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Comparing pedotransfer functions to estimate soil bulk density in northern Belgium

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INTRODUCTION

Soil bulk density (*D*) is required for estimating soil water retention characteristics and is an often required input parameter for water, sediment and nutrient transport models. Direct measurements of *D* are based on undisturbed samples and so they are labor-intensive and time-consuming. Consequently it is not routinely analysed. Much effort has been devoted to develop pedotransfer functions (PTF) (Bouma, 1989) which relate *D* with available basic soil properties.

D depends on the specific gravity of the soil particles and their arrangement. Since the specific gravity of soil minerals is more or less constant, soil structure is chiefly responsible for fluctuations of bulk density. The structural properties, in turn, are determined largely by the interacting influences of the soil particles and the degree of aggregation for which organic matter is responsible. As a consequence *D* is found to be related to soil texture and soil organic matter (Saini, 1966 and Adams, 1973).

Mostly PTF were developed for particular soil groups and so these have a limited applicability (Van Wambeke, 1974 ; Alexander, 1980 ; Mbagwu *et al.*, 1983 and Scott & Wood, 1989). Brakensiek *et al.* (1980) and McCuen *et al.* (1981) published class PTF with average *D* values for the USDA soil texture classes. PTF which are relevant for a wide range of soils were developed by Adams (1973) ; Rawls (1983) and Manrique & Jones (1991). Van Hove (1969) and Van Ruymbeke *et al.* (1991) developed class PTF for northern Belgium. Until now, no continuous PTF for *D* of soils in Northern Belgium were developed. The aim of this study was to compare PTF from literature to estimate soil bulk density in northern Belgium.

MATERIALS AND METHODS

Class pedotransfer functions

If no direct measurements are made, *D* of soils in northern Belgium is estimated using the two class PTF published in Van Hove (1969) and Van Ruymbeke *et al.* (1991). Van Ruymbeke *et al.* (1991) estimated *D* as being 1.45 g cm^{-3} for topsoil horizons (rich in organic matter) and 1.50 g cm^{-3} for underlying horizons (low in organic matter). Van Hove (1969) refined this by relating *D* of topsoil horizons of northern Belgium to the classes of the Belgian soil texture triangle (Figure 1).

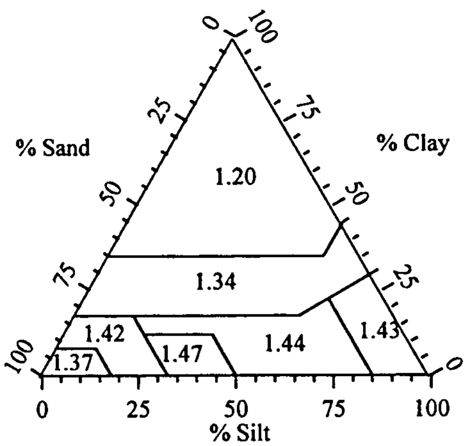

Figure 1 *D* of topsoil horizons in function of the classes on the Belgian soil texture triangle (Van Hove, 1969).

Continuous pedotransfer functions

Adams (1973) predicts D using the equation:

$$D = \frac{100}{\frac{OM}{D_{OM}} + \frac{100 - OM}{D_M}} \quad \textbf{Eq. 1}$$

with OM the organic matter content, D_{OM} the bulk density of the organic matter which is set to 0.224 g cm^{-3} and D_M the bulk density of the mineral fraction. Rawls (1983) published a contour map of D_M as a function of sand and clay content (Figure 2).

Manrique & Jones (1991) predicted D as a function of the square root of organic carbon (C):

$$D = 1.660 - 0.318\sqrt{C} \quad \textbf{Eq. 2}$$

They also grouped soils according to the USDA soil orders and determined a functional relation for each order. We translated the major Belgian soil series to USDA soil orders: Alfisols (Aba, Aca, Lba, Lca, Lda, sLba, Ldc, Sbc,), Entisols (Abp, sEdp, Udp), Inceptisols (Sbf, Sdm) and Podsols (Zdg, Zcg):

$$D = 1.704 - 0.005\,Cl - 0.127\,C \quad \textbf{Eq. 3}$$

for Alfisols

$$D = 1.861 - 0.452\sqrt{C} \quad \textbf{Eq. 4}$$

for Entisols

$$D = 1.720 - 0.403\sqrt{C} \quad \textbf{Eq. 5}$$

for Inceptisols

$$D = 1587 - 0259\sqrt{C} \quad \textbf{Eq. 6}$$

for Spodosols

with Cl the percentage of clay.

Validation data

The dataset published by Vereecken (1988) was used to compare these PTF. The dataset contains information on the soil textural fractions, organic matter and bulk density for the horizons (182) of 40 profiles representing the major soil series in northern Belgium.

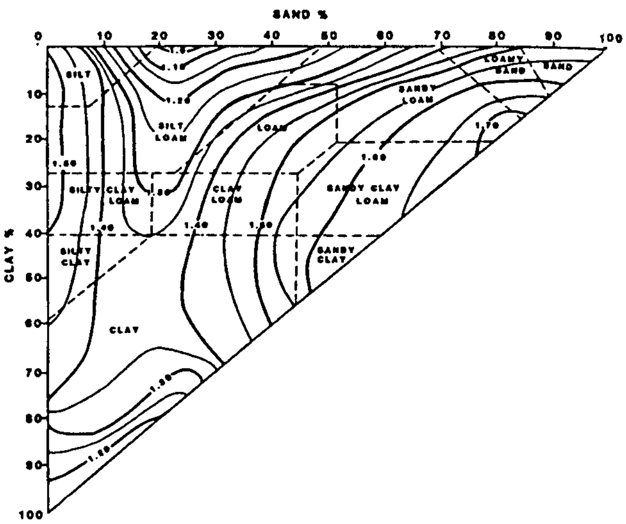

Figure 2 Contour map of D_M (g cm^{-3}) (Rawls, 1983)

The validation indices used to compare the PTF were the mean prediction error (*MPE*), the mean and the standard deviation of the square prediction error (*MSPE* and *SDSPE* respectively) and the Pearson correlation coefficient (r), defined as:

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(D_i - \hat{D}_i\right) \quad \textbf{Eq. 7}$$

$$MSPE = \frac{1}{n}\sum_{i=1}^{n}\left(D_i - \hat{D}_i\right)^2 \quad \textbf{Eq. 8}$$

$$SDSPE = \sqrt{\frac{\sum_{i=1}^{n}\left(\left(D_i - \hat{D}_i\right)^2 - MSPE\right)^2}{n-1}} \quad \textbf{Eq. 9}$$

$$r = \frac{Cov\left(D_i, \hat{D}_i\right)}{\sqrt{Var\left(D_i\right)Var\left(\hat{D}_i\right)}} \quad \textbf{Eq. 10}$$

In these equations D_i is the observed soil bulk density, $\hat{D}_i$ is the soil bulk density predicted by the PTF and n is the number of observations (182). The prediction should be unbiased, so *MPE* should approach zero. *MSPE* is a measure of the average precision, *SDSPE* is a measure of the variation in precision and both should be as small as possible. The Pearson correlation coefficient is a measure of the strength of similarity between observations and predictions.

RESULTS

Table 1 presents the validation values for the five PTF. For the class PTF (Van Hove, 1969 and Van Ruymbeke *et al.*, 1991) *MPEs* are close to zero and *MSPEs* are low. However the relationship between predictions and observations is poor (r<0.3) (Figure 3a-b) and also the *SDSPEs* have intermediate values.

Table 1 Performance of PTF for *D*

PTF	*MPE* $g\ cm^{-3}$	*MSPE* $g^2\ cm^{-6}$	*SDSPE* $g^2 cm^{-6}$	*r*
Van Ruymbeke *et al.* (1991)	0.007	0.0171	0.0407	0.17
Van Hove (1969)	0.025	0.0177	0.0410	0.25
Rawls (1983)	0.173	0.0501	0.0555	0.50
General PTF of Manrique & Jones (1991)	0.117	0.0305	0.0417	0.58
PTF based on the USDA orders (Manrique & Jones, 1991)	0.015	0.0184	0.0309	0.61

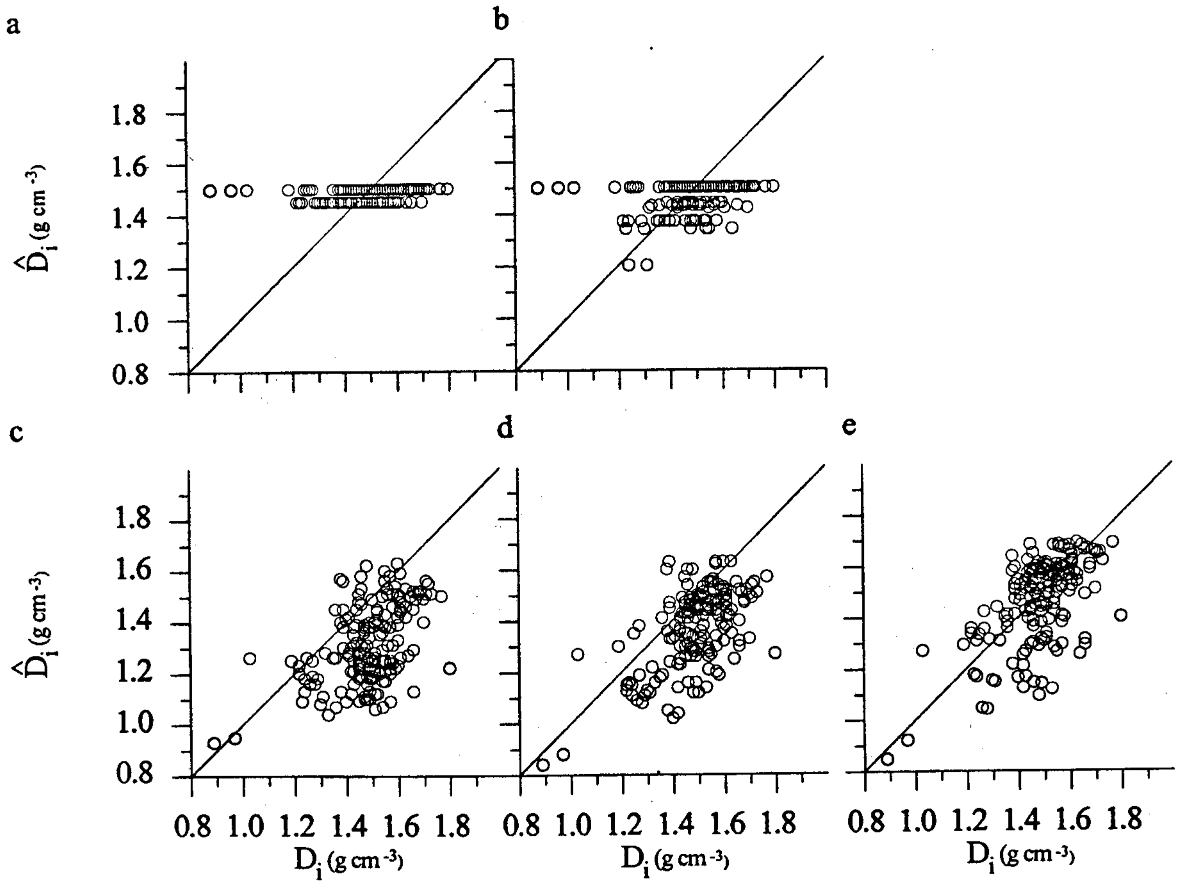

Figure 3 Estimated versus observed *D* for different PTF: (a) Van Ruymbeke *et al.* (1991), (b) Van Hove (1969), (c) Rawls (1983), (d) general PTF of Manrique & Jones (1991), (e) PTF based on the USDA orders of Manrique & Jones (1991).

For Manrique & Jones (1991) and Rawls (1983) the high *MSPEs* and *SDSPEs* indicate a poor accuracy, induced by an important systematic underestimation as indicated by the *MPE* and as can be visually observed in Figure 3c-d. However $r's \geq 0.50$ indicate a stronger relationship between predictions and observations than for the two class PTF.

The PTF based on the USDA orders (Manrique & Jones, 1991) score the best for the Pearson correlation coefficient (Figure 3e) and *SDSPE*. The *MPE* and *MSPE* approach the minimal values obtained by the class PTF. This study also points out that the evaluation of predictive methods should be based on several validation indices simultaneously.

CONCLUSIONS

For soils in northern Belgium predictions of bulk density are best performed by the PTF on the basis of the USDA orders (Manrique & Jones, 1991). If only the texture class is known, the class PTF of Van Hove (1969) is the best alternative.

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