Eurodrying'2019
Torino, Italy, July, 10-12 2019

DRYING BEHAVIOUR AND WATER TRANSPORT MECHANISMS DURING EVAPORATION OF AN AGRICULTURAL SOIL

Duc Kien Tran[1], Njaka Ralaizafisoloarivony[1], Aurore Degré[1], Angélique Léonard[2], Benoît Mercatoris[1], Dominique Toye[2], Robert Charlier[3]

[1]University of Liège, Gembloux Agro-Bio Tech,
Passage des Déportés 2, 5030 Gembloux, Belgium
[2]University of Liège, Chemical Engineering,
Quartier AGORA, Allée du 6 Août 19, 4000 Liège, Belgium
[3]University of Liège, Department ArGEnCo,
Quartier POLYTECH 1, Allée de la Découverte 9, 4000 Liège, Belgium

Email: a.leonard@uliege.be

Abstract

In this study, we aim to improve knowledge about the soil water evaporation process. First, evaporation tests were carried out to characterise the drying kinetics, soil temperature evolution and soil shrinkage. Second, numerical simulations of the test were performed using the finite element code LAGAMINE developed at the University of Liège. The aim is to reproduce numerically the drying behaviour of the soil and to emphasise the water transport mechanisms between the soil and the atmosphere.

Keywords*: soil water drying, drying kinetics, water transport mechanisms*

1. Introduction

The evaporation from soil surface is a complicated process in which liquid water moves from the deeper soil profile and then vaporises at the surface. The rate of evaporation depends not only on soil characteristics (structure, texture, etc.) or tillage methods but also on climatic conditions (radiation, relative humidity, temperature and wind speed). As a consequence of global warming and climate change, higher ambient air temperatures during dry seasons lead to a greater soil water evaporation fluxes, therefore, to a more rapid reduction of soil moisture contents in agricultural land. To cope with this situation, a comprehensive understanding of the kinetics of intensive evaporation and the soil behaviour during dry period are essential in order to maintain or even enhance the water retention capacity of the soil. Furthermore, it could help farmers to identify an appropriate tillage method and management practices to improve soil structure and maximise water storage.

2. Material and method

Composite soil samples were collected randomly from the upper surface of 0-10 cm from an agricultural field situated in Gembloux-Belgium. Evaporation tests were performed by means of HYPROP device, an accurate instrument to measure soil hydraulic properties through evaporation method (Peters and Durner, 2008). In this technique, saturated soil sample was placed on the device and both were weighed on a 0.01g precision balance. The soil surface then was exposed to a free evaporation. The variation in hydraulic head inside the soil sample was assessed by two tensiometers placed at different height while the changes in water content were determined by the changes in the weight of the sample. To accelerate the evaporation process, the measuring system with the sample were installed in a small environmental chamber heated by a heat lamp bulb. The temperature and the relative humidity of the chamber were sequentially recorded during the tests. A camera 12 Megapixels was also installed to capture the evolution of the soil surface each 30 mn of time interval.

For a better understanding of the water transfer mechanisms between the soil surface and the ambient, we performed numerical modelling of the evaporation test based on a fully coupled thermo-hydro-mechanical model in the framework of unsaturated soil and the experimental data obtained. Briefly, the mechanical model for soil skeleton behaviour is nonlinear elastic, written in terms of the Bishop's effective stress. For the fluid phases, a biphasic flow model is considered to describe the fluid transport processes in soil pore space. Considering that the soil we study is a loamy soil, we chose to fit the dual porosity model (Durner, 1994) for the water retention capacity. Finally, the drying kinetics is modelled using the boundary layer model (Gerard *et al.,* 2010), assuming that the vapour and heat transfer take place in a boundary layer at the surface of the porous medium.

3. Results and discussion

The drying kinetics of soil sample can be characterised by representing the drying curves in different ways: drying rate versus time or, drying rate versus the mean degree of saturation, in which the drying rate, $q = -\frac{dm}{dt}$, is calculated on the basis of the weight changes. Under the environmental conditions provided by the chamber-dryer, soil water started to evaporate at a very high rate, which decreased right after the beginning. This period lasted around 15h before the CRP started. It is noted that most of shrinkage of the soil samples took place during this period. Four periods of drying therefore were identified instead of three as in classical concept. The evolution of soil temperature at the soil top surface was also similar to Krischer's curve. However, the constant temperature observed in CRP, which corresponds to the wet-bulb temperature, was higher than the theoretical one. This fact may come from the experimental set-up, in which apart from the convective heat, the soil surface was subjected to a radiation heat flux from the drying air and the heat bulb lamp.

The numerical model was able to reproduce the kinetics of evaporation including the evolution of evaporation rate, soil temperature, as well as the soil surface shrinkage despite the lack of the mechanical properties. Four periods of the drying process were captured. On the moisture transport mechanisms, we showed that for high permeable materials such as agricultural soil, the Darcean advective flow is the predominant mechanism during the whole evaporation process. Open pathways for water vapour were also reproduced at the interface between the sample and the core ring of the device due to soil shrinkage.

4. Conclusions

In this study, we suggested using HYPROP device associated with a chamber-drier for the evaporation tests. This combination allowed at once to quantify qualitatively the drying kinetics and to characterise soil hydraulic properties, which is in general a time-consuming task. We also validated the capacity of the THM numerical model to reproduce the drying tests conducted.

Acknowledgments. The research was supported by one Post-doctoral fellowship funded by the "Fond Spéciale de la Recherche"- University of Liège, Belgium.

5. References

1. Peters, A., Durner, W., 2008. Simplified evaporation method for determining soil hydraulic properties. *J. Hydrol*., 356 (1–2): 147–162.

2. Durner, W., 1994. Hydraulic conductivity estimation for soils with heterogeneous pore structure. *Water Resour. Res.*, 30(2), 211-223.

3. Gerard, P., Léonard, A., Masekanya, J. P., Charlier, R., Collin, F., 2010. Study of the soil–atmosphere moisture exchanges through convective drying tests in non-isothermal conditions. *Int. J. Numer. Anal. Meth. Geomech.*, 34(12):1297-1320.