Particle densities of wetland soils in northern Alberta, Canada

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Redding, T. E. and Devito, K. J. 2006. **Particle densities of wetland soils in northern Alberta, Canada.** Can. J. Soil Sci. **86**: 57–60. Particle density is a fundamental soil physical property, yet values of soil and organic matter particle density (ρ_s and ρ_o) vary widely in the literature. We measured particle density of organic soils from five wetland types, and from exposed sediments of drying ponds, in northern Alberta, Canada. Our measured values of organic soil and pond sediment ρ_s varied widely (1.43–2.39 Mg m^{-3}); however, calculated values of ρ_o (1.34–1.52 Mg m^{-3}) were relatively constant. The measured and calculated ρ_s and ρ_o values were similar to those obtained in published studies using similar methods, but were higher than the values provided in many reference texts. Given the relatively small variability in ρ_o, the use of mean values of ρ_o, combined with measurements of organic matter loss-on-ignition, shows promise as a simple method for obtaining reliable estimates of ρ_s across a range of wetland types.

Key words: Particle density, peat, organic matter, wetland soil, loss-on-ignition

Redding, T. E. et Devito, K. J. 2006. **Masse volumique des particules dans les sols humides du nord de l'Alberta (Canada)**. Can. J. Soil Sci. **86**: 57–60. La masse volumique des particules est une propriété physique fondamentale des sols. Pourtant, les valeurs de la masse volumique du sol et des particules de matière organique (ρ_s et ρ_o) varient considérablement dans la documentation. Les auteurs ont mesuré la masse volumique des particules dans le sol organique de cinq types de terres humides ainsi que dans les sédiments dénudés d'étangs asséchés du nord de l'Alberta, au Canada. La ρ_s mesurée dans les sols organiques et les sédiments des étangs varie considérablement (de 1,43 à 2,39 Mg par m^3), mais la ρ_o calculée demeure assez stable (de 1,34 à 1,52 Mg par m^3). Les valeurs mesurées et calculées des deux masses volumiques ressemblent à celles qu'on retrouve dans les études recourant à des méthodes similaires, mais elles dépassent les valeurs publiées dans maints ouvrages de référence. Étant donné la variabilité relativement réduite de la ρ_o, l'utilisation d'une valeur moyenne pour cette dernière et la quantification de la matière organique perdue par calcination pourraient donner une méthode simple permettant d'estimer de manière fiable la ρ_s des terres humides de nature variée.

Mots clés: Masse volumique des particules, tourbe, matière organique, sol des terres humides, perte par calcination

The physical properties (e.g., bulk density, particle density, porosity, organic carbon content) of surface soils exert a strong influence on the exchanges of energy and water between the atmosphere and deeper soils (Baldocchi et al. 2000). Data on particle density (ρ_s), the mass of solids per unit volume of solids (Brady and Weil 1999), is of particular importance in hydrological studies because ρ_s is required for the calculation of porosity and heat capacity. Specific applications of particle density data include the measurement and modelling of soil thermal conductivity and heat capacity (de Vries 1963), quantification of shrink-swell behaviour of wetland soils (Price 2003), and calculation of surface saturation and hydrological connectivity from remotely sensed soil moisture data (Wolniewicz 2002).

Values of wetland soil ρ_s reported in the literature range from 0.84 to 1.67 Mg m^{-3} (Table 1). The ρ_s of wetland soils is a function of the relative proportions of organic (ρ_o, organic matter particle density) and mineral materials (ρ_m, mineral particle density) present in the soil. While ρ_m is generally assumed to be 2.65 Mg m^{-3} (Brady and Weil 1999; Skopp 2002), values of ρ_o reported in the literature range between 0.9 and 1.55 Mg m^{-3} (Table 1). Values of ρ_s for wetland soils are not provided in common wetlands reference texts (e.g., Mitsch and Gosselink 2000) or hydrology reference texts (e.g., Dingman 2002), while soils reference texts tend to concentrate on mineral soils from an agricultural perspective (e.g., Brady and Weil 1999; Skopp 2002). The primary literature contains measurements of ρ_s and ρ_o made with pycnometers that are fairly consistent between wetland types and geographical locations (Table 1), but are at odds with the values presented in common reference texts (Brady and Weil 1999; Skopp 2002; Lide 2002). Given the wide range of ρ_o and wetland ρ_s values reported in the literature, it is difficult to know which values to employ for the variety of wetland types encountered on the Boreal Plain of northern Alberta, Canada.

The objectives of this research were to determine the ρ_s and ρ_o values of a range of wetland types. We hypothesized that ρ_s and ρ_o would vary with wetland type, von Post index and loss-on-ignition. Particle density, bulk density, loss-on-igni-

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Abbreviations: **LOI**, loss on ignition; $\boldsymbol{\rho_o}$, organic matter particle densisty; $\boldsymbol{\rho_s}$, soil particle density tion and von Post decomposition index were measured for five wetland types and from exposed sediments of drying ponds on the Boreal Plain of northern Alberta at the Utikuma Research Study Area (URSA).

The URSA is located in the Utikuma Lake area (Lat: 56°N, Long: 115°30′W) of north-central Alberta. The site lies in the Boreal Plains Ecozone (EcoRegions Working Group 1989) and has mean annual precipitation and potential evapotranspiration values of 481 and 518 mm, respectively (Agriculture and Agri-Food Canada 1997). Wetlands at URSA are developed on outwash, glacial till and lacustrine deposits, with a total elevation range from ca. 640 to 680 m asl across the 50-km-wide study area.

Samples of wetland surface soils were collected from bogs, floating sedge mats, treed fens, open fens and swamps (National Wetlands Working Group 1988). In addition, samples were collected from exposed sediments at the edges of drying ponds. For each wetland type, three replicate wetlands were sampled, with two sampling locations in microtopographic hollows per replicate. Samples were collected using a metal core sampler (10 cm high, 10 cm diameter) at depths of 0–10 and 10–20 cm at each location. An additional 0–10 cm sample was collected from the top of hummocks in bog sites. At the edge of drying ponds, exposed sediment (gyttja) was sampled in the zone between the pond water surface and the boundary of colonizing vegetation. Samples of pond sediment were separated into those from ponds surrounded by riparian peatlands (n = 2) and those without a riparian peatland fringe (n = 1).

All samples were dried at 70°C for 48 h to determine dry mass for the calculation of bulk density (ρ_b, Mg m^{-3}). Subsamples of oven-dried material were ground to pass a 2-mm sieve prior to analysis for particle density and organic matter loss-on-ignition. Organic matter loss-on-ignition (LOI, g kg^{-1}) was measured using the combustion method by heating at 375°C for 1 h followed by 6 h at 500°C (Ball 1964). Particle density (ρ_s, Mg m^{-3}) was measured using the liquid pycnometer method with 95% ethanol as the displacing liquid (Blake and Hartge 1986). In this study, ρ_s is a measure of the whole sample (organic and mineral fractions).

By combining the ρ_s and LOI measurements, the density of the organic fraction (ρ_o, Mg m^{-3}) can be estimated following Parent and Caron (1993):

$$\rho_o = \frac{(LOI \cdot \rho_s)}{100 - \rho_s \cdot \dfrac{(100 - LOI)}{\rho_m}} \quad (1)$$

Where LOI is expressed as percentage mass loss (%), and ρ_m is the particle density of the mineral fraction, assumed to be 2.65 Mg m^{-3} (Brady and Weil 1999; Skopp 2000). Porosity (Φ) is calculated from ρ_b and ρ_s values:

$$\Phi = 1 - \left(\frac{\rho_b}{\rho_s}\right) \quad (2)$$

Wetland ρ_b, ρ_s, Φ, LOI and ρ_o were analyzed using the Kruskal-Wallis non-parametric analysis of variance (ANOVA) to determine the effects of wetland type (bog, floating sedge mat, treed fen, open fen and swamp) for each depth, and between depths within each wetland type using SYSTAT (version 11.0, SYSTAT Software Inc. 2004, Chicago, IL.). This method was selected because of the small samples size, which prevented testing for normality at the individual wetland (site) level. The analysis did not include the two categories of pond sediment, due to insufficient replication.

The physical properties of the soils examined in this study were expected to vary widely because they were collected from a range of wetland types (Table 2). However, there were no statistically significant differences ($P < 0.05$) in soil physical properties between wetland types for any property at a given depth, or between depths (0–10 and 10–20 cm) for a given wetland type. Measured ρ_s values ranged from 1.43 Mg m^{-3} in the floating sedge mat to a maximum of 1.58 Mg m^{-3} in the swamp. Particle density generally increased with increasing von Post decomposition class, but was inversely related to LOI, indicating that the relative proportions of mineral and organic matter content drive the soil ρ_s, as indicated in Eq. 1. LOI also tends to decrease with increasing decomposition as measured on the von Post scale (Table 2).

Although too few pond sediments were sampled for statistical analysis, there appear to be important differences between those with and without a riparian peatland fringe (Table 2). Bulk density, ρ_s, and ρ_o were greater, while Φ and LOI were lower in the pond sediments collected from a pond without a riparian peatland. This is related to differences in the organic matter content of the sediments with and without riparian peatlands (Fig. 1). We know of no other measured ρ_s values of pond sediments with which to compare our results.

There were no significant changes in ρ_s with depth from 0–10 to 10–20 cm for any of the wetland types, which is consistent with the findings of Silins and Rothwell (1998) who measured the ρ_s of drained and undrained fen peat, from the soil surface to a depth of 50 cm in central Alberta. The lack of differences in ρ_s with depth suggests that neither significant differences in the nature of the chemical composition of the soil nor substantial mixing of organic and mineral materials had occurred within the depth sampled.

The value of ρ_m is important for the estimation of ρ_o, and may vary between sediment types. Measurements of upland mineral soil ρ_s and ρ_m at URSA resulted in mean values of ρ_m were 2.65 Mg m^{-3} for sandy soils and 2.62 Mg m^{-3} for fine-textured soils (Redding and Devito, unpublished data). In addition, Redding et al. (2005) measured a ρ_s of 2.65 Mg m^{-3} for clean quartz sand. Based on these data, it is reasonable to use a ρ_m value of 2.65 Mg m^{-3} for the mineral material for the Boreal Plain when applying Eq. 1 to estimate ρ_o.

The values of ρ_s from organic matter dominated wetland soils in this study (1.43–1.58 Mg m^{-3}, Table 2) are within the range of values reported in the literature where the pycnometer method was employed (1.35–1.67 Mg m^{-3}, Table 1). However, they are much greater than those reported in reference sources that failed to describe the methods used to obtain their values of ρ_s (Brady and Weil 1999; Lide 2002; Skopp 2002). If these values were used, porosity could be underestimated by of 5% or more.

Table 1. Published particle density values for organic matter (ρ_o) and wetland soils (ρ_s). Descriptions of material types are taken from the original sources

Material type	ρ_o (Mg m^{-3})	ρ_s (Mg m^{-3})	Method	Source
Organic Matter	1.3		Not given	deVries (1963)
	1.55		Not given	Verdonck et al. (1978)
	<1.5		Not given	Blake and Hartge (1986)
	0.9–1.3		Not given	Brady and Weil (1999)
	1.0		Not given	Skopp (2002)
	1.51–1.52		Estimated[z]	Heiskanen (1992)
	1.41–1.43		Estimated[y]	Redding et al. (2005)
Histosols		1.1–2.0	Not given	Brady and Weil (1999)
Peat blocks		0.84	Not given	Lide (2002)
Sphagnum peat		1.4	Measured, Pycnometer (Alcohol)	Paivanen (1973)
Sedge peat		1.35		
Woody peat		1.39		
Horticultural Peat		1.59	Measured, Pycnometer (Water)	Heiskanen (1992)
Fen peat		1.5	Measured, Pycnometer (Ethanol)	Silins and Rothwell (1998)
Moorsh peat		1.62	Measured, Pycnometer	Oleszczuk et al. (2000)
Moss peat		1.62		
Sedge peat		1.63		
Alder peat		1.64–1.67		
Bog peat		1.45	Measured, Pycnometer	Price (2003)

[z]Estimated from measured ρ_s and LOI values of peat, assuming ρ_m of 2.65 Mg m^{-3}
[y]Estimated from measured ρ_s and LOI values of forest floor organic horizons, assuming ρ_m of 2.65 Mg m^{-3}

Table 2. Summary statistics for measured wetland soil physical properties. Values are mean and standard deviation [in parentheses (n = 3 sites)] for all wetland types, except for the pond sediments with (n = 2 sites) and without (n = 1 site) riparian peat, for bulk density (ρ_b), particle density (ρ_s), porosity (Φ), organic matter loss-on-ignition (LOI) and organic matter particle density (ρ_o)

	Depth (cm)	Bog (hummock)	Bog (hollow)	Floating sedge mat	Treed fen	Open fen	Swamp	Pond sediments (riparian peat)	Pond sediments (no riparian peat)
Von Post	0–10	2	2	3	3	6	5	–	–
	10–20	–	3	3	3	6	7	–	–
ρ_b (Mg m^{-3})	0–10	0.02 (0.01)	0.05 (0.01)	0.04 (0.02)	0.05 (0.03)	0.09 (0.06)	0.11 (0.03)	0.12 (0.02)	0.43 (0.01)
	10–20	–	0.07 (0.02)	0.06 (0.02)	0.08 (0.02)	0.09 (0.05)	0.15 (0.04)	0.17 (0.05)	0.54 (0.04)
ρ_s (Mg m^{-3})	0–10	1.44 (0.03)	1.50 (0.05)	1.44 (0.02)	1.51 (0.07)	1.57 (0.16)	1.57 (0.05)	1.51 (0.06)	2.32 (0.01)
	10–20	–	1.53 (0.03)	1.43 (0.03)	1.56 (0.02)	1.54 (0.05)	1.58 (0.10)	1.50 (0.06)	2.39 (0.05)
Φ	0–10	0.98 (0.003)	0.97 (0.01)	0.97 (0.01)	0.96 (0.02)	0.95 (0.03)	0.93 (0.02)	0.92 (0.01)	0.81 (0.002)
	10–20	–	0.96 (0.01)	0.96 (0.01)	0.95 (0.01)	0.94 (0.03)	0.91 (0.02)	0.89 (0.03)	0.78 (0.01)
LOI (g kg^{-1})	0–10	973.8 (20.8)	959.7 (20.5)	940.4 (15.4)	874.9 (94.7)	831.5 (121.8)	886.3 (39.4)	773.9 (100.1)	183.1 (0.2)
	10–20	–	955.0 (24.5)	951.9 (8.8)	889.2 (40.3)	890.0 (64.6)	856.1 (61.2)	798.6 (73.7)	143.0 (21.4)
ρ_o (Mg m^{-3})	0–10	1.43 (0.03)	1.47 (0.06)	1.40 (0.01)	1.42 (0.02)	1.44 (0.04)	1.49 (0.03)	1.34 (0.03)	1.48 (0.01)
	10-20	–	1.50 (0.03)	1.40 (0.03)	1.48 (0.02)	1.46 (0.05)	1.48 (0.05)	1.35 (0.01)	1.52 (0.05)

The values of ρ_o estimated in this study (1.40–1.52 Mg m^{-3}) are also higher than most values of organic matter reported in the literature (0.9–1.3 Mg m^{-3}, Table 1), except for those of Heiskanen (1992) and Redding et al. (2005) who used the pycnometer method to measure the ρ_o of horticultural peat (1.51–1.52 Mg m^{-3}) and organic forest floor materials (1.41–1.43 Mg m^{-3}), respectively (Table 1).

The results of this study show that ρ_s is strongly related to LOI across the range of wetland types. However, ρ_o does not vary widely across the range of wetland types on the western Boreal Plain. This is surprising given the differences in organic matter source, content and degree of decomposition of the soils from the different wetland types. The measured values of ρ_s and ρ_o are similar to literature sources where ρ_s and ρ_o were measured using pycnometers, but greater than those provided in reference texts, which did not provide methods. In the future, we suggest that organic soil ρ_s should either be measured using pycnometers or estimated after determination of LOI, using the appropriate ρ_o value for the wetland type of interest (Table 2). We recommend that the results of this study be used for sites on the Boreal Plain, to improve the measurement and modelling of wetland hydrological and biogeochemical processes (e.g., Wolniewicz 2002). Further measurements of ρ_s and ρ_o should be made across a wider range of organic soil types and organic matter contents to reduce our reliance on un-referenced values provided in common textbooks and reference materials.

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