天水条件下のマルチ被覆ダイズ栽培土壌中の水・熱移動解析
Modeling of water and heat flow in mulched soil under rain-fed soybean cultivation

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1. Introduction

Global warming and irregular rainfall pattern have been limiting agricultural water resources in arid and semi-arid regions, which need effective utilization of water by managing soil environment. Soil mulching is one of the useful water management technologies in rainfed cultivation which is crucial to conserve soil moisture by reducing evaporation, alter soil temperature, and improve water use efficiency as well as crop yields (Kader et al., 2017). Numerical modeling is an effective way for predicting water and heat flow in mulched soils in order to increase the opportunity for efficient use of mulching in agriculture. We simulate soil water and heat flow for two types of mulch, straw and plastic-hole (a new type of mulch application method designed by cutting extra holes on plastic film for increasing rainwater infiltration in addition to the holes for planting) in comparison with bare soil (no mulch) in a rainfed soybean field and quantify water balance and effectiveness of mulching.

2. Materials and methods

Experiments: A two-year field experiment was conducted during 2015 and 2016 at Gifu University, Japan in which rainfed soybean (*Glycine max cv. Meguro*) was cultivated in a sandy loam soil with the treatments of rice straw mulching (0.5 kg m^{-2}), plastic with hole mulch (film thickness 20 µm, hole size 3 cm and density 0.36 m^2) and bare soil (no mulch). Several sensors/probes and dataloggers were employed to record hourly meteorological data at study site and hourly soil moisture and temperature data of each treatment was collected from 5, 15 and 25 depths. Soil physical properties like soil water retention function, saturated hydraulic conductivity, soil texture, bulk density were analyzed at laboratory for the soil profile of 0–30 cm with 10 cm intervals.

Simulations: HYDRUS-1D (Šimůnek et al., 2013) is used for straw mulched soil by considering an additional layer (surface to 3 cm depth) equivalent to straw material to simulate the coupled flow of vapor, water and heat. Hydraulic and thermal properties are optimized for straw layer. HYDRUS-2D (Šimůnek et al., 2018) is used for plastic-hole mulched soil by considering soil surface boundary conditions according to the state of the surface. Time variable flux (0 cm d^{-1}) boundary is set for the plastic-mulched area and the atmospheric boundary is for bare surface planting and plastic-holes area. Input parameters for atmospheric boundary were imposed by daily data of rainfall and potential evapotranspiration estimated using air temperature, soil surface temperature and net radiation. The hydraulic and thermal parameters of each layer was optimized by inverse solution and trial-error approaches for best fitting of field monitored data. Initial soil hydraulic parameters for inverse solution were obtained from RETC software following van Genuchten-Mualem model. Statistical indicator RMSE is used to analyze the performance of model.

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3. Results and key findings

The straw mulch and bare soil treatments are successfully simulated with small RMSE (0.016–0.044 cm^3cm^{-3} for soil moisture and 0.94–1.63°C for soil temperature) (**Fig. 1**). The simulation reveals that straw layer significantly reduces soil water consumption and soil water storage change compared to no-mulch (**Table 1**). The extra layer of straw mulch stores heat and transferres it to soil surface and, consequently, reduces temperature of the mulched soil compared to bare treatment. The calculated results also reveal that the straw layer enhances rain water infiltration and limits evaporation from the soil surface in the soybean field.

The accuracy of the simulation for plastic-hole mulch and bare soil are satisfactory with lower RMSE for soil moisture (0.028–0.055 cm^3 cm^{-3}) and soil temperature (0.70–1.54°C) **(Fig. 2)**. Water balance results reveal that infiltration is 52 % lower, evaporation is 53% lower and water loss from the bottom is 42% lower in the plastic-hole mulch than bare soil **(Table 1)**. Transpiration is higher in plastic-hole mulch than plastic mulch without extra holes and almost same as bare soil.

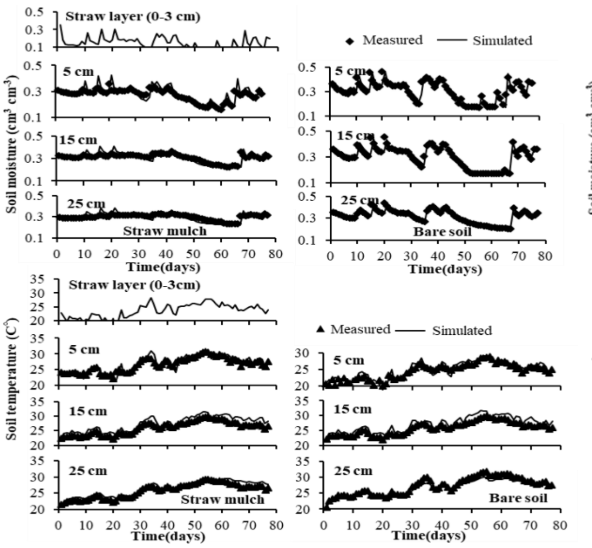

Fig. 1 Comparisons of measured and simulated soil moisture and temperature for straw and bare treatments.

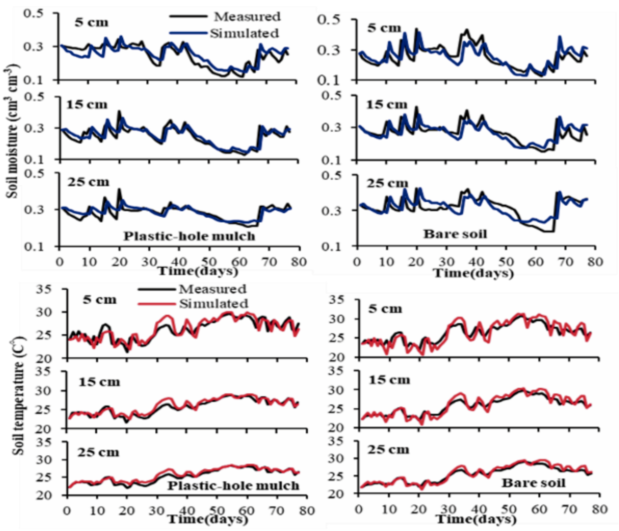

Fig. 2 Comparisons of measured and simulated soil moisture and temperature for plastic-holes and bare treatments.

Table 1 Water balance components during simulation periods.

Water balance component for straw and bare treatments							
Treatments	Infiltration	Evaporation	Runoff	vTop	vRoot	vBot	ΔS
	Total cumulative value (cm)						(cm)
Bare 2015	71.00	5.14	0.20	65.66	32.10	36.30	–2.74
Straw 2015	71.49	6.17	0.45	64.87	32.79	34.35	–2.27
Bare 2016	59.98	3.82	0.16	55.99	36.07	46.04	–26.11
Straw 2016	60.21	7.45	0.47	52.30	35.18	32.98	–15.86
Water balance component for plastic-holes and bare treatments							
Treatments	Infiltration	Evaporation	vRoot	vBot	ΔS		
	Total cumulative value (cm^2)				(cm^2)		
Plastic	6933.1	1197.1	5091.1	992.46	–347.56		
Plastic-hole	9312.9	1694.6	5238.1	3728.0	–1347.8		
Bare soil	17710	3151.1	5223.1	8839.3	496.50		

vRoot: actual transpiration rate, vTop and vBot: actual flux at the surface and bottom of soil profile, ΔS: change in soil-moisture storage. "Plastic" treatment has holes only for planting.

References 1) Kader, M.A. et al., 2017. Recent advances in mulching materials and methods for modifying soil environment. Soil Till. Res., 168, 155–166. 2) Šimůnek, J. et al., 2013. The HYDRUS-1D software package for simulating the movement of water, heat, and multiple solutes in variably saturated media, version 4.17, HYDRUS Software Series 3. 3) Šimůnek, J. et al., 2018. The HYDRUS software package for simulating two- and three-dimensional movement of water, heat, and multiple solutes in variably-saturated porous media. Technical manual version 3.