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Experimental investigation of thermal and moisture behaviors of wet and dry soils with buried capillary heating system

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Abstract

An experimental study of thermal and moisture behaviors of dry and wet soils heated by buried capillary plaits was done. This study was carried out on a prototype similar to an agricultural tunnel greenhouse. The experimental procedure consisted on three different measuring phases distinguished by three different operational conditions of the capillary plaits: heating at 70 °C, heating at 40 °C and without heating in summer. During an experimental run, quantities measured are soil temperature, soil water content at various depths, soil surface heat flux, solar radiation under the plastic cover, internal relative humidity, internal and external air t\emperature. In unsaturated moist soils, the transport of heat is complicated by the fact that heat and mass transfer is a coupled process. During the daily soil temperature variation, it was found that the surface temperature amplitude was higher in wet soil than in dry soil. The water content increased during daytime and decreased during nighttime. The diurnal variation amplitude of water content was higher without underground heating and decreased with the buried heat source temperature.

Keywords: Wet soil; Dry soil; Temperature; Moisture content; Soil heat flux; Underground heating

1. Introduction

Soil warming in horticulture, especially in greenhouses, is used to store thermal energy and to restore it for cold weathers. It is a method for increasing crop yield and growth rates. It is an attractive alternative to conventional heating techniques because it relies on low temperature energy sources, such as industrial waste heat, geothermal and solar energy (Dayan et al., 1984). Temperature and moisture content in the root zones of plants are affected by solar radiation, ambient temperature variations and underground heating. A significant soil temperature fluctuation can influence the plants and the insects biological processes, pesticides and

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fertilizers decomposition, nutriments mineralizing and micro-organisms breathing. Thus, it would be of great interest to understand thermal and moisture behaviors of soil with underground heating.

Heat and mass transfer in moist soils is a coupled process (Philip and De Vries, 1957). The heat transport is complicated by the fact that temperature gradients cause moisture movement, so that the moisture will tend to redistribute itself when temperature field changes. The moisture movement, which occurs both in the liquid and in the vapor phases, gives rise to a transport of sensible and latent heat, which again influences the temperature distribution (De Vries, 1963). Moisture moves in the form of water vapor from the warm to the cold soil while liquid water transfer takes place in the opposite direction. The mass flux of water vapor is primarily due to the temperature gradient, while the mass flux of water liquid is primarily due to the difference in the soil moisture content (Shah et al., 1984).

When a temperature gradient exists within unsaturated soil, a natural thermally insulating region of dry soil near the warm surface will be developed. This insulation will causes the surface heat flux to fall and the surface temperature to rise (Sifaoui and Perrier, 1978; Ewen, 1990).

Thermal properties (thermal conductivity, heat-storage capacity and thermal diffusivity) in wet soil (after rain in the field) increase with water content and wet soil temperature decrease in comparison with dry soil (Anandakumar et al., 2001). Poulovassilis et al. estimated apparent soil thermal diffusivity and heat flux densities according to the amplitude and phase delay methods from soil temperature data at several depths for wet and dry soil. They deduced that the two methods used give reasonable estimates. Ratios of the thermal diffusion coefficient to the moisture diffusion coefficient, for two types of soils, were experimentally determined by Shah et al. (1984). The ratio of the diffusions coefficients was found to increase with increasing moisture content, reach a broad maximum, and thereafter decrease except for the driers regions near the worm end.

Buried heating systems affect the heat and mass transport in the soil. There is a vast literature on this subject (Santamouris et al., 1994; Mihalakakou et al., 1994). Temperature distribution in soil around a network of subsurface horizontal warm water pipes was investigated by Dayan et al. (1984). Computation of soil thermal conductivity revealed a linear dependence on temperature due to the presence of moisture and induced vapor diffusion within the pore space. Analysis were extended to account for effects of desiccation around the heated pipes. Moya et al. (1999) analysis experimentally heat and moisture transfer around a heated cylinder buried into an unsaturated soil. The main motivation for their work was its application for high voltage power distribution with underground cables. They found that great soil capacity for retaining moisture is an important feature if high thermal conductivities around the heat source are desired.

The present paper describes an experimental investigation of the soil thermal and moisture behaviors when a buried capillary system was used. Experiments were conducted simultaneously for wet and dry soils under three different operational conditions of the capillary plaits: heating at 70 °C, heating at 40 °C and without heating in summer.

2. Experimental installation and process

This study was carried out on a prototype which simulates an agricultural tunnel greenhouse consisted of

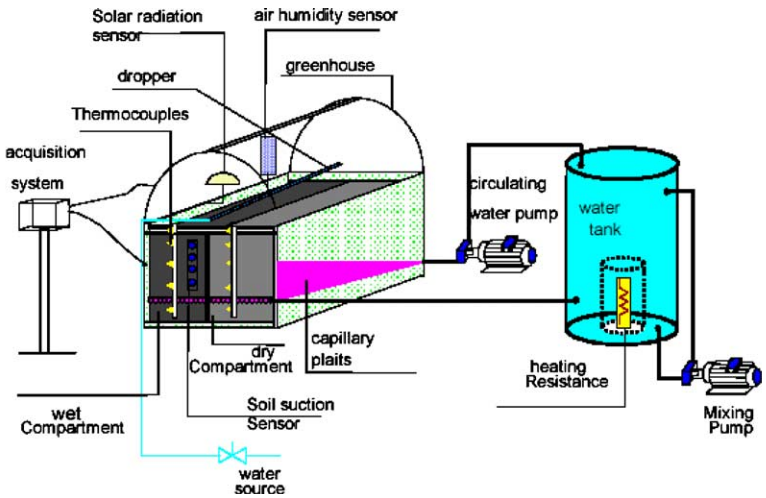

Fig. 1. Experimental installation.