Soil Hydrothermal balance in farmland system and its response to human activities

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Abstract: The problem of soil hydrothermal balance in farmland system is an important issue to study the formation and change mechanism of farmland climate and microclimate. As an important part of terrestrial ecosystem, the farmland ecosystem has dynamic changes in soil moisture and heat. Due to its particularity, the farmland ecosystem is also a land type directly affected by human activities. This paper systematically summarized the importance of soil hydrothermal interactions in farmland systems, the law of water and heat balance in farmland system and the recent research on the coupling model of hydrothermal balance in farmland system at home and abroad. In addition, this paper also elaborated the research progress of the response of farmland water and heat balance to farmland irrigation, film mulching and other human activities, so as to provide a theoretical basis for the effective use of farmland water resources and the cultivation of high-quality crops in the future.

1. Introduction
Soil-plant-atmospheric continuum (SPAC) is the core issue in the field of agricultural ecosystem research. As an important part of terrestrial energy balance and water cycle, water transport and heat transfer play an extremely important role in this system[1]. By the end of 2016, the cultivated area of the whole country in China reached 135 million ha. Agricultural activities have become one of the important factors affecting the soil hydrothermal balance of the SPAC system[2]. Simultaneously, with the promotion of national industrialization and urbanization, China's arable land area has a general trend of shrinking. The studies of soil hydrothermal balance in farmland system will provide a theoretical basis for selecting reasonable planting mode and achieving the agricultural management goal of increasing production.

The hydrothermal balance of farmland system is also an important issue in the study of farmland climate and microclimate formation and its mechanism of change. As an important part of the terrestrial ecosystem, farmland ecosystem is a land type directly affected by human activities[3]. With the intensification of human activities and the improvement of social technology, farmland ecosystem gradually evolved into the product of human irrigation and agriculture development and so as to have a significant impact on farmland ecosystem[4]. Therefore, the understanding of water and heat coupling characteristics and their respective change rules in farmland system is not only conducive to the cognition of the current situation and the prediction of future change trend of farmland, but also an important prerequisite for the analysis and evaluation of farmland ecosystem's production capacity and production potential[5]. In this paper, the importance of the relationship between water and heat in farmland system, the law of soil hydrothermal balance in farmland system and the recent research on the coupling model of soil hydrothermal balance in farmland system are summarized. In addition, this
paper also makes an in-depth analysis and elaboration on the response of farmland water heat balance to human activities, so as to provide a theoretical basis for the research on farmland water heat balance and the efficient utilization of farmland water resources in the future.

2. Soil Hydrothermal Balance in Farmland System

2.1. Status and importance of hydrothermal interrelationships in agricultural system
The heat of farmland soil mainly comes from the radiation of sunlight, which is expressed by soil temperature. Soil surface temperature affects the sensible heat flux, latent heat flux and net radiation in the soil, thus affecting the heat flux of the soil itself. Soil surface moisture distribution affects evaporation and runoff, and controls the absorption and emission of solar radiation by soil and crops[6]. At the same time, the change of soil temperature affects the migration of soil moisture, and in turn, there will be heat transfer in the process of water migration in farmland soil. It can be seen that water and heat in farmland soil are interrelated. Therefore, the study of the relationship between soil water and heat, analysis of the mechanism of moisture migration and heat transmission in each link in farmland system, as well as its relationship with environmental conditions, which is helpful to predict the distribution of soil moisture and agricultural production.

2.2. Soil Hydrothermal Balance in Farmland System
At present, many domestic and foreign scholars have done a lot of researches on the soil hydrothermal balance in farmland system. As a simulation technology for complex engineering, the model can more conveniently reproduce the migration and distribution of water and heat in farmland system[7]. Therefore, many scholars have conducted more studies on the hydrothermal balance of farmland system by means of model simulation.

Wegehenkel proposed the THESEUS system model by summarizing and analyzing other water and heat balance models[8]. The model mainly simulated the relationship between water balance factors and crop growth, and solved the coupling problem of water and heat transfer and exchange between the atmosphere and the surface of the earth in the process of water balance that had not been solved by other models[8,4]. New Zealand scholar J Olejnik et al. applied the actual hydrothermal data of farmland systems in central Europe to THESEUS water balance model for further research and evaluation. The study found that the evapotranspiration calculated by energy Bowen ratio is in good agreement with the simulation results[9]. The Aboitiz found that the change of evapotranspiration in the time domain can be described by the regression moving average ARMA model, and the model can be established according to the random change law of evapotranspiration[10]. Schütze and Kloss followed Aboitiz's research to optimize farm irrigation decisions based on the established stochastic model combined with the crop yield model[11].

Domestic researches on the hydrothermal balance within the microclimate of farmland began in the 1980s. Kang Shaozhong et al. proposed the SPAC water transmission simulation model for three systems, namely dynamic simulation of soil water in root area and simulation of water absorption, evaporation and transpiration of crop root system, and designed a general software for water transfer simulation of SPAC[12]. Mao Xiaomin et al. conducted a simulation study on the latent heat-soil-plant-atmosphere system of farmland in arid regions, discussed the influencing factors of latent heat-evaporation, and established a mathematical model of submersible evaporation by combining the theory of hydro-heat transfer in soil and the theory of hydro-heat transfer between land and atmosphere[13]. Wang Haibao et al. proved that the P-M formula based on remote sensing could well achieve the estimation of evapotranspiration of farmland systems in arid regions[14]. Zhang Yongqiang et al. used bowen ratio energy balance method and vorticity correlation technique to comprehensively study the flux balance process of typical farmland in North China Plain, and numerically revealed the long-term change process of hydrothermal transfer[15]. Yao Delang et al. established the hydrodynamic coupling model of red soil farmland, proposed the second-order precision Euler implicit scheme in the finite difference calculation, and carried out numerical
simulation of the terrestrial land-gas and water-heat exchange process of red soil rapeseed field[16]. Based on the energy balance equation and the hydrothermal coupling equation of red loam, Wu Hongyan et al. established the SPAC model by integrating the hydrothermal changes of crop canopy and soil interior, and simulated the hydrothermal transfer process of cotton field[17].

3. Response of Soil Hydrothermal balance in Farmland System to Human Activities

3.1. Effect of Irrigation on Soil Hydrothermal Balance in Farmland System

At the end of 2016, the irrigated farmland in China covered an area of 61.89 million ha[3]. Irrigation can increase farmland moisture, enhance solar radiation absorption, and change near-surface temperature, humidity, and soil properties.

By using SWAT model, Gosain et al. studied the spatial-temporal variation characteristics of groundwater regression caused by farmland irrigation, and evaluated the study of irrigation and other human activities on farmland water balance[18]. By observing the micro-climatic factors such as temperature and humidity in the paddy field ecosystem, Li Qian et al. systematically studied the law of water-heat balance in the paddy field system, and based on this, established the coupling model of water-heat transmission in irrigated paddy field. It is concluded that irrigation can significantly change the water state in the paddy field system. When the water layer is relatively shallow, increasing irrigation water can significantly improve the overall humidity, but at the same time reduce the overall air temperature and leaf temperature in the paddy field[8]. Ji Xinbin et al. used Richard's equation and a water balance model to simulate the condition of crops in the semi-arid area of Northwest China under traditional irrigation conditions. The experimental results show that the SPAC system is used for the relationship between plant evapotranspiration and groundwater infiltration, and through experiments proved that increasing the number of irrigation and reducing the irrigation is more suitable for local water shortage conditions[19].

3.2. Effect of Film Mulching on Soil Hydrothermal Balance in Farmland System

Film mulching technology is widely used in vegetable planting in the world, in order to improve crop yield, film mulching technology is not only used for vegetables, but also used in corn, cotton, wheat, potato and other crops in arid and semi-arid areas in China. By 2014, China's film mulching farmland area accounted for 19% of China's available farmland area[20]. Film mulching will affect the surface energy balance, and thus affect the process of water-heat transfer in farmland soil.

Malik and Tran studied the influence of plastic film mulching on radiation transmission, and found that the water droplets formed by plastic film would reduce the transmittance of long-wave radiation, but have little influence on the transmittance of short-wave radiation of the sun. In order to study the influence of transparent film on soil water and heat under soil mulch, Mahrer et al. established a one-dimensional model of soil water and heat movement under mulch, and compared soil simulated humidity and temperature profiles of light clay and sandy soil with field observations. The results showed that plastic film mulch had a significant influence on the distribution of soil water and heat[21]. Qi Mingdi et al. conducted research and analysis on farmland microclimate factors, water and heat fluxes under full drip irrigation conditions, and found that film mulching changed the water and heat balance of the farmland system, reduced the net radiation of corn, increased the soil heat flux, and reduced soil evapotranspiration, which changes the distribution pattern of water and heat flux in the farmland system[22]. Film mulching can prevent vertical evaporation of water and reduce water deficit. The film cut off the soil and the outside of the water exchange, the latent heat exchange. Film mulching have a weakening effect on the long wave anti-radiation, which slows down the temperature drop[23].
4. Main issues and Outlook

4.1. Main issues
The law of the soil hydrothermal balance in farmland system is relatively scattered. In order to provide good conditions for the water and heat problem of farmland ecosystem, it is necessary to systematize and deepen the theory and standardize and unify the observation methods.

The coupling model of dynamic simulation of soil hydrothermal balance in farmland system is seldom studied. Therefore, the construction of a coupling model that can dynamically simulate the soil hydrothermal balance within the farmland system will be the focus and direction of future research.

4.2. Outlook
With the more extensive application of computer technology, the further development of automatic observation, remote sensing and model simulation makes soil science, plant physiology and other research fields combine with science and technology, which will vigorously promote people's understanding of the nature of the process of hydrothermal balance and the mechanism of hydrothermal transmission in farmland system. In addition, the impacts of human activities on the water-heat balance of farmland system summarized in this paper are only irrigation and film mulching. Other response researches, such as farmland management mode and crop planting mode, can be further studied to provide a reliable theoretical basis for improving the global environment and maintaining the balance of farmland ecosystem.

5. Conclusions
Soil hydrothermal balance in farmland system involves a wide range of contents, including the research on the dynamic change of farmland soil water, farmland water balance and farmland heat balance, farmland evaporation and transpiration, and farmland radiation balance.

Soil moisture and heat in farmland are frequently disturbed by human activities. When the water layer is relatively shallow, increasing irrigation water can significantly improve the overall humidity, but at the same time reduce the overall air temperature and leaf temperature in the paddy field. Mulch will affect the surface energy balance, and thus affect the process of water-heat transfer in farmland soil.

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References
[1] Liu, C.M., Sun, R. (1999) Ecological Aspects of Water Cycle: Advances in Soil Vegetation Atmosphere of Energy and Water Fluxes. J. Advances in Water Science, (03): 3-5.
[2] State Statistical Bureau, (2018). Bulletin of Key Data of the Third National Agricultural Census (No. 1). http://www.stats.gov.cn/tjsj/tjgb/nypcgb/qgnypcgb/201712/t20171214_1562740.html.
[3] Wang, B., Liu, S.R., Cui, X.H., Bai, X.L. (2002) Advances in the Research on Water and Heat Balance Laws of the Global Terrestrial Ecosystem. J. World Forestry Research, (01): 19-28.
[4] Chu, G.M., Pan, C.D., Wang, M., Jin, Y. (2011). Construction of Shelter-ecological Security System of Artificial Oasis. J. Hubei Agricultural Sciences, 50 (02): 277-280.
[5] Wang, B. (2002) Water and Heat Balance and Its Coupling simulation at Transition Region between Oasis and Desert. D. Chinese Academy of Forestry.
[6] Yao, D.L., Li, J.C., Shen, W.M. (1996) A Coupling Model of Water-Heat Movement in the Soil of Sand-Fixation Area. J. Chinese Journal of Theoretical and Applied Mechanics., (05): 2-10.

[7] Kato, C., Nishimura, T., Hiromi, I., et al. (2010) Applicability of Hydrus to Predict Soil Moisture and Temperature in Vadose Zone of Arable Land under Monsoonal Climate Region. C. World Congress of Soil Science, Soil Solutions for a Changing World. Brisbane., 1-4.

[8] Li, Q. (2018) Study on Water-Heat Exchange Characteristics and Coupling Model of Rice under Irrigation. D. Nanjing University of Information Science & Technology.

[9] Olejnik, J., Eulenstein, F., Kedziora, A., et al. (2001) Evaluation of A Water Model using Data for Bare Soil and Crop Surfaces in Middle Europe. J. Agricultural and Forest Meteorology., (106): 105-116.

[10] Aboitiz, M., Labadie, J.W., Heermann, D.F. (1986) Stochastic Soil Moisture Estimation and Forecasting for Irrigated Fields. J. Water Resources Research., 22 (2): 180-190.

[11] Schütze, N., Kloss, S., Lennartz, F., et al. (2012) Optimal Planning and Operation of Irrigation Systems under Water Resources Constraints in Oman Considering Climatic Uncertainty. J. Environmental Earth Sciences, 65 (5): 1511-1521.

[12] Kang, S.Z., Liu, X.M., Gao, X.K., Xiong, Y.Z. (1992) Computer Simulation of Water Transport in Soil-Plant-Airmosphere Continuum. J. Journal of Minzu University of China (Natural Sciences Edition). (02): 101-110.

[13] Mao, X.M., Yang, S.X., Lei, Z.D. (1998) Research on Water and Heat Transfer in SPAC of Winter Wheat in Yerqiang Irrigation Area. J. (07): 3-5.

[14] Wang, H.B., Ma, M.G. Estimation of Transpiration and Evaporation of Different Ecosystems in An Inland River Basin Using Remote Sensing Data and the Penman-Monteith equation. J. Acta Ecologica Sinica., 34 (19): 5617-5626.

[15] Zhang, Y.Q., Liu, C.G., Yu, Q., Sun, H.Y., Jia, J.S., Shen, Y.J., Tang, C.Y. (2002) Measurement and Analysis of Water, Heat and CO2 Flux from a Farmland and in the North China Plain. J. Acta Geographica Sinica., (03): 333-342.

[16] Yao, D.L., Zhang, Q., Du, Y., He, Y.Q., (2003) Land-Atmosphere Coupling Model and Its Application in Red Soil Areas. J. Journal of Minzu University of China (Natural Sciences Edition). (02): 101-110.

[17] Wu, H.Y., Shen, S.H., Xu, W.G. (2001) A Multi-Layer Model for Water and Heat Transfer in Soil Plant Atmosphere System of Cotton. J. Transactions of Atmospheric Sciences., (01): 137-142.

[18] Gosain, A.K., Rao, S., Srinivasan, R., et al. (2005) Return-Flow Assessment for Irrigation Command and in the Palluru River Basin Using SWAT Model. J. Hydrological Processes., 19 (3): 673-682.

[19] Ji, X.B., Kang, E.S., Chen, R.S., Zhao, W.Z., Zhang, Z.H., Jin, B. (2007) A Mathematical Model for Simulating Water Balances in Cropped Sandy Soil with Conventional Flood Irrigation Applied. J. Aragicultural Water Management., 337-346.

[20] Ming, G.H. (2018) Heat, Water, Salt and Carbon Fluxes under Plastic Mulched Drip Irrigation in An Oasis. D. Tsinghua University.

[21] Mahrer, Y., Naot, O., Rawitz, E., et al. (1984) Temperature and moisture regimes in soils mulched with transparent polyethylene. J. Soil Science Society of America Journal., 48 (2): 362-367.

[22] Qi, M.D. (2019) Effects of Film Mulching on Microclimate and Maize Farmland under Full drip Irrigation. D. Shandong University of Technology.

[23] Zhang, D.Q., Miao, Y.C., Jia, Z.K. (2005) Agricultural Research in the Arid Areas. J. Agricultural Research in the Arid Areas., (01): 208-213.

[24] Li, Q.Z., Li, Y.Z., Guo, J.X., Liu, X.Y., Xu, C.Y. (2010) Effects of Field Rainwater Harvesting by Plastic Mulch and Complement Irrigation on Soil Water and Yield of
Winter Wheat. J. Transactions of the Chinese Society of Agricultural Engineering, 26 (02): 25-30.

[25] Kato, C., Nishimura, T., Hiromi, I., et al. (2010) Applicability of Hydrus to Predict Soil Moisture and Temperature in Vadose Zone of Arable Land under Monsoonal Climate Region. C. World Congress of Soil Science, Soil Solutions for a Changing World. Brisbane., 1-4.