Le Corps professoral de

Gembloux Agro-Bio Tech - Université de Liège vous prie

de lui faire l'honneur d'assister à la défense publique de la dissertation originale que

Monsieur CHEN Baoqing,

Titulaire d'un *master of agricultural extension*

présentera en vue de l'obtention du grade et du diplôme de

DOCTEUR EN SCIENCES AGRONOMIQUES ET INGENIERIE BIOLOGIQUE,

le 29 mai 2018, à 16 heures précises (personne ne sera admis après cette heure),

en l'auditorium TOPO1 (Topographie, bât. 3)**,**

Passage des Déportés, 2 à 5030 GEMBLOUX.

Cette dissertation originale a pour titre :

« Measuring and modeling spatio-temporal soil moisture dynamics at the field scale with plastic mulching in dryland agriculture ».

Le jury est composé comme suit :

Président : Prof. J. BOGAERT, Professeur ordinaire,
Membres : Prof. S. GARRE (Promoteur), Prof. Y. CHANGRONG (Copromoteur - CAAS, Chine), Prof. A. DEGRE, Dr B. DUMONT, Prof. G. COLINET, Prof. M. XU (CAAS, Chine), Prof. E. LIU (CAAS, Chine).

Summary

Drylands include arid, semi-arid, and dry sub-humid ecosystems characterized by low and irregular rainfall and high evapotranspiration. Drylands cover about 41% of the Earth's land surface and are home to more than 30% of the total global population. Water shortages and low soil water content (SWC) in dryland seriously limit crop production, especially when irrigation is not available (i.e., rain-fed agriculture). Moreover, because of the long duration of drought and intense water pulses, drylands usually experience intense soil moisture fluctuation (SMF), which leads to a high risk of soil degradation. Plastic mulching (PM) has been developed as an effective measure to alleviate drought in rain-fed drylands. Although soil water dynamics under PM have been widely studied, most of our knowledge is derived from measurements at the point scale, which only represent a small portion of whole soil profiles. There is still a lack of knowledge regarding spatial variations in SWC and SMF. 'From points to profiles' not only allows for a deeper understanding of the effects of PM on soil moisture dynamics, it also lays the foundation for further understanding soil processes driven by soil moisture dynamics, improves the sensing and modeling strategies for soil processes, improves PM practices, and further contributes to the development of dryland agriculture.

In this dissertation, we adopted a research route including field measurements, model optimization, and model prediction to quantify how partial PM affects soil moisture dynamics in space and time simultaneously. Specifically, we first measured the soil moisture using point-scale methods in the field; second, we optimized two-dimensional (2D) simulation methods using measured point-scale soil water data. Finally, spatio-temporal soil moisture dynamics were predicted using optimized 2D simulation; at the same time, electrical resistivity tomography (ERT) was applied to verify the 2D simulation results.

For the first part of our research, we mainly aimed to address how PM influences the soil water dynamics at the point scale. At the same time, we also aimed to identify the effects of PM on crop yield, water use efficiency (WUE), and economic benefits. Considering plastic pollution, a PM method called *one film for two years* (PM2) was proposed in this study, and comparisons were conducted among no mulch (NM), traditional PM, and PM2. According to two years of field experiments, we found that PM and PM2 are effective in improving the soil moisture content during the growing season. Compared to NM, the PM treatment led to yield improvements of 12.1% and 25.0% in the two experimental years. Compared to PM, similar average soil moisture contents, maize yields, and WUE were recorded in PM2, but economic profits were improved because of savings on plastic film, tillage costs, and labor costs. Moreover, because the amount of plastic residue was reduced by half and no tillage was adopted to prevent the incorporation of plastic residue into soil in PM2, PM2 has potential to promote the sustainable development of drylands.

In the second part, we aimed to optimize simulation to reproduce soil water dynamics in fields with PM with the measured soil water data in the field. Considering the dominant role of rainfall infiltration in rain-fed agriculture, we developed a simulation approach that uses a bare strip boundary, a plastic strip boundary, and a planting hole boundary (BPH) to consider the effects of rainfall canopy redistribution and film side infiltration. We compared this approach's performance to that of two others that were developed by previous researchers: a BP- approach that uses a bare strip boundary and a plastic strip boundary without considering film side infiltration and rainfall canopy redistribution and a BP+- approach that uses a bare strip and a plastic strip that considers film side infiltration by increasing rainfall infiltration in the bare strip. Our results that showed BP and BP+ failed to reproduce soil water dynamics in field, while BPH showed good performance. This result suggests that is necessary to take into account changing canopy redistribution, crop growth, and film side infiltration in simulations by numerically solving the Richards equation using PM.

Finally, we quantified the field-scale spatial variations in SWC and SMF with the optimized simulation strategy and ERT measurements. The modeling results indicated that the highest SWC appeared in the zone near the planting hole. The center zone of the plastic strip was drier, and the bare strip was the driest. Compared to NM, PM not only improved the SWC in the plastic strip but also improved the SWC in the bare strip. The modeling and ERT results suggested that the application of PM resulted in contrasting SMF between the mulched strip and the bare strip in PM, and the SMF in the mulched strip was relatively constant compared to that in the bare strip. Nevertheless, when the SMF was compared between PM and NM using Hydrus 2D, we found that PM reduced the SMF of the whole soil profile compared to NM, meaning that the PM not only alleviated the SMF in the mulched strip but also alleviated it in the bare strip.

In this dissertation, the spatio-temporal soil water dynamics were addressed using PM at the field scale in a maize field, which was located in a semi-arid, rain-fed area with sandy loam soil. As the development of new PM methods and materials is ongoing and spatio-temporal soil water dynamics may change with changing soil and climate conditions, further studies on different PM methods and materials in different climate and soil conditions may be necessary. In a broad sense, improving crop yield, economic benefits, and sustainability is important for the development of dryland agriculture. Our study contributes to improving these factors by improving PM methods to ensure higher economic benefits and sustainability, improving the modeling of soil water transport, laying the foundation to model other processes related to crop production and environmental sustainability, and providing soil water dynamics information in a high spatio-temporal resolution, which is necessary to further improve PM methods and regulate the soil processes driven by soil water dynamics. Even with this knowledge, improving plastic technology and developing dryland agriculture still have a long way to go. In particular, we are facing a revolution in PM technology from the pursuit of yield and economic benefits to the pursuit of higher yields, economy benefits, and environmental sustainability. Long-term experiments are necessary to clarify the influences of PM on the environment other than yield improvements. Supplementary studies are still needed in the future in order to select effective and sustainable PM strategies for the agriculture of the future.