Contribution of stony phase in hydric properties of soils

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Abstract
Stony soils cover about 30% of the surface soils of Western Europe, and 60% in Mediterranean areas. They consist of rock fragments whose diameters are larger than 2 mm (the rock fragment). These fragments may alter the physical, chemical and agricultural properties of soils. To better understand the role of stones in the water supply of crops, structure and hydric properties of coarse elements of stony soils were studied. Monitoring the moisture was done on coarse fragments from sedimentary rocks, and revealed that rock fragments can store as much water as the fine earth. Applying the concept of field capacity and wilting point to coarse fragments, a simple pedotransfer function was defined to estimate the contribution of the pebbles to the Available Water Content of a stony soil.

Key Words
Pebbles, pedotransfer function, bulk density, water content, field capacity, wilting point.

Introduction
Stony soils contain coarse fragments, so called stones, which limits some tillage operations. Moreover, these soils are often thin, and therefore very vulnerable to the leaching of nitrates and pesticides. They cover about 30% of the surface soils of Western Europe and 60% in Mediterranean areas (Poesen and Lavee 1994). Though stony soils are widely spread and create problems to agriculture production, they have been little studied. As stones characterization is difficult, the stony phase is often neglected in the characterization of the properties of stony soils. However, the rock fragments could modify the physical, chemical and hydrodynamic properties of soils (Ravina and Magier 1984; Brakensiek and Rawls 1994; Poesen and Lavee 1994; Certini *et al*. 2004), and affect the behaviour and characteristics of agricultural soils. Indeed, the stony phase may participate in the water supply of crops (Coile 1953; Hanson and Blevins 1979; Gras 1994; Danatalos *et al*. 1995) and change the storage capacity of soil water (Coutadeur *et al*. 2000; Cousin *et al*. 2003). All these previous studies suggest some water transfers between the rock fragments and fine earth in soil. The objective of this work was to study the contribution of stony phase to some soils hydric properties using the structure and the water retention capacity of rock fragments from different types of stony soils.

Methods
Sampling
Stones were sampled in the cultivated horizon (0 - 30 cm) of different types of stony soils in the Central part of France. Only the pebble fraction (2 cm < stone diameter < 5 cm) was studied. Most of the stones were collected when the soil was at field capacity. The pebbles were sampled in soils developed over sedimentary rocks and were of the following types: gaize, chalk, chert, flint, and limestone.

Characterization of pebbles structure
The structure of each pebble was characterized by measurements on dried pebbles of bulk density and density of solid, and by calculation of the void ratio of the sample. The bulk density was determined by the oil method (Monnier *et al*. 1973) and the solid density by a gas pycnometer. The void ratio was calculated according to the following formula:
$e = (Ds / Bd) - 1.$ (1)
where e represents the void ratio, Ds represents the solid density and Bd represents the bulk density.

Characterization of pebbles hydric properties
The hydric properties were determined by measurements of gravimetric water content when the pebbles were at saturation or equilibrated at -100 hPa and -15000 hPa in pressure plates during 7 days.

Results

Characterization of pebbles structure

The porosity in pebbles was not equal to zero. In addition, the porosity, but also bulk density and void ratio varied according to the type of stone. Moreover, results showed that the bulk density of pebbles varied within a single type of stone, and especially for the limestones. The bulk density was the lowest for gaizes and the highest for flints and limestones (Figure 1).

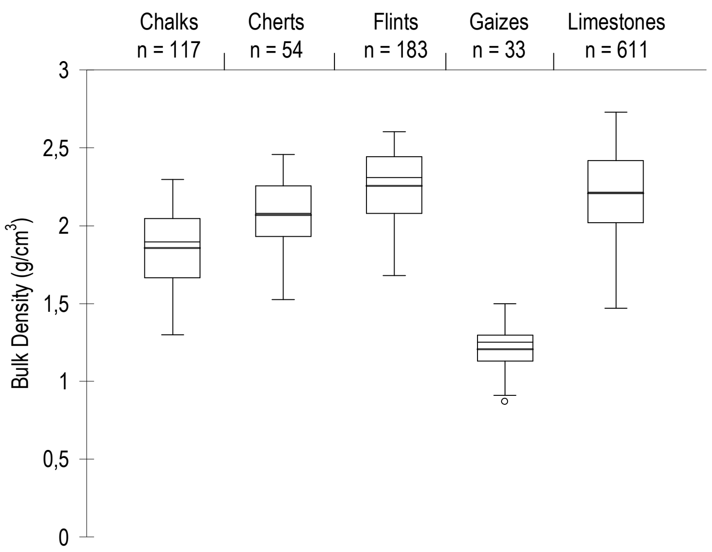

Figure 1: Box plot representing the ranges of bulk density by pebbles' type. n = sample number.

The same ordering was found for the measurements of solid density, but the reverse order was observed for the void ratio. Indeed, the void ratio increased in the following order limestones > flints > cherts > chalks > gaizes.

Characterization of pebbles hydric properties

Water content measurements showed that all types of studied pebbles can retain water, and the saturated water content can reach more than 60% for gaize. The determination of some points of the retention curve allowed us to show the following two results:

1/ Whatever the type of pebble, the water content at field capacity was very close to the water content at -100 hPa (Figure 2; Student test with r =0.99, P < 0.00001 and α = 0.05). For the different materials studied here, a simple relationship exists between the humidity of pebbles at -100 hPa and at field capacity.

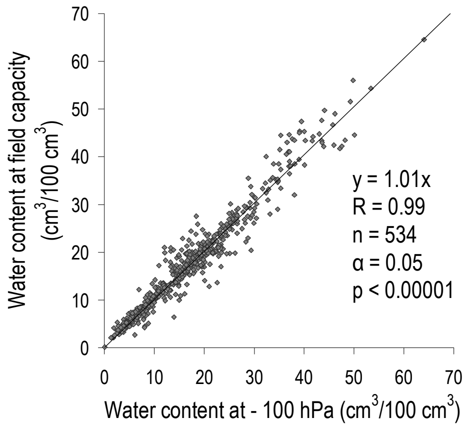

Figure 2: Relationship between water content at -100 hPa and at field capacity. R = correlation coefficient. n = sample number, all pebbles' type confused. α = threshold of significance. p = the probability that the hypothesis would be null.

2/ We also demonstrated that the water content at wilting point was, on average, equal either to half or three quarters of the water content at field capacity, depending on the pebble type. These relationships were validated statistically by a Student test.

From these two results, we derived a simple and useful pedotransfer function to calculate the Available Water Content (AWC) in pebbles contained in stony soils. The latter was calculated from the difference between the water content at -100 hPa and the water content at -15000 hPa:

$$AWC \sim \theta_{-100} - \theta_{-15000} \sim \zeta\, \theta_{fc} \quad (2)$$

where θ_{-100} represents the water content at -100 hPa, θ_{-15000} represents the water content at -15000 hPa, θ_{fc} represents the water content at field capacity and ζ is a parameter equal ½ or ¼ depending of the type of stone.

Conclusion

We demonstrated that pebbles have different porosity and water retention capacity depending of their type - limestones, flints, cherts, chalks, gaizes - but all could contribute to the hydric properties of stony soils. We also defined a simple pedotransfer function to estimate the contribution of the pebbles to the Available Water Content of a stony soil. The latter can be easily calculated from the water content at field capacity. This pedotransfer function has been validated over a large range of types of stones in sedimentary rocks and is robust. The next step would consist in determining pedotransfer functions in the fine earth to characterize its contribution to the Available Water Content. In the future, these pedotransfer functions will be used to map the Available Water Content of stony soils over large areas.

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