCS in the 0–100 cm profile agreed with previous findings, where SOCS was always higher in the upper layers (Figure 5). Most previous studies focused on the variations in SOCS in the 0–100 cm profile under different vegetation cover types, whereas few have considered the variations in SOCS during the soil development process under the influence of human disturbances, which we addressed in the present study. Our results indicated that SOCS decreased in the upper layer during the early stages of human disturbances (from DBS to SDBS), before increasing slightly in the upper layer under grass meadow and the destruction of woodland (from SDBS to MDBS), and there were then substantial increases in SOCS in the upper layer with further increases in grass meadow and albic soil (from MDBS to WSDBS). Subsequently, SOCS decreased in the upper layer decreased with the further establishment of grass meadow (from WSDBS to MS). Finally, SOCS decreased in the upper layer in low lying areas (from MS to and BS) (Figures 1, 5). Hassink et al. (1997) explained that the depletion of soil organic carbon is due to the lower protective capacity of coarser textured soils and their greater susceptibility to erosion.

Relationship between AWC and SOCS. The correlation between SOCS and AWC is shown in Figure 6. When AWC was low (AWC less than 21.97×10^{-2} cm^3/cm^3), an increase in AWC led to a decrease in SOC. By contrast, when AWC was high (AWC greater than 21.97×10^{-2} cm^3/cm^3), an increase in AWC resulted in an increase in SOCS. However, this correlation was not very strong ($r^2 = 0.4797$), whereas other studies found a significant relationship between AWC and SOCS (da Silva & Kay 1997; Olness & Archer 2005). These inconsistent results may be explained by differences in the effects of organic matter or clay contents (Petersen et al. 1968; Rawls et al. 2003). It is well known that clayey soils have higher humus contents than sandy soils. The presence of humus in the soil will increase the soil water storage capacity (Morris 2004; O'Geen 2013). In addition, the fraction of macropores will be increased due to the impact of the soil humus content on the soil structure. Consequently, these competing effects might lead to no significant changes in SOCS with variations in AWC as found in the present study. Additionally, studies have shown that the high organic matter content obtained from decomposed leaves can increase the amount of small pores but reduce the abundance of large pores, and thus increase the AWC (Wall & Heiskanen 2003; Haghighi et al. 2010).

CONCLUSION

Our results indicate that human disturbance led to significant changes in the key soil properties comprising SOCS and AWC. Among the six main soil groups/subgroups, MDBS had the greatest AWC value (17.37×10^{-2} cm^3/cm^3). SOCS was lower in BS (213.58 t/hm^2) compared with the other five main soil groups/subgroups. These findings indicate that the decrease in SOCS caused by deforestation and concomitant soil erosion as well as the negative impact of this decrease on SOCS in the Changbai Mountains area were not caused completely by the reductions in AWC. In addition, during the soil development process from DBS to BS in response to deforestation, the AWC levels differed in the profile distribution and even among the individual layers, whereas SOCS was focused in the upper layer. The mathematical relationship between the SOCS and AWC at a depth down to 100 cm in the six main soil groups/subgroups was represented as a concave curve, and the point of inflexion occurred at 21.97×10^{-2} cm^3/cm^3.

https://doi.org/10.17221/150/2019-SWR

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Received: December 5, 2019
Accepted: May 11, 2020
Published online: May 26, 2020