Water exchange between the fine earth and pebbles in remoulded soil samples

Marion Tétégan[A, B], Nathalie Korboulewsky[A,C], Alain Bouthier[B] and Isabelle Cousin[A]

[A] INRA, UR 0272 Science du Sol, Centre de recherche d'Orléans, 2163 Avenue de la Pomme de Pin, CS 40001 Ardon 45075 Orléans Cedex 02, France. Email Marion.Tetegan@orleans.inra.fr
[B] Arvalis – Institut du Végétal, Domaine expérimental du Magneraud 17700 Saint Pierre d'Amilly, France. Email a.bouthier@arvalisinstitutduvegetal.fr
[C] Aix-Marseille Université, IMEP, UMR CNRS-IRD - Centre Saint-Charles, case 4, 3 place Victor Hugo 13331 Marseille Cedex 03, France. Email nathalie.korboulewsky@univ-provence.fr

Abstract
Stony soils cover about 30% of the surface soils of Western Europe, and 60% in Mediterranean areas. Rock fragments may alter the physical, chemical and agricultural properties of soils. In particular, the stony phase may participate in the water supply of crops and change the storage capacity of soil water. This implies the existence of water transfer between rock fragments and fine earth. To better understand the interaction between the fine earth and rock fragments, we studied the transfer of water between the pebbles and the fine earth on remoulded soils in the presence and absence of plants.

Key Words
Stones, fine earth, water content, water exchange.

Introduction
Lots of physical and chemical exchanges occur in the rhizosphere between the soil, plant roots and micro-organisms. The physico-chemical, biochemical and biological processes that take place at the soil-root interface affect water transfer and fluxes of many elements, macro- nutrients like potassium and phosphorus or micro-nutrients like iron. But rock fragments are also a potential reservoir of water and nutrients for plants (Poesen and Lavee 1994; Coile 1953; Gras 1994; Cousin *et al*. 2003), suggesting that the stony phase of soil can participate in water supply to crops and affect the storage capacity of soil water. Some water exchanges between the rock fragments and the fine earth should then exist. The understanding of these exchanges between the rhizosphere and the soil would be a significant progress and would improve the existing "soil-plant" models. It is then necessary to understand mechanisms taking place between the different phases of soil: fine earth and stones. Our experiment, conducted on remoulded samples during one season under controlled conditions, aimed to analyse the water transfer between stones and fine fractions of soil and the effects of the proportion (0, 20, 40% in volume) of rock fragments and of the rhizosphere (with or without plants).

Methods
Experiments in controlled conditions (artificial light and 22°C in a greenhouse) with remoulded soils in containers (3 L) were conducted. Rock fragments and fine earth were collected separately from the Ap horizon of a calcareous lacustrine limestone silty soil located in the central region of France. The fine earth was sieved at 2 mm and air-dried. The rock fragments were sieved at 2-5 cm, which corresponds to the pebble fraction, washed under tap water and dried at 105°C during 2 days in an oven. The pebbles' bulk density was about 1.98 g/cm^3. Pebbles were mixed with the fine earth to reach a bulk density of the fine earth of 1.1 g/cm^3. Four modalities of remoulded soil, with different percentage in volume of pebbles, were created:

"0%p": 0 % pebbles + 100 % fine earth + plant
"20%p": 20 % pebbles + 80% fine earth + plant
"40%p": 40 % pebbles + 60% fine earth + plant
"40%": 40 % pebbles + 60% fine earth

Fifteen containers were created for each modality and cuttings of *Populus robusta* were planted in the three first modalities. All containers were saturated, then irrigated by capillarity and controlled to maintain a moderate water stress continuously. After three months, the containers were again saturated and then allowed to dry. At that time, plants were from 27 cm to 43 cm height depending on the modality. Soil samples were collected at 5 dates following this second saturation: D0, Day 2 = D0 + 2 days, Day 4 = D0 + 4 days, Day 7 = D0 + 7 days, Day 11= D0 + 11 days, where D0 corresponds to the soil water content equal to the Available Water Content. At each sampling date, the fine earth and the pebbles were separated at five depths inside each container. The gravimetric water content of the fine earth (Wfe) and the gravimetric water content of the pebbles (Wp) were measured; and the gravimetric water content of the soil (Wsoil) was calculated, knowing the volume percentage of fine earth and pebbles. Three containers of each modality were used at each date. Differences in water content between the pebbles and fine earth, and between the dates, were analysed by a variance analysis (ANOVA with a threshold of 5%).

Results

During drying, the water content decreased in both the fine earth and the pebbles, and differences between modalities were observed for each phase (Figure 1).

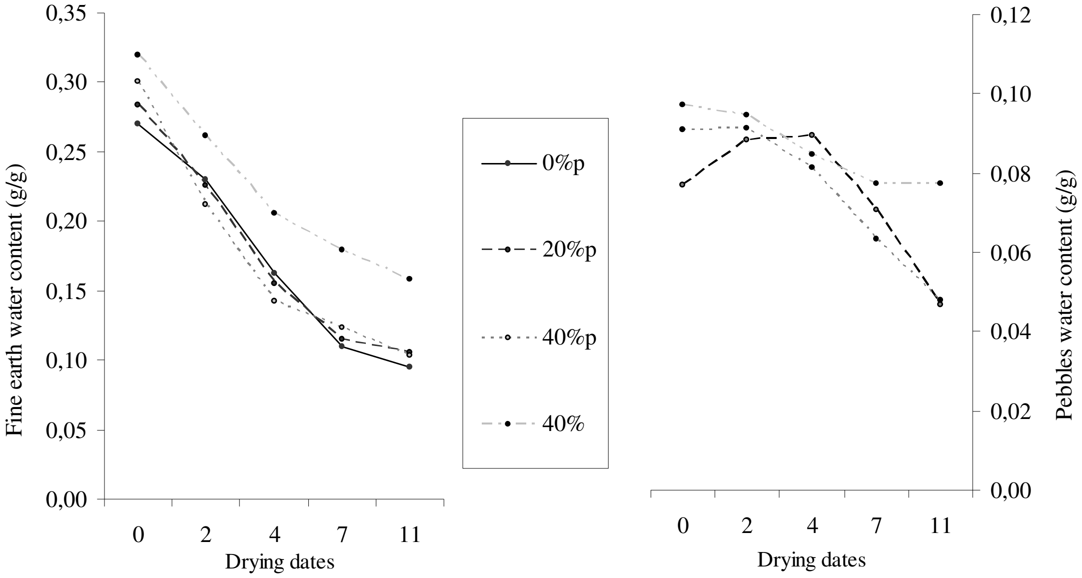

Figure 1. Temporal evolution of water content of fine earth (left) and pebbles (right).

The pebbles' effect

To study the effect of the proportion of pebbles, a statistical comparison was made between the modalities "0%p", "20%p" and "40%p".

The water content of fine earth in all modalities decreased from the beginning but the rate of decrease was less rapid from Day 4 to Day 11 (Table 1 and Figure 1). In contrast, the water content of the stony phase stayed stable at the beginning, and decreased after Day 7 for the modality "20%p", and after Day 4 for the modality "40%p".

There were significant differences in water content of the fine earth from the 4th day between the modalities (Table 2). The stony phase shows no differences for the modalities concerned (20%p and 40%p).

These results show that the fine earth of the modality without pebbles (0%p) lost water faster compared to modalities with pebbles ("20%p" and "40%p") from the 7th day. Meanwhile, pebbles lose water only from the 4th day or 7th day. This suggests a water transfer from the pebbles towards the fine earth occurs when drought starts to be severe which would explain the higher water content in fine earth for modalities with pebbles.

Table 1. Statistical analysis results on the temporal evolution of mass water content (g/g) by phase and by modality. The table reads left to right. Letters in group column correspond to differences between dates within a modality.

Fine Earth	Day 0			Day 2			Day 4			Day 7			Day 11		
	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group
0%p	0,270	0,016	a	0,230	0,019	b	0,162	0,007	c	0,110	0,003	d	0,095	0,005	d
20%p	0,283	0,038	a	0,226	0,021	b	0,155	0,010	c	0,115	0,003	d	0,105	0,002	d
40%p	0,301	0,021	a	0,212	0,014	b	0,143	0,005	c	0,123	0,003	cd	0,103	0,006	d
40%	0,320	0,014	a	0,261	0,029	b	0,206	0,012	c	0,179	0,007	cd	0,158	0,004	d

Pebbles	Day 0			Day 2			Day 4			Day 7			Day 11		
	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group
20%p	0,077	0,015	a	0,088	0,017	a	0,090	0,005	a	0,071	0,011	a	0,047	0,002	b
40%p	0,091	0,009	a	0,091	0,005	a	0,081	0,004	a	0,063	0,002	b	0,048	0,006	c
40%	0,097	0,006	a	0,095	0,008	a	0,085	0,007	ab	0,077	0,009	b	0,077	0,004	b

Table 2. Statistical analysis results on the daily comparison of water content (g/g) by phase between modalities. The table reads vertically. Letters in group column correspond to differences between modalities within a date.

Fine Earth	Day 0			Day 2			Day 4			Day 7			Day 11		
	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group
0%p	0,270	0,016	b	0,230	0,019	ab	0,162	0,007	b	0,110	0,003	c	0,095	0,005	c
20%p	0,283	0,038	ab	0,226	0,021	ab	0,155	0,010	bc	0,115	0,003	bc	0,105	0,002	b
40%p	0,301	0,021	ab	0,212	0,014	b	0,143	0,005	c	0,123	0,003	b	0,103	0,006	bc
40%	0,320	0,014	a	0,261	0,029	a	0,206	0,012	a	0,179	0,007	a	0,158	0,004	a

Pebbles	Day 0			Day 2			Day 4			Day 7			Day 11		
	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group	Average	Standard Deviation	Group
20%p	0,077	0,015	a	0,088	0,017	a	0,090	0,005	a	0,071	0,011	a	0,047	0,002	b
40%p	0,091	0,009	a	0,091	0,005	a	0,081	0,004	a	0,063	0,002	a	0,048	0,006	b
40%	0,097	0,006	a	0,095	0,008	a	0,085	0,007	a	0,077	0,009	a	0,077	0,004	a

The plant's effect

In order to study this effect, modalities "40%p" and "40%" were statistically compared. The water content decreased at a similar rate for the fine earth and we noted the same water content from the 7th sampling date for the fine earth for the 2 modalities (Table 1 and Figure 1). For the stony phase, significant differences from this 7th date onward were observed.

The day by day comparison between modalities (Table 2) showed that the water content of the fine earth of the "40%p" modality was significantly greater than the "40%"modality after Day0. Similarly, the drying of the rock fragments was more pronounced with a plant by Day 11.

These results indicate that, whatever the percentage of stones, the moisture of the fine earth reduces on average 1.3 times faster with a plant (modality "40%p") than without a plant (modality "40%p").

Conclusion

Results showed different behaviour for water loss between fine earth and pebbles during a drying period of 11 days. While water content of fine earth decreased from the beginning and onward, pebbles only started to lose water several days after. Plants enhanced the drying processes due to their transpiration but did not seem to modify the water transfer trends.

Evolution of water content in the fine earth and the coarse fraction suggests the existence of water exchange between the two phases to establish a water balance. In the future work we aim to determine the water exchanges using water retention curves of pebbles and fine earth to determine the radii of pores involved in this exchange.

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