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METHODS OF DETERMINING A NATURAL BULK DENSITY OF SOIL I. SUGGESTIONS REFERED TO HOMOGENEOUS SOILS

METODY OZNACZANIA GĘSTOŚCI NATURALNEJ GLEB. KONCEPCJE POWIĄZANE Z GLEBAMI HOMOGENICZNYMI

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ABSTRACT: The natural bulk density is a parameter associated with the character of the soil. In the arable layer of soil formed from boulder loams, during the vegetation period the natural bulk density differs from temporary bulk density by values up to + 0,30 Mg m^{-3}. The natural bulk density of two profiles of black earths formed from boulder loams was determined 19 times during the period of 2,5 years, and statistical treatment of the data. Measurements on 162 profiles (depth of 0-240 cm) were used to estimate the natural bulk density of a group of loam soils (generally having 20-40 % of particles < 0,02 mm). For comparative purposes, the natural bulk density of 39 soil profiles formed from other materials were also determined. It was found that the natural bulk density in profiles of loamy soils increased from 1,574 at the surface to 1,847 Mg m^{-3} at the depth of 130 cm. Soils formed from loesses had a natural bulk density about 0,214 Mg m^{-3} lower and soils derived from fluvioglacial sands (in most cases light loamy sands) about 0,144 Mg m^{-3} lower than loam soils of postglacial origin.
KEY WORDS: Temporary bulk density, natural bulk density, soils formed from boulder loams

Introduction

Bulk density of soils, in this paper called the temporary bulk density, changes considerably in every layer at soil profile with time. In surface horizons (depth to 30 cm) of black earths (Września Region of Central Poland) the bulk density varied from 1,30 to 1,84 Mg m^{-3} (Reimann and Cieśla 1965). Soils of the Mall

(Washington, DC) had bulk density ranging from 1,25 to 1,85 Mg m^{-3} (Short et al 1986). In a arable land (Norfolk sandy loam) similar differences in bulk density were obtained for all depths in soil profiles, for example. at 0,2 m depth the bulk densities ranged from 1,41 to 1,73, with mean 1,63, and at 1,0 m depth 1,61 - 1,93 with mean 1,81 Mg m^{-3} (Dane et al, 1986). The bulk density of other soils, for example in arable layers of chernozems of USSR (Ulianowsk District) ranged 0,98 - 1,26 Mg m^{-3} (Podvoiski 1972).

It is not known that values within the range mentioned above, are the most characteristic for the particular discussed groups of soils under investigation. An interpretation of actual conditions and processes in soil profiles, based on such different data may be faulty and useless to form optimal physical properties of soil for plants growth. Undoupted values of soil bulk density must be at our disposal.

The natural bulk density of soil is a parameter connected with the character of soil matter. It is generally independent of climate, cultivation and vegetation and determination of value for the particular layer of soil profile is necessary.

The research work to determine the natural bulk density of different soils, initiated by the author about about 27 years ago, has been conducted by several methods: (1) repeated measurement of temporary bulk density in selected soil profiles during several years, and statistical treatment of the data, (2) measurement of temporary bulk density for samples from many soil profiles having similar physical properties, and a statistical correction of the data, (3) examination of some characteristics of soils, for example, plant available water retention or enzymatic activity in relation to soil bulk density, (4) pot and field experiments with factors such as porosity or bulk density of soil in relation to growth and yield of plants, (5) collection of temporary bulk density of topsoil from areas where plants yields are very high, (6) determining of of the natural bulk density for each soil horizon based on other physical properties of soil, i.e. determinants of soil natural bulk density. This is perhaps the simplest and serviceable method.

Materials and methods

Two methods were used in this study: (1) and (2)

The longer term examination of temporary bulk density of soils was carried out in two black earths located at Inowrocław Plain (Kondracki, 1965). At first, the samples were taken 9 times from 5 horizons (series a_{1-9} - Table 1, b_{1-9}) and then 10 times from 6 horizons (series A_{1-10}, B_{1-10} - Table 1) during the period from March 1974 to July 1976. Average values were situated according to a linear equation for each series of measurement and profile.

Measurement of bulk density for the group of loam soils formed from boulder loams were made for samples from 162 profiles. Most of them (95 black earths and 10 brown soils) were taken in the Inowrocław Plain, and the remaining in Krajna Lakeland (35 profiles), Chełmno Lakeland (8), Kujawy Lakeland (7) and other regions (7) (Figure 1). In total, the samples from loam soils profiles were taken from 862 layers. The mean values of bulk density for each 10 cm thick layer (shown in Table 1) were in addition averaged by a statistical analysis.

TABLE. 1. The mean and natural bulk densities in profiles of loam soils (Mg m^{-3})

Depth in profile /cm/	ρm			Number of samples	ρn	ρa_{1-9}			ρB_{1-10}		
	$\bar{X}m \pm$	CI	CV %		Xc±0.050	$\bar{X}m \pm$	$\bar{X}c$	D %	$\bar{X}m \pm$	$\bar{X}c$	D %
1-10	1.611	0.015	7.7	249	1.585	1.571	1.545	1.7	-	1.520	-
11-20	1.601	0.024	7.5	97	1.606	-	1.570	-	1.563	1.549	0.9
21-30	1.643	0.014	5.9	188	1.627	-	1.595	-	1.579	1.577	0.1
31-40	1.641	0.018	7.1	170	1.648	1.595	1.621	1.6	1.635	1.606	1.8
41-50	1.612	0.024	7.6	102	1.669	1.653	1.646	0.4	-	1.635	-
51-60	1.663	0.025	6.7	80	1.690	-	1.671	-	1.566*	1.678*	6.7
61-70	1.705	0.021	5.4	74	1.711	1.700	1.696	0.2	-	1.692	-
71-80	1.739	0.030	7.3	72	1.732	-	1.721	-	1.734	1.721	0.8
81-90	1.774	0.017	3.6	54	1.753	-	1.747	-	-	1.749	-
91-100	1.791	0.026	4.1	32	1.774	-	1.772	-	-	1.780	-
101-110	1.797	0.023	4.0	38	1.795	1.813	1.797	0.9	1.849	1.807	2.3
111-120	1.808	0.022	3.1	28	1.816	-	1.822	-	-	1.835	-
121-130	1.825	0.015	2.3	32	1.837	-	1.848	-	-	1.864	-
131-140	1.915	0.100	3.4	4	1.847	-	1.860	-	-	1.878	-
141-150	1.831	0.030	4.2	22	1.847	-	1.860	-	-	1.878	-
171-180	1.812	0.020	0.9	6	1.847	-	1.860	-	-	1.878	-
195-205	1.792	0.049	6.1	22	1.847	-	1.860	-	-	1.878	-
215-225	1.830	0.020	2.3	15	1.847	-	1.860	-	-	1.878	-
231-240	1.863	0.050	2.5	6	1.847	-	1.860	-	-	1.878	-
Mean	1.750	0.030	5.5	68	1.754	1.666	1.661**	1.0	1.654	1.656**	2.1

ρm $\bar{X}m$ - mean bulk density; CI - 95% confidence semi-interval; CV - coefficient of variation; ρn - natural bulk density for the group of loam soils; Xc ± 0.050 - mean value of natural bulk density with 95% confidence semi-interval; ρa_{1-9} - mean bulk density in series a_{1-9}, where $\bar{X}m$ - measured value, $\bar{X}c$ - calculated value, D - deviation $/\bar{X}m - \bar{X}c/\bar{X}c/ \times 100$; ρB_{1-10} - mean bulk density in series B_{1-10}, where $\bar{X}m$, $\bar{X}c$ - as mentioned above; * - value for depth of 60 cm; ** - value only for depth where measurement were made.

For comparison with the data from loam soils, the natural bulk density also determined for 39 profiles of soils formed from other materials (Fig. 1), namely alluvial silts on boulder loam (15 profiles), fluvioglacial deposit, in most giving light loamy sands (14), loesses (5), and fluvial and deluvial materials (5).

The samples of soil with natural structure were taken with 100 cm^3 Kopecky's cylinders in four replications, occasionally in three replications.

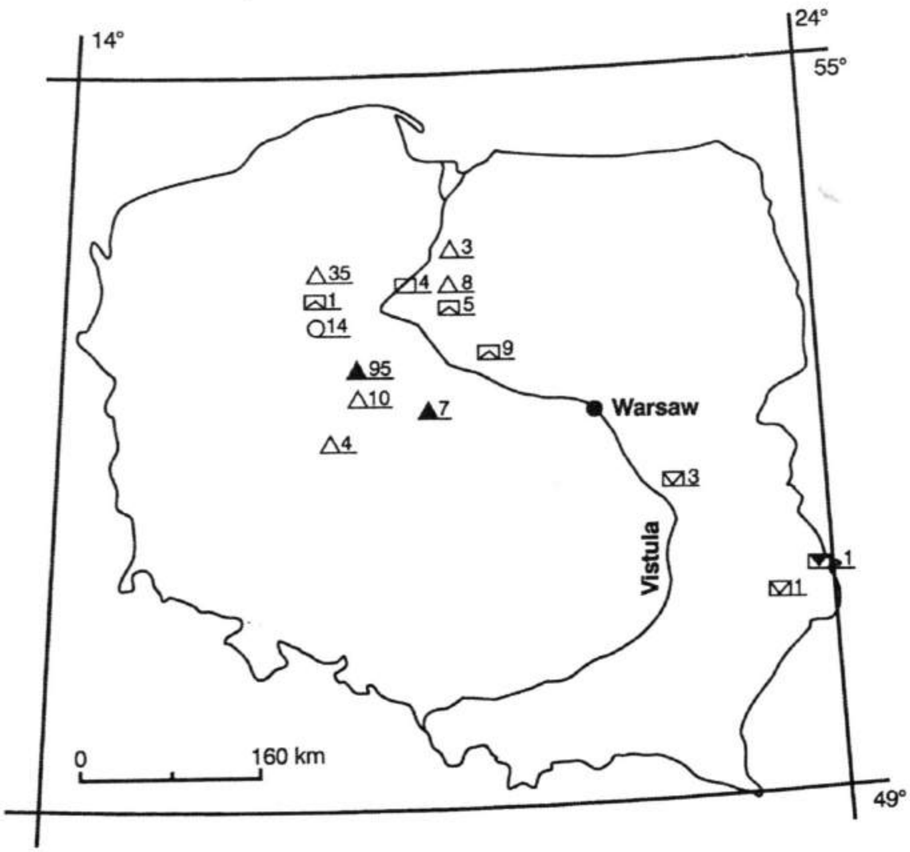

FIG. 1. Location of soil profiles

▲ black earths and △ brown or lessive soils developed from loams

□ different type of soils developed from fluvial silts ⊠ and fluvial silts on boulder loams

⊠ chernozems and ⊠ brown or lessive soils developed from loess

○ different type of soils developed from fluvioglacial sands

95 number of profiles at middle region

Results and discussion

The bulk density was measured over 2,5 yrs at two longer-term sites fluctuated more in upper than in lower horizons. The greatest differences were noted in 21-30 cm layers, where temporary bulk density varied from 1,700 in the middle of July 1975 to 1,328 Mg m^{-3} a week after tillage at 30-cm depth in August 1975; the coefficients of variation reached 9,3%. Bulk density reached a maximum in June and July, when the soil was dry. Tillage at a depth of 30 cm decreased the bulk density in arable layer by 0,072 to 0,372 Mg m^{-3}, however, it was incresed by 0,017 - 0,060 Mg m^{-3} at a depth of 30 - 40 cm. These changes persisted to the middle of the next growing season.

The average values of bulk density in various soil horizons were approximated by linear regression analysis. For example, the linear regression covering 45 results for series a_{1-9} takes the form:

$$r\,n_{a1-9} = 0{,}0252\ z + 1{,}5223; \quad r = 0{,}748, \quad r_{0,001} = 0{,}467$$

where $r\,n_{a1-9}$ - bulk density in different layers of the profile (Mg m^{-3}),

z - depth in soil profile (dm),
r - correlation coefficient.

For the B_{1-10} set, covering 60 results, the linear regression equation was:

$$r\,n_{B1-10} = 0{,}0287\ z + 1{,}5055; \quad r = 0{,}724, \quad r_{0,001} = 0{,}409$$

The average values of bulk density for the group of loam soils are shown in Table 1. The greatest variability of these was observed in the arable layer, and at a depth of 31-50 cm, where particle-size distribution varied most. Variability of bulk density in surface horizon was generally at the same level for the group of loam soils and profiles in the long-term experiment. Whereas, for the middle part of profiles (at depth 30 - 80 cm), the coefficient of variation was usually 2 - 4%, and below 100 cm - 1% higher for the group than for the individual profile. The bulk density increased with depth (of profiles) to 130 cm, and then became stabilized.

About 16% of results for the samples from loam soils exceeded 1,8 Mg m^{-3} and were not presented in Kachinski's system (1958). The majority of these, i.e. 56,4% was within the range of bulk density for strongly compacted layers, notably in podzolic and saline soils. Not a single result was obtained suggested by Kachinski for soil of good culture, and for loose soil. Moreover, all these densities are not greater than the density of another group of soils formed from boulder loams, see Cieśla (1961), Konecka-Betley et al. (1970), and Olszewski et al. (1962). Our results are a little lower than those obtained by Drzymała

(1977) for soils of the „Krotoszyński" type and black earths of the Września Region (Reimann and Cieśla, 1965).

The average values of bulk density obtained from each of 10-cm layers in soil profile to a depth 130 cm were subject to the regression analysis. The resultant equation is:

$$r\,n = 0{,}0210\ h + 1{,}5736; \qquad r = 0{,}964, \qquad r_{0{,}001} = 0{,}760$$

The symbols are the same as those mentioned above.

In order to establish a 95% confidence interval of natural bulk density, there was selected the highest standard deviation equal to 0,143, from which semi-interval ± 0,044 was calculated to be ± 0,05 Mg m^{-3}.

The data from fluvioglacial sand (in most cases light loamy sand) soils corrected by the same slope of regression line indicate the natural bulk density values less by 0,144. and for loess soils 0,214 Mg m^{-3} than for loam soils.

The slope of the regression line calculated for the group of loam soils is less than for each idividual profile from the long-term experiment. The difference of organic matter content in humus horizon caused this effect (Wojtasik, 1987). For instance, the profile described as $B_{1\text{-}10}$ has 4,05% of organic matter at a depth of 15 cm, and $a_{1\text{-}9}$ - 3,72% but the group of loam soils, on average has 2,14%.

Deviation in calculated values of natural bulk density between the group and individual profile, on the average, is 1,9%, whereas the difference from mean measured values (showed in Table 1 only for $a_{1\text{-}9}$ and $B_{1\text{-}10}$ series) reaches 5,4%. However, if the profile has alternately different particle-size distribution within its layers, perhaps it will be better to use the mean long-time measured values than calculated ones as an assessment of the natural bulk density.

Conclusions

1. The temporary bulk density in soil profiles fluctuated in particular horizons with time. Coefficients of variation generally did not exceed 7 - 8%.
2. High values of mesurement bulk density in profiles of soils formed from boulder loams were caused by geological character of soil material, especially by particle-size distribution.
3. The soil profiles from boulder loams revealed the natural bulk density to be greater by 0,144 Mg m^{-3} than soil derived from fluvioglacial sands and by 0,214 Mg m^{-3} than soil formed from loess.
4. The natural bulk density criterion may be useful in checking phisical properities of soil and from the most appropriate soil conditions for plant growth.

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Streszczenie

Okazjonalnie oznaczana gęstość objętościowa gleb, nazwana w tej pracy gęstością tymczasową, chwilową (temporary density) i określona symbolem r t, nie w pełni oddaje charakter gleby, gdyż wielkość ta zmienia się w czasie, osiągając w okresie wegetacji roślin zakres ± 0,30 Mg m^3 w stosunku do wielkości, którą nazwano gestością naturalną gleby (r n). Do wyznaczania gęstości naturalnej gleb zaproponowano 5 metod. W tej pracy szczegółowo opisano dwie metody. Są to: (1) wielokrotne oznaczenia tymczasowej gęstości gleby w tych samych reprezentatywnych dla określonej grupy gleb profilach w ciągu kilku lat, a następnie wypośrodkowanie wyników dla poszczególnych warstw za pomocą rachunku regresji; (2) nagromadzenie wyników oznaczeń r t otrzymanych w różnych miejscach i w różnym czasie, ale odnoszących się do tych samych warstw w profilach gleb jednorodnych, o takich samych lub bardzo podobnych właściwościach i, tak samo jak w poprzedniej metodzie, wypośrodkowanie danych za pomocą regresji.

Pierwszą metodę zastosowano w dwóch profilach czarnej ziemi wytworzonej z gliny zwałowej na Równinie Inowrocławskiej. Gęstość tymczasową gleby (rt) mierzono w sześciu warstwach profilów 19 razy w ciągu ponad 2,5 roku. Drugą metodę zastosowano w odniesieniu do 162 profilów gleb wytworzonych z gliny zwałowej. Następnie 862 wyniki wypośrodkowano za pomocą rachunku regresji dla kolejnych 10-centymetrowych warstw w profilach aż do głębokości 240 cm. Nie stwierdzono istotnych różnic pomiędzy wielkościami r n otrzymanymi według jednej i drugiej metody. Natomiast dla analogicznych pod względem głębokości warstw w profilach gleb wytworzonych z piasków fluwioglacjalnych (przeważnie o składzie piasku słabo gliniastego) otrzymano wielkości średnio o 0,144 Mg m^{-3}, a w glebach wytworzonych z lessów o 0,214 Mg m^{-3}, niższe.