Prediction of soil water retention properties after stratification by combining texture, bulk density and the type of horizon

Parmi les nombreuses fonctions de pédotransfert (PTF) précédemment publiées, les classes de fonctions de pédotransfert (CFPT) n'ont fait l'objet que d'un nombre très limité d'études car leurs performance sont généralement considérées comme étant très limitées. Cependant, des études récentes ont montré que les performances de classes de fonctions de pédotransfert (CFPT) peuvent être similaires à celles obtenues avec les fonctions de pédotransfert continues (FPTC) qui sont beaucoup plus connues. Dans ce chapitre, nous comparons les performances de CFPT basés sur des classes de texture et sur des classes combinant la classe de texture et de densité apparente, et après stratification en fonction du type d'horizon (horizons de surface et de subsurface) en utilisant un jeu de données de 456 horizons prélevés dans plusieurs régions de France. Les performances de CFPT ont été discutées pour deux valeurs de potentiel (-330 hPa et -15000 hPa) en utilisant un jeu de données de 197 horizons appartenant à des sols français.

Nos résultats ont montré que la meilleure performance a été enregistrée avec les CFPT établies en utilisant la texture et la densité apparente (CFPT texuro-structurales). Les résultats ont aussi montré que l'analyse après stratification en fonction du type d'horizon ne montre pas d'amélioration très sensible de la prédiction. La comparaison des performances de prédiction à -330 hPa et à -15000 hPa a seulement montré une petite différence n'indiquant pas de biais en fonction du potentiel. L'utilisation de CFPT pour établir des cartes de la capacité de stockage en eau (*RU*) avec la base de données géographique des sols de France à 1 :1000000, a conduit à une distribution légèrement différente de la capacité de stockage en eau sur l'ensemble du territoire métropolitain. Cependant, la moyenne de la capacité de stockage calculée n'a pas différé avec les différentes CFPT utilisées.

Among the numerous pedotransfer functions (PTFs) earlier published, the class-PTfs received little attention because their accuracy was often considered as limited. However, recent studies showed that performance of class-PTFs can be similar to the continuous-PTFs that are much more popular. In this study, we compared the performance of PTFs that were established by using a set of 456 horizons collected in France and classes of texture and bulk density and the type of horizon (topsoil and subsoil). The performance of these class-PTFs were discussed at -330 and -15000 hPa. Our results showed that the best performance was recorded with the class-PTFs that use both texture and bulk density (texturo-structural class-PTFs). They showed also that utilization of the type of horizon did not improve the prediction performance. Comparison of the performance at -330 and -15000 hPa showed only very little difference thus indicating no bias according to the value of water potential. Use of the class-PTFs to establish maps of the available water capacity with the 1:1 000 000 Soil Geographical Database of France led to slightly different distribution of the AWC at the scale of the whole French territory. However, the averaged AWC computed did not differ with the different class-PTFs used.

Chapitre VI

Prediction of soil water retention properties after stratification by combining texture, bulk density and the type of horizon[1]

I. INTRODUCTION

Pedotransfer functions (PTFs) relate the basic soil properties that are as easily accessible to the less often measured soil properties such as hydraulic properties (Bouma and van Lanen, 1987). Among the PTFs developed over the last three decades, most were continuous-pedotransfer functions (continuous-PTFs) that are mathematical continuous functions between the water content at discrete values of potential or the parameters of a unique model of water retention curve and the basic soil properties (mostly particle size distribution, organic carbon content and bulk density) (e.g. Bastet *et* al., 1999; Wösten *et al*., 2001; Pachepsky *et al*., 2006). Thus continuous-PTFs enabling prediction of water content at particular water potentials (Rawls *et al*., 2004) or estimation of the parameters of models of the water retention curve (Vereecken *et al*., 1989; Bruand *et al*., 1994; Leenhardt, 1995; Minasny *et al*., 1999; Wösten *et al*., 2001; Cresswell *et al*., 2006; Tranter *et al*., 2007) were developed.

[1] Ce chapitre a été soumis à la revue Soil Use and Management : AL MAJOU H., BRUAND A., DUVAL O., Le Bas C., Vautier A., 2008 – Prediction of soil water retention properties after stratification by combining texture, bulk density and the type of horizon. *Soil Use and Management* (Soumis).

In addition to the development of continuous-PTFs, class pedotransfer functions (class-PTFs) were also developed (Wösten *et al*., 1995; Lilly, 2000; Pachepsky *et al*., 2003; Rawls *et al*., 2003). Most class-PTFs provide average water contents at particular water potentials or one average water retention curve for every texture class (e.g. Nemes *et al*, 2001; Nemes, 2002; Bruand *et al*., 2003 & 2004). Due to the range in particle size distribution, clay mineralogy, organic matter content and structural development within each texture class, water retention properties for individual soils were indeed considered as varying considerably (Wösten *et al*., 1999). However, class-PTFs are easy to use because they require little soil information and well adapted to the prediction of the water retention properties at the continental and national scale because the information on soils is often limited to classes of composition at that scale (Wösten *et al*. 1995; Lilly *et al*., 1999; Wösten *et al*. 1999; Nemes *et al*., 2003).

Several studies provided information about the performance of continuous-PTFs (Minasny *et al*., 1999; Wösten *et al*., 2001; Cornelis *et al*., 2001; Donatelli *et al*., 2004) and class-PTFs (Pachepsky and Rawls, 1999; Wösten *et al*., 2001; Ungaro *et al*., 2005) but there very little about the comparison of the performance of continuous- and class-PTFs (Wösten *et al*., 1995). Al Majou *et al*. (2007) discussed the performance of class- and continuous-PTFs and showed similar performance despite a better consideration of the soil composition with the continuous-PTFs. These results reinforce the significance of the class-PTFs developed by Bruand *et al*. (2003) that were based on texture alone or on both texture and clod bulk density, the latter leading to best performance. Nevertheless, utilization of these class-PTFs remained limited because the clod bulk density is not available in most soil databases. In this study, on the basis of the results recorded by Al Majou *et al*. (2007) and having in mind the necessity to propose class-PTFs that can be used easily, we developed class-PTFs for the volumetric water content at several water potentials by combining the texture, the bulk density and the type of horizon. The validity of these class-PTFs was discussed at -330 and -15000 hPa water potential and class-PTFs developed were used to establish maps of the available water capacity at the scale of the whole France territory.

II. MATERIALS AND METHODS

A. Data collection

Class-PTFs were developed using a set of 456 horizons comprising 138 topsoil horizons (from 0 to 30 cm depth) and 318 subsoil horizons (> 30 cm depth) collected in Cambisols, Luvisols, Planosols, Albeluvisols, Podzols and Fluvisols (ISSS Working Group R.B., 1998) located mainly in the Paris basin and secondarily in Britany, the western coastal marshlands and Pyrenean piedmont plain (Figure 6.1). A set of 197 horizons was constituted in order to test the class-PTFs established. These horizons were collected in Cambisols, Luvisols and Fluvisols (ISSS Working Group R.B., 1998) located in several areas of France and developed on a large range parent materials.

B. Basic and water retention properties

The particle size distribution was measured using the pipette method after pre-treatment of samples with hydrogen peroxide and sodium hexametaphosphate (Robert & Tessier 1974). The FAO triangle of textures was used to standardize the texture data (FAO, 1990) (Figure 6.2). The cation exchange capacity (CEC, in $cmol_c\,kg^{-1}$ of oven-dried soil) was measured using the cobalt-hexamine trichloride method (Ciesielski & Sterckeman 1997) and organic carbon by oxidation using excess potassium bichromate in sulphuric acid at 135°C (Baize 2000). The bulk density (D_b) was measured by using cylinders 1236 cm^3 in volume when the soil was near to field capacity. The gravimetric water content was determined for the 456 horizons data set at –10, –33, –100, –330, –1000, –3300 and –15000 hPa water potential, and for the 197 horizons data set at –330 and –15000 hPa water potential, by using undisturbed samples (10–15 cm^3 in volume) collected when the soil was near to field capacity (Bruand and Tessier, 2000). Then, the volumetric water content (θ) for each horizon was computed by using the bulk density of horizon (Table 6.1).

C. Analysis of the class-PTFs performance

Most discussions of PTFs performance were based the root mean square error (*RMSE*) that is also called root mean squared deviation or root mean square residual (Wösten *et al.*, 2001). Because the *RMSE* varies according to both the prediction bias and precision, we computed also the mean error of prediction (*MEP*) that enables discussion of the prediction bias alone on one hand and the standard deviation of prediction (*SDP*) that enables discussion of the prediction precision alone on the other hand. Thus we computed the *RMSE*, *MEP* and *SDP* at –330 and –15000 hPa water potential as following:

$$RMSE = \left\{ \frac{1}{l' \cdot l} \sum_{j=1}^{l'} \sum_{i=1}^{l} \left(\theta_{p,j,i} - \theta_{m,j,i} \right)^2 \right\}^{1/2}$$

$$MEP = \frac{1}{l' \cdot l} \sum_{j=1}^{l'} \sum_{i=1}^{l} (\theta_{p,j,i} - \theta_{m,j,i})$$

$$SDP = \left\{ \frac{1}{l' \cdot l} \sum_{j=1}^{l'} \sum_{i=1}^{l} \left[(\theta_{p,j,i} - \theta_{m,j,i}) - MEP \right]^2 \right\}^{1/2}$$

where $\theta_{p,j,i}$ is the predicted water content at potential *i* for the horizon *j*, $\theta_{m,i,j}$ is the measured water content at potential *i* for the horizon *j*, and *l* is the number of water potentials for each horizon (*l*=7 in this study) and *l'* is the number of horizons (*l'* ≤ 197 in this study). The *MEP* corresponds to the bias and indicates whether the class-PTFs overestimated (positive) or underestimated (negative) the water content, whereas *SDP* measures the precision of the prediction.

III. RESULTS AND DISCUSSION

A. Deriving the class-PTFs

The class-PTFs developed in this study corresponded to average water contents at seven water potentials. They were first established according to soil texture (textural class-PTFs) in the FAO triangle (FAO, 1990) for the whole set of horizons (Table 6.2). Then, because of different proportion of macroporosity and microporosity between topsoil and subsoil horizons, and consequences for the bulk density of the horizons, textural class-PTFs were also developed after stratification by the type of horizon (topsoil and subsoil horizons) (Table 6.3). Then, class-PTFs were established according to both texture and D_b (texturo-structural class-PTFs) for the whole set of horizons without any other stratification (Table 6.4) and also after stratification by the type of horizon (topsoil and subsoil horizons) (Table 6.5).

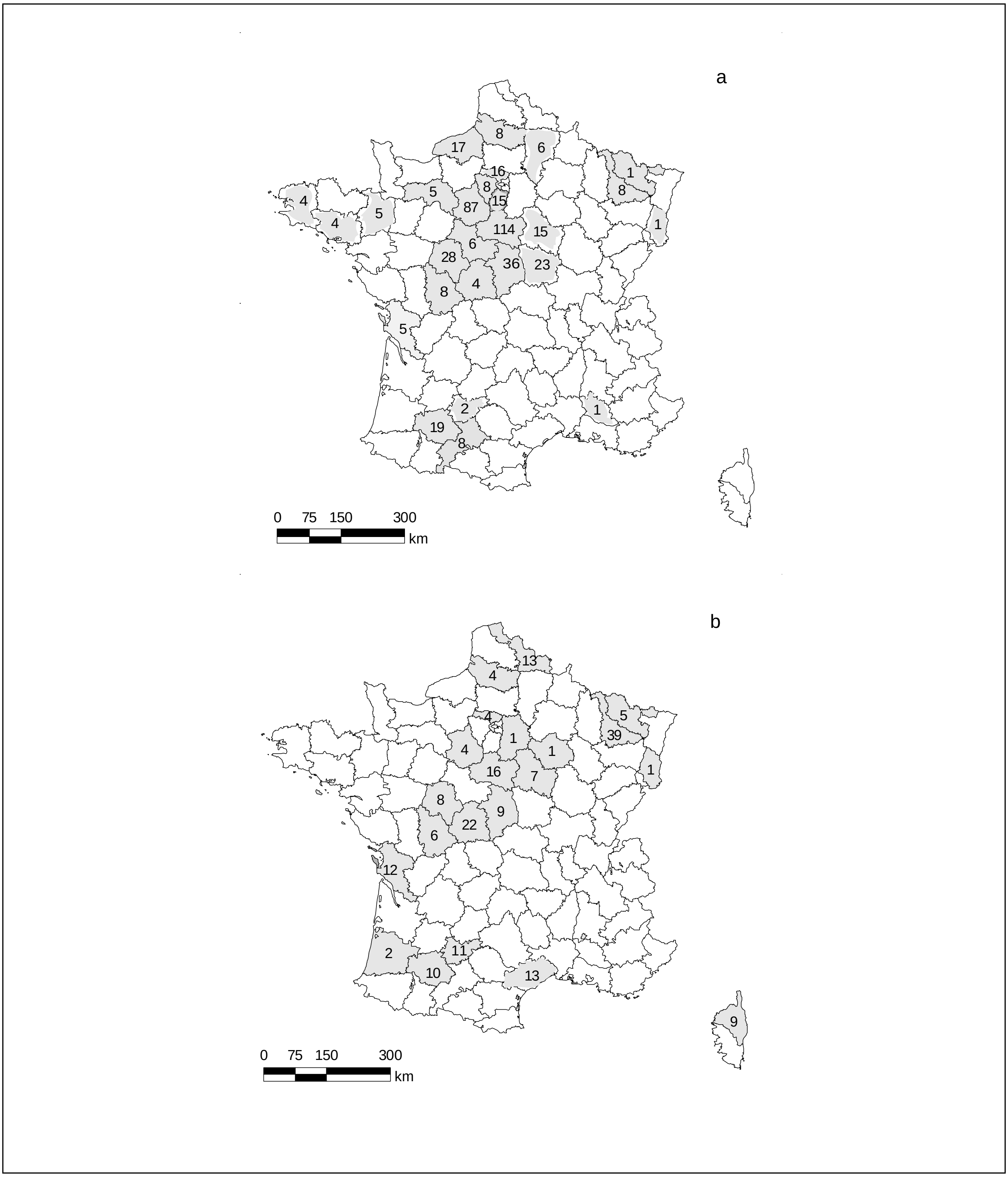

Figure 6.1: Location of the soil studied (number of horizon by department) that were used to establish the class-PTFs (a) and to test their validity (b).

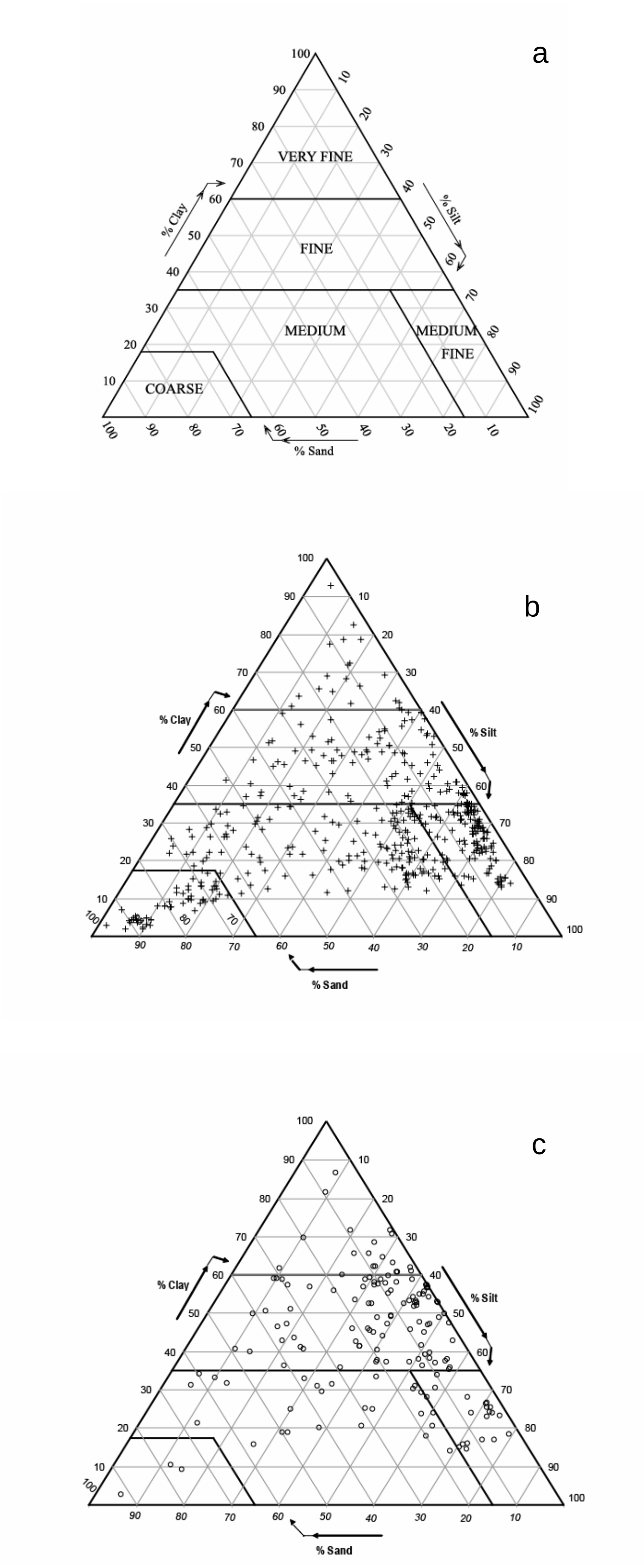

Figure 6.2: Triangle of texture used (a), texture of the horizons used to establish the class-PTFs (b) and texture of those used to test their validity (c).

B. Validity of the textural and texturo-structural class-PTFs

The textural class-PTFs developed underestimated the water retained (*MEP* = –0.015 $cm^3.cm^{-3}$) when they are applied to the test dataset (Table 6.6). The precision of the estimation was small with *SDP* = 0.041 $cm^3.cm^{-3}$. There was a decrease in the prediction bias (Δ*MEP* = 0.011 $cm^3.cm^{-3}$) and an increase in the precision (Δ*SDP* = 0.009 $cm^3.cm^{-3}$) with the texturo-structural class-PTFs. With the textural class-PTFs, the highest bias and smallest precision were recorded for the texture Fine (*MEP* = -0.025 $cm^3.cm^{-3}$ and *SDP* = 0.042 $cm^3.cm^{-3}$), and the improvement of the estimation performance was particularly significant for that texture with the texturo-structural class-PTFs (*MEP* = -0.005 $cm^3.cm^{-3}$ and *SDP* = 0.032 $cm^3.cm^{-3}$).

Therefore, the high *RMSE* recorded with the textural class-PTFs (*RMSE* = 0.044 $cm^3.cm^{-3}$) was related to a relatively poor prediction precision (*SDP* = 0.041 $cm^3.cm^{-3}$), the bias being small (*MEP* = -0.015 $cm^3.cm^{-3}$). This *RMSE* was however smaller than the *RMSE* recorded by Bruand *et al*. (2003) for the volumetric water content with textural class-PTFs that enabled prediction of the gravimetric water content at -330 and -15000 hPa water potential. The smaller *RMSE* recorded with the texturo-structural class-PTFs (Δ*RMSE* = 0.011 $cm^3.cm^{-3}$) was related to the significant decrease in the estimation bias and increase in the precision. The *RMSE* recorded with the texturo-structural class-PTFs was again smaller than the *RMSE* recorded by Bruand *et al*. (2003) for the volumetric water content with texturo-structural class-PTFs developed in their study.

C. Validity of the textural and texturo-structural class-PTFs after stratification by the type of horizon

Establishing textural class-PTFs after stratification according to the type of horizon (i.e. by separating topsoil and subsoil horizons) did not improve the performance of the textural class-PTFs (Δ*MEP* = 0.001 $cm^3.cm^{-3}$ and Δ*SDP* = 0.002 $cm^3.cm^{-3}$) (Table 6.6). There was also no improvement of the performance with the texturo-structural class-PTFs after stratification by the type of horizon (Δ*MEP* = 0.001 $cm^3.cm^{-3}$ and Δ*SDP* = 0.003 $cm^3.cm^{-3}$) (Table 6.6). This lack of improvement explains the similar *RMSE* that were recorded with the textural and texturo-structural class-PTFs with or without stratification by the type of horizon (Figure 6.4a).

Table 6.1: Characteristics of the horizons used to establish the PTFs.

	Particle size distribution (%)			OC $g.kg^{-1}$	$CaCO_3$ $g.kg^{-1}$	CEC $cmol_c kg^{-1}$	D_b $g.cm^{-3}$	Volumetric water content[1] ($cm^3.cm^{-3}$)						
	<2 µm	2-50 µm	50-2000 µm					$\theta_{1.0}$	$\theta_{1.5}$	$\theta_{2.0}$	$\theta_{2.5}$	$\theta_{3.0}$	$\theta_{3.5}$	$\theta_{4.2}$
Horizons used to derive the class-PTFs (n = 456)														
mean	29.3	43.8	26.9	6.0	54.2	14.8	1.52	0.354	0.335	0.315	0.289	0.259	0.221	0.187
s.d.	15.4	21.8	25.6	5.1	171.3	9.0	0.15	0.068	0.070	0.075	0.076	0.079	0.076	0.073
min.	1.9	1.6	0.1	0.0	0.0	0.6	0.95	0.134	0.100	0.080	0.056	0.045	0.033	0.013
max.	92.9	82.1	95.4	28.8	982	52.8	1.98	0.605	0.596	0.586	0.557	0.510	0.462	0.370
Horizons used to test the class-PTFs (n = 197)														
mean	39.4	39.3	21.3	5.6	31.5	19.9	1.45	-	-	-	0.330	-	-	0.235
s.d.	16.9	17.1	19.2	5.8	58.7	7.8	0.16	-	-	-	0.071	-	-	0.070
min.	2.7	5.4	0.0	0.0	0.0	3.3	1.16	-	-	-	0.107	-	-	0.065
max.	86.7	79.4	91.9	40.3	212.0	40.4	1.94	-	-	-	0.468	-	-	0.360

[1] Volumetric water content at water potential h ($\theta_{\log|h|}$)

Table 6.2: Textural class-PTFs.

	Volumetric water content[1] ($cm^3.cm^{-3}$)						
	$\theta_{1.0}$	$\theta_{1.5}$	$\theta_{2.0}$	$\theta_{4.2}$	$\theta_{3.0}$	$\theta_{3.5}$	$\theta_{4.2}$
After stratification by texture alone (n = 456)							
Very fine (n = 20)	0.457	0.439	0.426	0.404	0.387	0.352	0.327
Fine (n = 102)	0.405	0.390	0.374	0.351	0.333	0.299	0.262
Medium fine (n = 127)	0.361	0.345	0.329	0.300	0.257	0.211	0.178
Medium (n = 151)	0.336	0.318	0.300	0.273	0.244	0.204	0.164
Coarse (n = 56)	0.257	0.220	0.180	0.150	0.123	0.102	0.082

[1] Volumetric water content at water potential h ($\theta_{\log|h|}$)

Table 6.3: Textural class-PTFs developed according to the type of horizon (topsoil and subsoil horizons).

	Volumetric water content[1] ($cm^3.cm^{-3}$)						
	$\theta_{1.0}$	$\theta_{1.5}$	$\theta_{2.0}$	$\theta_{2.5}$	$\theta_{3.0}$	$\theta_{3.5}$	$\theta_{4.2}$
Topsoil horizons (n = 138)							
Very fine (n = 2)	0.468	0.450	0.431	0.402	0.378	0.332	0.293
Fine (n = 17)	0.437	0.410	0.392	0.367	0.354	0.304	0.272
Medium fine (n = 48)	0.359	0.340	0.324	0.297	0.250	0.196	0.155
Medium (n = 40)	0.346	0.328	0.311	0.289	0.260	0.208	0.161
Coarse (n = 31)	0.272	0.235	0.198	0.167	0.138	0.115	0.091
Subsoil horizons (n = 318)							
Very fine (n = 18)	0.456	0.438	0.425	0.405	0.388	0.354	0.330
Fine (n = 85)	0.399	0.386	0.370	0.348	0.328	0.298	0.261
Medium fine (n = 79)	0.363	0.349	0.332	0.302	0.262	0.221	0.192
Medium (n = 111)	0.332	0.315	0.296	0.267	0.238	0.203	0.165
Coarse (n = 25)	0.237	0.201	0.158	0.129	0.104	0.086	0.070

[1] Volumetric water content at water potential h ($\theta_{log|h|}$)

Table 6.4: Texturo-structural class-PTFs.

		Volumetric water content[1] ($cm^3.cm^{-3}$)						
		$\theta_{1.0}$	$\theta_{1.5}$	$\theta_{2.0}$	$\theta_{2.5}$	$\theta_{3.0}$	$\theta_{3.5}$	$\theta_{4.2}$
Very Fine (n = 20)	$1.10 \le D_b < 1.30$	0.491	0.469	0.450	0.423	0.405	0.361	0.334
	$1.30 \le D_b < 1.50$	0.463	0.443	0.430	0.408	0.386	0.346	0.330
	$1.50 \le D_b < 1.70$	0.390	0.374	0.376	0.370	0.367	0.354	0.308
Fine (n = 102)	$1.00 \le D_b < 1.20$	0.529	0.503	0.492	0.462	0.438	0.368	0.270
	$1.20 \le D_b < 1.40$	0.444	0.429	0.411	0.380	0.364	0.325	0.281
	$1.40 \le D_b < 1.60$	0.392	0.375	0.359	0.340	0.320	0.288	0.258
	$1.60 \le D_b < 1.80$	0.353	0.346	0.331	0.309	0.295	0.278	0.249
Medium Fine (n = 127)	$1.20 \le D_b < 1.40$	0.360	0.344	0.326	0.293	0.241	0.192	0.159
	$1.40 \le D_b < 1.60$	0.363	0.346	0.329	0.300	0.259	0.211	0.178
	$1.60 \le D_b < 1.80$	0.356	0.346	0.331	0.308	0.271	0.238	0.200
Medium (n = 151)	$1.20 \le D_b < 1.40$	0.361	0.340	0.320	0.285	0.253	0.202	0.154
	$1.40 \le D_b < 1.60$	0.347	0.328	0.307	0.275	0.240	0.200	0.160
	$1.60 \le D_b < 1.80$	0.319	0.304	0.289	0.267	0.245	0.207	0.169
	$1.80 \le D_b < 2.00$	0.296	0.294	0.276	0.273	0.269	0.245	0.209
Coarse (n = 56)	$1.20 \le D_b < 1.40$	0.255	0.200	0.175	0.136	0.114	0.094	0.076
	$1.40 \le D_b < 1.60$	0.254	0.208	0.163	0.137	0.111	0.092	0.078
	$1.60 \le D_b < 1.80$	0.262	0.239	0.199	0.167	0.138	0.113	0.088
	$1.80 \le D_b < 2.00$	0.237	0.181	0.153	0.127	0.100	0.091	0.065

[1] Volumetric water content at water potential h ($\theta_{log|h|}$)

Table 6.5: Texturo-structural class-PTFs developed according to type of horizon (topsoil and subsoil horizons).

		Volumetric water content[1] ($cm^3.cm^{-3}$)						
		$\theta_{1.0}$	$\theta_{1.5}$	$\theta_{2.0}$	$\theta_{2.5}$	$\theta_{3.0}$	$\theta_{3.5}$	$\theta_{4.2}$
Topsoil horizons (n = 138)								
Very fine (n = 2)	$1.10 \leq D_b < 1.30$	0.468	0.450	0.431	0.402	0.378	0.332	0.293
Fine (n = 17)	$1.00 \leq D_b < 1.20$	0.468	0.422	0.402	0.383	0.376	0.312	0.280
	$1.20 \leq D_b < 1.40$	0.453	0.431	0.410	0.382	0.378	0.324	0.293
	$1.40 \leq D_b < 1.60$	0.420	0.394	0.377	0.354	0.332	0.289	0.256
Medium Fine (n = 48)	$1.20 \leq D_b < 1.40$	0.358	0.343	0.325	0.294	0.239	0.189	0.153
	$1.40 \leq D_b < 1.60$	0.360	0.338	0.324	0.299	0.257	0.200	0.156
Medium (n= 40)	$1.20 \leq D_b < 1.40$	0.372	0.353	0.335	0.302	0.270	0.214	0.164
	$1.40 \leq D_b < 1.60$	0.349	0.328	0.311	0.294	0.265	0.215	0.171
	$1.60 \leq D_b < 1.80$	0.308	0.295	0.281	0.261	0.236	0.186	0.133
Coarse (n= 31)	$1.20 \leq D_b < 1.40$	0.265	0.206	0.178	0.146	0.120	0.100	0.077
	$1.40 \leq D_b < 1.60$	0.258	0.210	0.171	0.148	0.120	0.098	0.085
	$1.60 \leq D_b < 1.80$	0.290	0.271	0.234	0.195	0.164	0.136	0.103
Subsoil horizons (n = 318)								
Very fine (n = 18)	$1.10 \leq D_b < 1.30$	0.487	0.463	0.445	0.421	0.406	0.367	0.344
	$1.30 \leq D_b < 1.50$	0.463	0.443	0.430	0.408	0.386	0.346	0.330
	$1.50 \leq D_b < 1.70$	0.378	0.370	0.378	0.374	0.371	0.354	0.295
Fine (n = 85)	$1.00 \leq D_b < 1.20$	0.560	0.544	0.536	0.502	0.469	0.396	0.265
	$1.20 \leq D_b < 1.40$	0.440	0.429	0.411	0.379	0.358	0.325	0.276
	$1.40 \leq D_b < 1.60$	0.387	0.372	0.356	0.337	0.318	0.287	0.259
	$1.60 \leq D_b < 1.80$	0.353	0.346	0.331	0.309	0.295	0.278	0.249
Medium Fine (n = 79)	$1.20 \leq D_b < 1.40$	0.366	0.349	0.331	0.291	0.249	0.207	0.180
	$1.40 \leq D_b < 1.60$	0.365	0.350	0.332	0.301	0.259	0.217	0.190
	$1.60 \leq D_b < 1.80$	0.356	0.346	0.331	0.308	0.271	0.238	0.200
Medium (n = 111)	$1.20 \leq D_b < 1.40$	0.340	0.317	0.293	0.254	0.222	0.179	0.134
	$1.40 \leq D_b < 1.60$	0.346	0.328	0.306	0.267	0.228	0.194	0.154
	$1.60 \leq D_b < 1.80$	0.321	0.305	0.290	0.268	0.246	0.211	0.175
	$1.80 \leq D_b < 2.00$	0.296	0.294	0.276	0.273	0.269	0.245	0.209
Coarse (n = 25)	$1.40 \leq D_b < 1.60$	0.241	0.199	0.150	0.114	0.093	0.077	0.066
	$1.60 \leq D_b < 1.80$	0.235	0.207	0.164	0.139	0.112	0.089	0.073
	$1.80 \leq D_b < 2.00$	0.237	0.181	0.153	0.127	0.100	0.091	0.065

[1] Volumetric water content at water potential h ($\theta_{\log|h|}$)

D. Validity of the textural and texturo-structural class-PTFs according to the water potential

Analysis of the results according to the water potential showed that each type of class-PTF studied led to roughly similar performance at -330 and -15000 hPa (Figure 6.3). The bias was however slightly smaller at -330 hPa for each type of PTF discussed (Figure 6.3). On the other hand, the precision was a little greater and the *RMSE* smaller at -15000 hPa except for the texturo-structural PTFs (Table 6.7). This weak difference of performance at -330 and -15000 hPa would mean no prediction bias according to the water potential for the class-PTFs discussed.

E. Application of class-PTFs to the whole territory of France

Class-PTFs developed in this study were used to compute the available water capacity (AWC) of the Soil Typological Units (STU) of the 1:1 000 000 Soil Geographical Database of France (King *et al*., 1995). The available water was considered to be the water held between wilting point (-15 000 hPa water potential) and field capacity (-100 hPa water potential). A water potential of -100 hPa was indeed shown as the water potential at field capacity for the soil studied (Al Majou *et al*., 2008). The depth, texture and bulk density of the topsoils and subsoils were based on the available descriptions of the STU attributes (King *et al*., 1995). The amount of available water for each topsoil and subsoil was derived from the appropriate class-PTFs multiplied by the thickness of each horizon. Then, the total available water in mm for each STU was computed by summation of the corresponding topsoil and subsoil. Next, the available water in mm for each Soil Mapping Unit (SMU) was computed according to the proportion of the different STU present in each SMU (King *et al*., 1995; Wösten *et al*., 1999).

A first map of the AWC was established by using the texture class-PTFs without discrimination of the topsoil and subsoil for each STU. Thus, the same class-PTFs were applied to the topsoil and subsoil (Table 6.2, Figure 6.4a). Then, another map of the AWC was established by using the texture class-PTFs discriminating the topsoil and the subsoil for each STU (Table 6.3, Figure 6.4b). Finally, a map of the AWC was established by using the texturo-structural class-PTFs that showed the best performance (Table 6.4, Figure 6.4c).

Table 6.6: Validity of the class pedotranfer functions derived after stratification by texture alone, after stratification by texture and bulk density of horizon and according to the type of horizon.

	n	Mean error of prediction (*MEP*) ($cm^3.cm^{-3}$)	Standard deviation of prediction (*SDP*) ($cm^3.cm^{-3}$)	Root mean squared error (*RMSE*) ($cm^3.cm^{-3}$)
Textural class-PTFs				
Very Fine	18	-0.005	0.026	0.026
Fine	98	-0.025	0.042	0.049
Medium Fine	22	-0.004	0.035	0.035
Medium	51	-0.007	0.043	0.044
Coarse	8	0.003	0.021	0.020
All textures together	197	-0.015	0.041	0.044
Texturo-structural class-PTFs				
Very Fine	18	0.003	0.024	0.024
Fine	98	-0.005	0.032	0.032
Medium Fine	22	-3.10^{-4}	0.036	0.036
Medium	51	-0.005	0.036	0.037
Coarse	8	-0.005	0.014	0.015
All textures together	197	-0.004	0.032	0.033
Textural class-PTFs after stratification by the type of horizon				
Very Fine	18	-0.003	0.026	0.026
Fine	98	-0.026	0.043	0.050
Medium Fine	22	0.002	0.037	0.037
Medium	51	-0.005	0.046	0.046
Coarse	8	0.012	0.019	0.022
All textures together	197	-0.014	0.043	0.045
Texturo-structural clas-PTFs after stratification by the type of horizon				
Very Fine	18	0.004	0.026	0.026
Fine	98	-0.007	0.032	0.032
Medium Fine	22	0.003	0.037	0.037
Medium	51	-0.003	0.043	0.043
Coarse	8	0.003	0.013	0.013
All textures together	197	-0.003	0.035	0.035

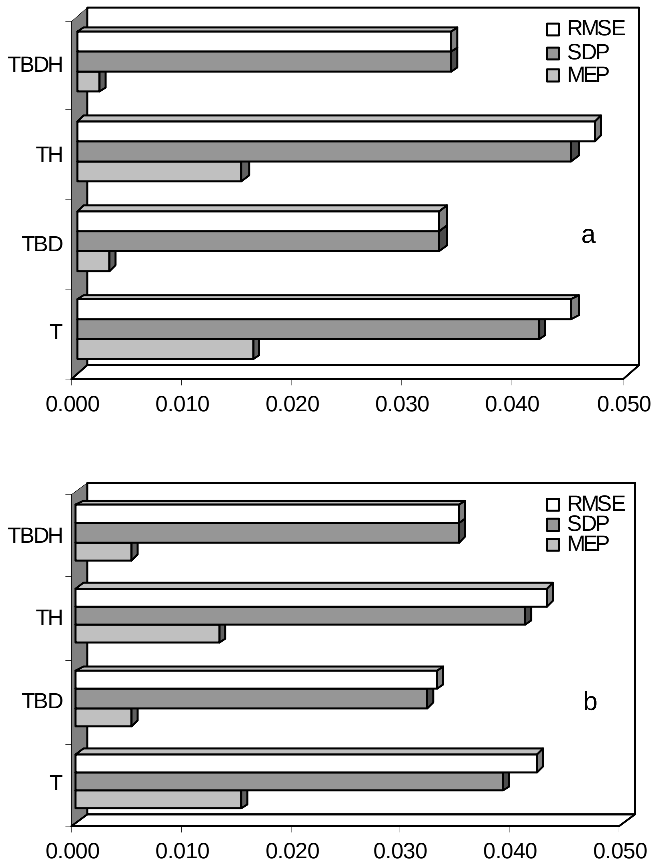

Figure 6.3: Validity of the class-PTFs developed (MEP absolute value, SDP and RMSE $cm^3.cm^{-3}$) at -330 hPa (a) and at -15000 hPa (b) (T: Texural class-PTFs, TBD: Texturo-structural class-PTFs, TH: Textural class-PTFs and the type of horizon and TBDH: Texturo-structural class-PTFs and the type of horizon).

Table 6.7: Validity of the textural and texturo-structural class pedotranfer functions according to the water potential.

	Mean error of prediction (*MEP*) ($cm^3.cm^{-3}$)		Standard deviation of prediction (*SDP*) ($cm^3.cm^{-3}$)		Root mean squared error (*RMSE*) ($cm^3.cm^{-3}$)	
	-330 hPa	-15000 hPa	-330 hPa	-15000 hPa	-330 hPa	-15000 hPa
Textural class-PTFs						
All textures together according to the water potential	-0.016	-0.015	0.042	0.039	0.045	0.042
Texturo-structural class-PTFs						
All textures together according to the water potential	-0.003	-0.005	0.033	0.032	0.033	0.033
Textural class-PTFs after stratification by the type of horizon						
All textures together according to the water potential	-0.015	-0.013	0.045	0.041	0.047	0.043
Texturo-structural class-PTFs after stratification by the type of horizon						
All textures together according to the water potential	-0.002	-0.005	0.034	0.035	0.034	0.035

Analysis of the maps recorded showed a greater AWC in several regions with the textural class-PTFs after discrimination of the topsoils and subsoils for the STU (Figure 6.4b). This was particularly visible in the north-east and centre of France. This would be mainly related to the greater AWC of the STU when textural class-PTFs discriminate topsoils and subsoils. Comparison of the maps recorded with the textural class-PTFs without any discrimination between topsoils and subsoils showed also a greater AWC in several regions with the texturo-structural class-PTFs (Figure 6.4c). This was particularly visible in west, centre and north-east of France. The average AWC was computed for the whole France by taking into account the surface area proportion of each STU and showed however no or very little difference between the three types of class-PTFs discussed (Table 6.8). Thus, if the distribution of AWC be different across France according to the type of PTF used, this does not affect the averaged AWC for the whole French territory.

Table 6.8: Averaged available water capacity (AWC) computed for the whole French territory with different class-PTFs.

Class-PTFs	Averaged AWC mm
Textural class-PTFs	104
Texturo-structural class-PTFs	107
Textural class PTFs after stratification by type of horizon	104

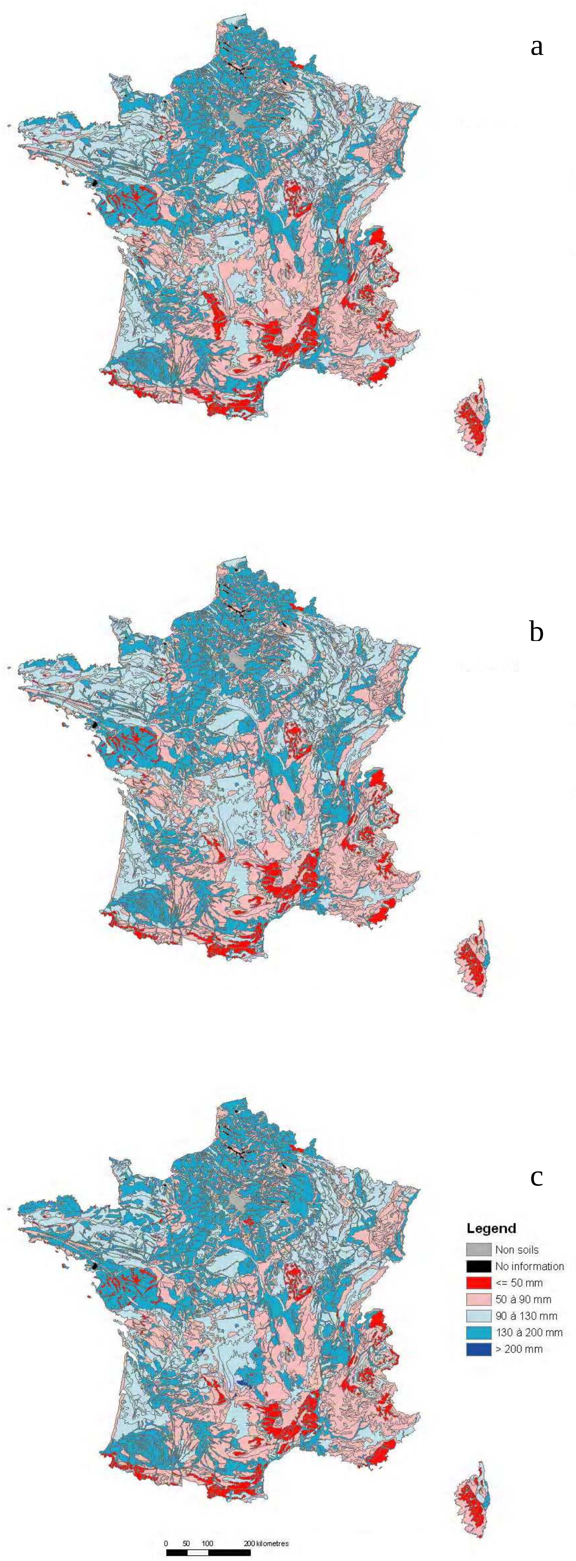

Figure 6.4: Available water capacity (mm) at the scale of the whole territory of France using the different class-PTFs (a, Textural class-PTFs; b, Textural class-PTFs according to the type of horizon; c, Texturo-structural class-PTFs).

IV. CONCLUSION

Our results showed that the best performance was recorded with the class-PTFs that use classes of both texture and bulk density (texturo-structural class-PTFs). They showed also that utilization of the type of horizon did not improve the prediction performance. Comparison of the performance at -330 and -15000 hPa showed only very little difference thus indicating no bias according to the value of water potential. Use of the class-PTFs to establish maps of the available water capacity with the 1:1 000 000 Soil Geographical Database of France led to slightly different distribution of the AWC at the scale of the whole French territory. However, the averaged AWC computed did not differ with the different class-PTFs used.