Soil-Water Dynamics Pattern in a Lettuce Cropping Field under Various Mulches Coverage

Krissandi Wijaya[1(✉)], Hideto Ueno[2], Arief Sudarmaji[1], Purwoko Hari Kuncoro[1], Susanto Budi Sulistyo[1], and Ropiudin[1]

[1] Department of Agricultural Technology, Faculty of Agriculture, Jenderal Soedirman University, Purwokerto, Indonesia
krissandi.wijaya@unsoed.ac.id

[2] Department of Agro-Biological Science, Faculty of Agriculture, Ehime University, Matsuyama, Japan

Abstract. Soil-water dynamics pattern in a lettuce cropping field under cotton mulch (CM), plastic mulch (PM), and zero mulch (C) coverage was characterized. Three lettuce plots of 300 cm x 100 cm large each were prepared. Soil-water content, electrical conductivity (EC) and temperature at 0–10 and 10–20 cm depth were monitored hourly. Soil-hydraulic conductivity (K_{us}) within each soil profile was characterized and modelled using van-Genuchten model. The soil with CM showed higher water content (0.29–0.33 cm^3 cm^{-3}) than that with PM (0.29–0.31 cm^3 cm^{-3}) and C (0.26 cm^3 cm^{-3}). At 32.1 mm d^{-1} rainfall rate, the soil EC with CM (0.22–0.30 dS m^{-1}) was higher than others ($<$ 0.02 dS m^{-1}). The soil temperature with CM was 2–3 and 4–5 °C lower than that with PM and C, respectively. Furthermore, the CM plot had higher K_{us} (3.1–4.4 cm d^{-1}) compared to the PM (0.18–0.21 cm d^{-1}) and C plot (0.36 cm d^{-1}). The results reflect a unique characteristic of the cotton mulch, which is able to provide sufficient water and nutrient availability, and to control weeds and temperature in soil profile, for effective growth as well as sustainable production of the crop.

Keywords: Cotton mulch · lettuce crop · soil-water dynamics · sustainable agriculture · weeds suppression

1 Introduction

During last couple of decades, mulch has been utilized in agriculture due to its benefit in maintaining soil moisture and temperature, reducing erosion impact, suppressing weeds and insects, and enhancing soil nutrients [1, 5, 7, 9, 11, 17, 25, 45, 50]. Over various types of mulches, plastic is the most common mulch, which is low cost and easy to be applied [56]. The mulch also is effective in reducing evaporation rate from soil surface by 55% [53]. However, an intensive use of plastic mulches tends to deteriorate soil condition and enhance environmental risks [33]. For instance, polyethylene films generally causes an extreme high temperature inside soil profile, especially in hot climate or summer,

S. B. Sulistyo et al. (Eds.): ICSARD 2022, ABSR 30, pp. 183–198, 2023.
https://doi.org/10.2991/978-94-6463-128-9_20

Table 1. Physical properties of Shikoku's decomposed-granite (loamy-sandy soil or *Masa-do* in Japanese)

Parameter	Value
Texture (Sand: Silt: Clay) (g g^{-1})	82.9: 9.6: 7.6 (loamy-sand) 3)
Particle density (g cm^{-3})	2.67 – 2.68 1)
Dry bulk density (g cm^{-3})	1.40 – 1.43 1)
Porosity (%)	60 – 70 3)
Hydraulic conductivity (cm d^{-1})	50.9 – 419.9 2,3)
Soil organic matter or C-N ratio (%)	8.68 – 11.01 4)

1) [12]; 2) [14]; 3) [8]; 4)[26]

resulting in low soil microbial activities as well as organic matter mineralization, and high rate of soil nutrients volatilization [22]. In fact, the application of huge amount of plastic mulches, i.e., 60,000 t y-1, in Japan, has brought to agricultural field pollution by its landfill disposal [37, 38].

Cotton sheet is a new type of biodegradable mulch produced from cotton waste. Ehime University and Marusan Sangyo Co. Ltd., Japan, has proposed the use of cotton mulch for fruits and vegetables cultivation under Ehime's Masado or loamy-sandy soil, as an alternative way to minimize potential risk of CO_2 emission by its waste incineration in surrounding areas. According to some experiments on cabbage growing field by [36], the mulch is effective in suppressing weeds, enhancing soil-N uptake as well as improving growth and yield of the crop, and also is potential to prevent soil and nutrient loss by erosion. Furthermore, the application of the cotton waste on the lettuce crop in summer can provide suitable nutrient added into soil [4] as well as good productivity [19]. However, the effect of the cotton mulch sheet on the soil-water properties as well as soil-water dynamics in the lettuce cropping field, including the correlation to nutrients distribution in the soil profile and uptake rate by the crop, has not been evaluated yet.

This research was aimed to characterize the soil-water properties as well as soil-water dynamics pattern in a lettuce cropping field under cotton, plastic, and zero mulch application. In further steps, this information is essential to model water and nutrients transports within the field for sustainable farming system of the crop.

2 Materials and Method

2.1 Experimental Plot and Data Collection

The research was conducted at Field Science (FS) Center, Ehime University, Japan (decomposed-granite or loamy-sandy soil, Table 1). Three lettuce plots of 300 cm x 100 cm large were prepared for cotton mulch (CM), plastic mulch (PM), and zero mulch (C), respectively. The lettuce seeds were sowed on each plot with interval of 30 cm x 30 cm (Fig. 1, top). At each plot, water content, electrical conductivity (EC), and temperature of soil within 0–10 and 10–20 cm depth were monitored hourly by using 5TE

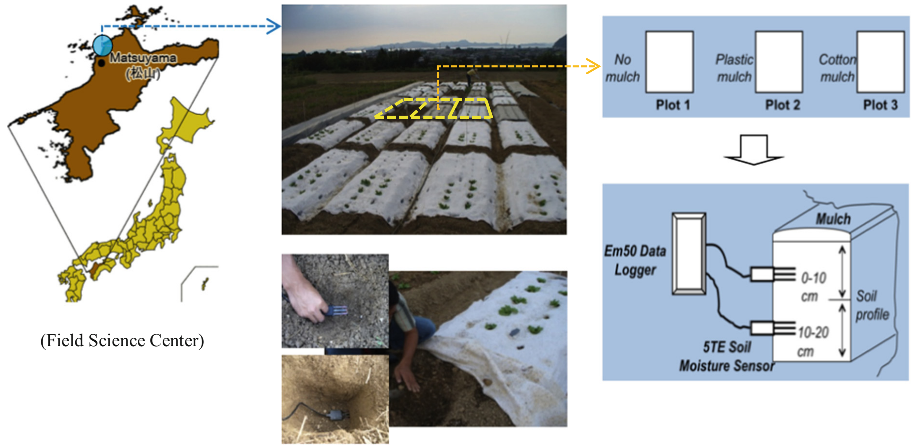

Fig. 1. Schematic diagram of the field monitoring for water content, temperature, and EC in the lettuce growing soil with three different mulches coverage.

moisture sensors coupled with EM50 data logger (Decagon Devices Inc.) (Fig. 1, bottom). Undisturbed soil samples from the same depths were taken for laboratory analysis of water content, dry bulk density, and hydraulic conductivity of the soil. Meteorological data including precipitation, aerial temperature, relative humidity, wind speed, and solar radiation were summarized from the local weather station installed at the FS Center.

2.2 Laboratory Water Flow Modelling

Prior to the field monitoring, 5TE moisture sensors were calibrated specifically by using loamy-sandy soil to gain more representative data. This step was conducted by repacking soil into an acrylic cylinder with 8 cm diameter and 7 cm height, and followed by sensor operation into the repacked sample for seconds.

The sensor output (mV) was recorded by using Em50 data logger. Volumetric water content of repacked sample was then measured gravimetrically by using oven dryer, and then was plotted against the output voltage data by employing the least square method to obtain a specific calibration formula.

Soil physical properties, mainly, volumetric water content and dry bulk density, then saturated hydraulic conductivity, were measured by using gravimetric and falling head method, respectively. The latter was then used as a data input of for the water flow (($K(\theta)$)) simulation based on the field monitored or laboratory measured data with help of van-Genuchten model [29]. The model was expressed in Eq. (1), (2), and (3).

$$K(\theta) = K_s S_e{}^{l}\left[1 - (1 - S_e{}^{1/m})^m\right] \tag{1}$$

$$S_e = \theta - \theta_r/\theta_s - \theta_r = 1/(1 + |\alpha h|^n)^m \tag{2}$$

$$m = 1 - 1/n \; n > 1 \tag{3}$$

where: *K(θ)*: unsaturated hydraulic conductivity, as a function of volumetric water content (cm d^{-1}), K_s: saturated hydraulic conductivity (cm d^{-1}), S_e: effective saturation (cm^3 cm^{-3}), θ: actual or field volumetric water content (cm^3 cm^{-3}), θ_r: residual volumetric water content (cm^3 cm^{-3}), θ_s: saturated volumetric water content (cm^3 cm^{-3}), and *n, α, l*: fitting parameters.

The hydraulic properties are usually required to determine the soil water and nutrients dynamics as well as their balance in an agricultural field, since the parameters are inter-correlated one to another. In this study, the water balance at each lettuce plot was determined by quantifying the incoming and outgoing water flow into the root zone over a certain period of time. The rainfall or irrigation was added water to the root zone, and part of them was lost by runoff or deep percolation toward groundwater recharge. The water in the root zone might was also depleted to atmosphere by evapotranspiration. Therefore, the dynamic change in water within soil profile (ΔSW) was calculated by using Eq. (4).

$$\Delta SW = (P + I) - (R_n + P_c + ET) \tag{4}$$

where: P, I, R_n, P_c, and ET: added or depleted water by the rainfall (mm), irrigation (mm), runoff (mm), percolation (mm), and actual evapotranspiration (mm), respectively.

The ET was determined by comparing ΔSW and potential evapotranspiration (ETo, in mm d^{-1}) of Penman-Monteith (Eq. (5)). If the former is superior to the latter, the ET was equalized to the ETo, instead of ΔSW, and vice versa (Eq. (6)).

$$ET_o = 0.408\Delta(R_n - G) + \gamma\frac{900}{T + 273}u_2(e_s - e_a)/\Delta + \gamma(1 + 0.3u_2) \tag{5}$$

$$ET = \begin{cases} ET_o \; ET_o < \Delta SW \\ ET_o \; ET_o \geq \Delta SW \end{cases} \tag{6}$$

where: R_n: net radiation at crop surface (MJ m^{-2} d^{-1}), G: soil heat flux density (MJ m^{-2} d^{-1}), T: mean daily air temp. at 2 m in height (°C), u_2: wind speed at 2 m height (m s^{-1}), e_s: saturated vapor pressure (kPa), e_a: actual vapor pressure (kPa), Δ: slope of vapor pressure curve (kPa $°C^{-1}$), and γ: psychometric constant (kPa $°C^{-1}$).

3 Results

3.1 Specific Calibration

Figure 2A shows specific calibration results for 5TE moisture sensors, of which relationship between volumetric water content and output voltage was expressed in a linear regression with R^2 of 0.90. The calibrated equation (Eq. (7)) was reliable within range of 0.05–0.50 cm^3 cm^{-3} volumetric water content, and was overestimated the default equation proposed by Decadon Devices Inc., and also the general calibration results of the previous dielectric constant-based moisture sensors. The former was about 5–8% higher in its calculated data compared to the latters. Furthermore, fitting the data against the gravimetric volumetric water content in 1:1 relation (Fig. 2B) reveals that calculated

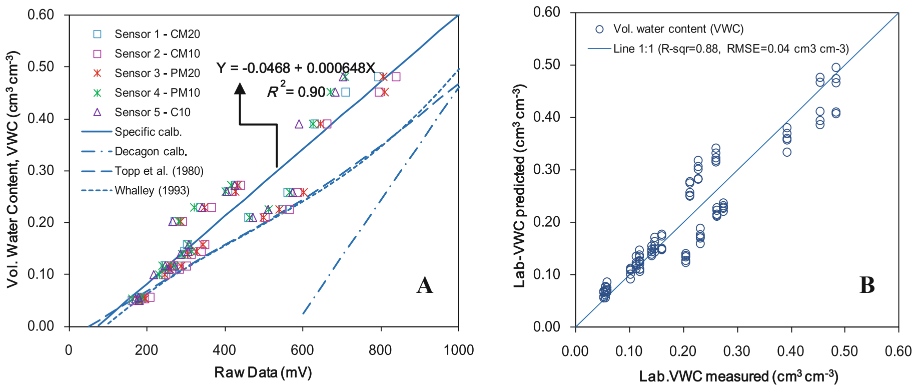

Fig. 2. Calibration of 5TE sensor: volumetric water content vs. sensor output voltage for specific and default/general calibrations (A), and measured vs. predicted volumetric water content (B).

data agreed well with the measured ones with high accuracy ($R^2 = 0.88$) or low error and ($RSME = 0.04$ cm^3 cm^{-3}).

$$\theta = 0.0468 + 0.000648v \quad (7)$$

where: θ: calculated/predicted volumetric water content by the specific calibrated eqution (cm^3 cm^{-3}), and v: output voltage of 5TE moisture sensors read by EM50 data logger (mV).

3.2 Spatio-Temporal Change in Soil Water Content, EC, and Temperature

The distribution pattern of water content in lettuce field with various mulches coverage at 0–10 and 10–20 cm depth in response to rainfall and irrigation during 20–46 days after transplanting (DAT) is presented in Fig. 3A. The maximum soil water content with CM was higher (0.290–0.333 cm^3 cm^{-3}) than that with PM (0.297–317 cm^3 cm^{-3}) and C (0.267 cm^3 cm^{-3}).

Figure 3B shows the distribution pattern of EC in the lettuce growing soil profile with various mulches coverage at 0–10 and 10–20 cm depth during 20–46 DAT. Change in the soil EC, mainly for the cotton mulch (CM) plot, strongly corresponded with either rainfall or irrigation rate, in which it reached a maximum value of 0.30 dS m^{-1} when total water supply was in highest rate, i.e., 32.1 mm d^{-1}.

Unlike soil water content and EC having positive correlation with rainfall or irrigation rate, soil temperature in most plots corresponded inversely to both those parameters, in which the latter was decreased with increasing water supply rate and soil water content (Fig. 4A). Such phenomena was related to high capacity of water in conducting and transmitting heat from soil after rainfall or irrigation added to surrounding profile, hence reduced its temperature. Specifically, since CM plot had highest soil water content over others, the decrease in soil temperature for CM plot within 0–10 and 10–20 cm depth was lowest (22–29 °C), and consecutively followed by PM (25–31 °C) and C plot (23–34 °C). Furthermore, the change in microclimate parameters such as aerial temperature

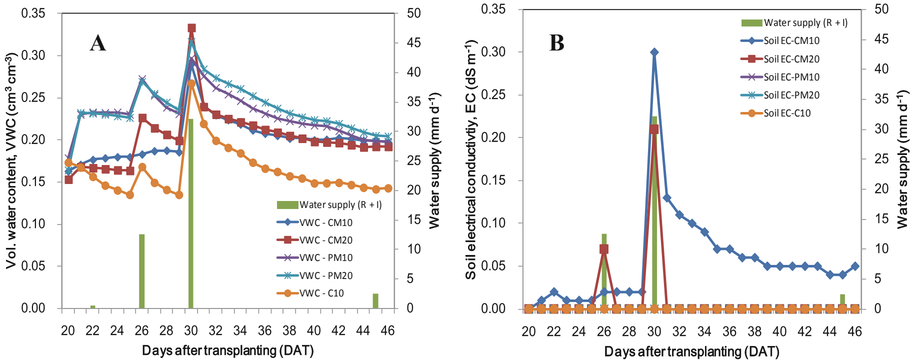

Fig. 3. Distribution pattern of: water (A) and electrical conductivity (B) in lettuce growing soils with cotton, plastic, and zero mulch coverage.

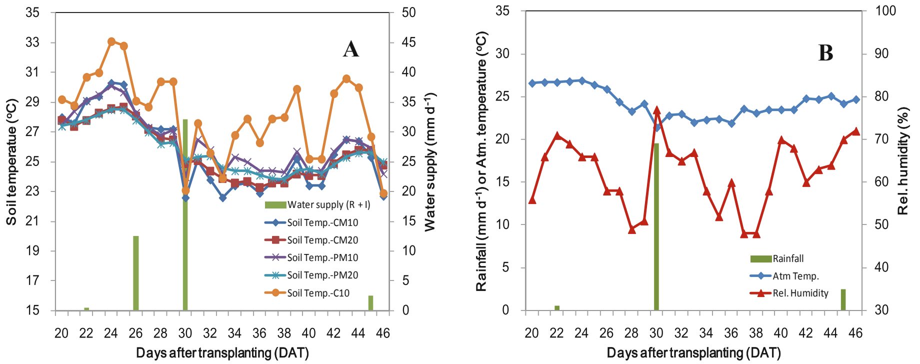

Fig. 4. Distribution pattern of: soil temperature (A) and atmospheric temperature and relative humidity (RH) (B) in the lettuce plots with cotton, plastic, and zero mulches coverage.

and relative humidity were also related to rainfall rate (Fig. 4B), and might in turn correspond to heat or water vapor rate released from lettuce growing soil.

3.3 Soil Water Characteristics

Unsaturated hydraulic conductivity (K_{us}) was predicted by employing evaporation inverse analysis (van Genuchten model in Hydrus-1D) based on the monitored/observed volumetric water content of the lettuce growing soils, especially after heavy rainfall and irrigation during 30–46 DAT (Fig. 3A). The volumetric water contents of the loamy-sandy soil under various mulches coverage at 0–10 and 10–20 cm depth were fitted well by the model with R^2 values of 0.982–0.996 (Table 2 and Fig. 5A). According to its 1:1 relation, there was a good agreement between the predicted and monitored/observed volumetric water content with R^2 of 0.996 and root mean square error (*RMSE*) of 0.0028 $cm^3\ cm^{-3}$ (Fig. 5B).

Concerning the soil-water characteristics curve of each plot (Fig. 6A, B), it is shown that CM plot, mainly at 10 cm depth, had highest soil water holding capacity, followed

Table 2. Fitted hydraulic parameters of the lettuce growing soil with cotton mulch (CM), plastic mulch (PM), and zero mulch (C) coverage at 10 and 20 cm in depth

Parameters	**Cotton mulch (CM)**		**Plastic mulch (PM)**		**Zero mulch (C)**	**v-G model** [5)]
	10-cm	20-cm	10-cm	20-cm	10-cm	
θ_r	0.138	0.144	0.032	0.0000111	0.00813	0.028 – 0.060
θ_s	0.298	0.344	0.308	0.317	0.267	0.314 – 0.350
α	0.116	0.272	0.106	0.094	0.0819	0.079 – 0.940
n	1.335	1.98	1.226	1.140	1.34	1.148 – 1.611
K_s	27.49	9.79	7.07	1.19	5.92	–
l	0.5	0.5	0.5	0.5	0.5	–
R^2	0.991	0.982	0.961	0.985	0.996	0.690 – 0.820
SSQ (x10^{-5}) [6)]	7.16	33.2	46.1	20.9	6.66	–

[5)] v-G model for Loamy-sandy soil (Takeshita and Kohno (1993); Fujimaki et al. (2004); Yang et al. (2004))
[6)] SSQ (sum of square): an objective function of fitting, of which smaller value means higher precision of fitting.

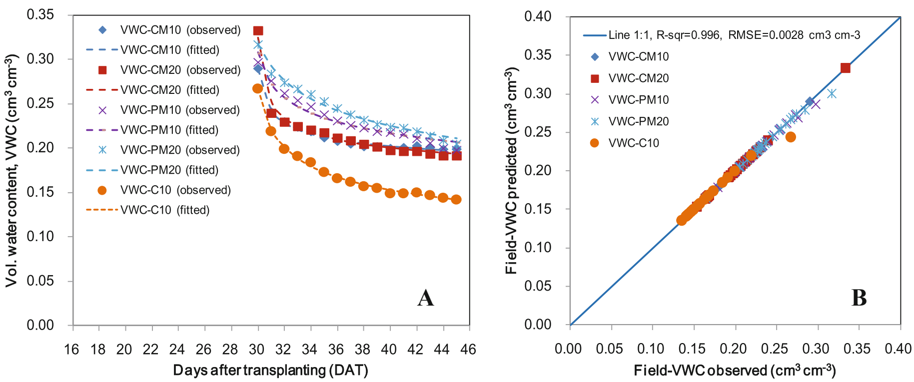

Fig. 5. Fitted (or predicted) vs. observed volumetric water contents (VWC) of the lettuce growing soils at 10 and 20 cm depth concerning with: its temporal change during 30 – 46 DAT (A) and 1:1 relation (B).

by PM and C, while at 20 cm depth it was relatively similar to others. This corresponded to the results shown in Fig. 3A, of which CM plot was more effective in transmitting as well as maintaining rainfall and irrigation water input than PM and C plot.

The lower bulk density of CM soil (Fig. 7C) compared to others corroborated the above results. Accordingly, the hydraulic conductivity of CM soil at 0–10 and 10–20 cm depth were significantly higher than that of PM and C soil, in which at field capacity those ranged between 3.1–4.4, 0.18–0.21, and 0.36 cm d^{-1}, respectively (Fig. 7A).

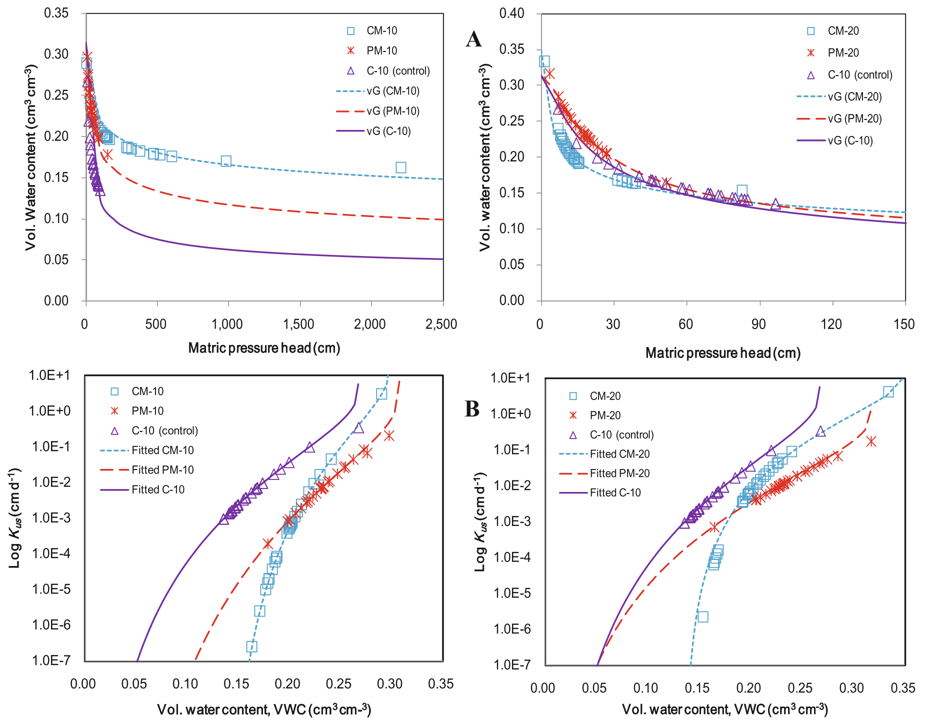

Fig. 6. Soil water characteristics: matric potential vs. VWC (A) and unsaturated hydraulic conductivity vs. VWC (B) of the lettuce soils with various mulches coverage.

Furthermore, the saturated water flow rate within CM soil profile, either temporary (Fig. 7A) or spatially (Fig. 7B), was higher than the PM and C covered soils.

3.4 Soil Water Balance

Figure 8 shows the water balance in the lettuce growing plots under various mulches coverage at 0–10 and 10–20 cm depth during 20–46 DAT. The soil water storage in most plots observed was temporary fluctuated, dependent on the rate of water input. According to Fig. 8A and 8B, the CM plot had the fluctuation of -14.3 to 23.8 mm and cumulative water storage of 7.3 mm) The PM plot had the fluctuation of -5.4 to 14.7 mm and cumulative water storage of 5.9 mm. The C plot had the fluctuation of -4.8 to 13.2 mm and cumulative water storage of -3.0 mm. The fluctuation and cumulative water storage in CM plot was larger and higher than the PM and C plot. As compared to PM plot, the *ET* of CM plot was higher in the initial 20–29 DAT, but lower in the last 30–46 DAT, while such in C plot was lowest among others (Fig. 8B). Accordingly, the cumulative *ET* of CM plot (43.42 mm) was similar as that of PM plot (43.17 mm), but both were significantly higher than that of C plot (34.27 mm) (Fig. 8C). By assuming the surface runoff (R_n) to be zero (sandy soil), it was found that the soil water loss by percolation was higher in C plot (16.47 mm within 0–10 cm depth or 5.15 mm within

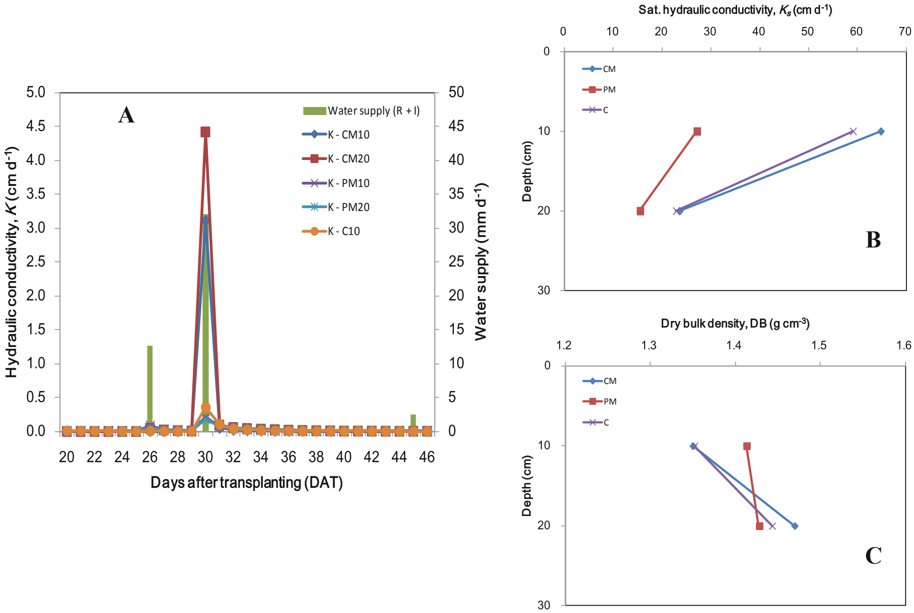

Fig. 7. Temporal (A) and spatial pattern (B) of soil hydraulic conductivity, in relation to its dry bulk density at the end of cultivation period (C), in the lettuce field with various mulches coverage.

0–20 cm depth) than in CM and PM plot, namely -3.04 and -1.43 mm, respectively (negative indicated the upward or capillary movement of the soil water) (Fig. 8C).

4 Discussions

4.1 Specific Calibration Formula

The overestimated calibration results over the default equation proposed by Decadon Devices Inc., and the general formulas of the previous dielectric constant-based TDR moisture sensors proposed by [35] and [40] revealed that the specific calibration formula tended to be more reliable and applicable, other than the default or general formula, for measuring soil physical properties. This reason in further has encouraged [41, 42, 44] and [43] to develop and apply the similar specific calibration formula for measuring and monitoring soil water distribution in several upland and lowland soils, namely andisol, alluvial, and regosol soil to gain more representative results.

4.2 Soil Water Content-EC-Temperature Changes and Relations

The water content change for most plots observed were sensitively depended on rainfall and irrigation rate, which was due to the basic characteristics of loamy-sandy soil having high total macro-pore inside [45, 46, 54, 55]. Specifically, the higher capability of CM over others in intercepting and distributing rainfall and irrigation water within soil

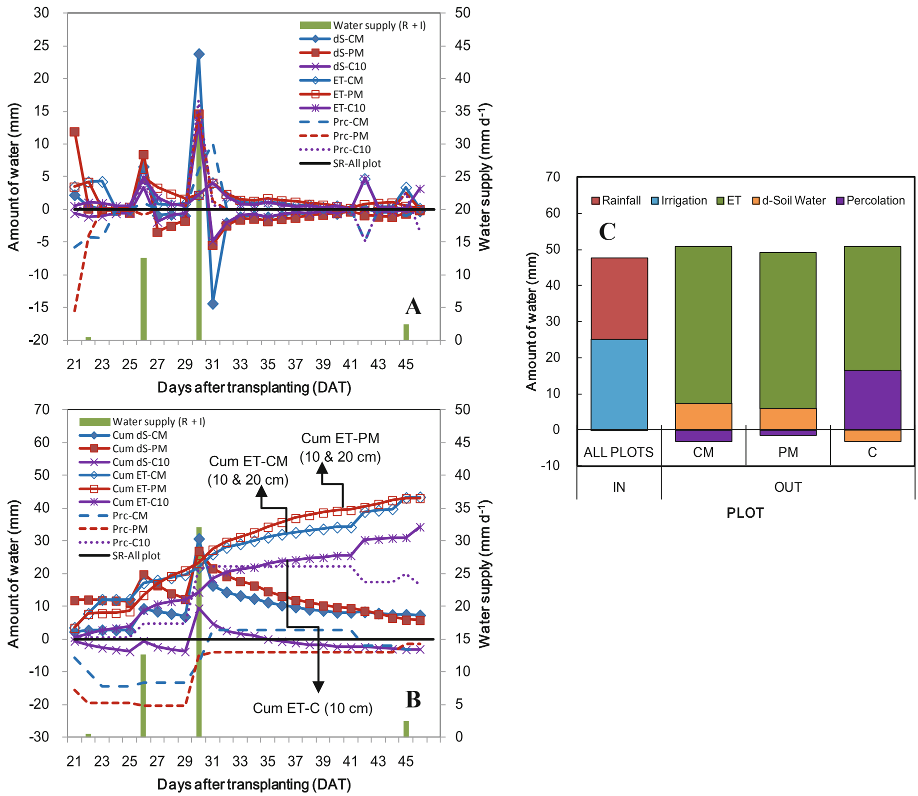

Fig. 8. Water balance, in term of: (A) temporal change, (B) cumulative, and (C) budget in lettuce cropping field with various mulches coverage throughout a cultivation period.

profile as well as preventing upward water loss by evaporation verified its prospective applicability in crop cultivation to support better water management [7, 34, 47, 52].

The higher soil EC value at maximum water supply was affected by the higher decomposed-granite content in Masado, reflecting higher plasticity or cation exchange capacity (CEC) than the common sandy soils [23]. In fact, the water might act as an electrolyte medium conducting mineral ions to move easily through soil pore [27, 28]. Furthermore, [15, 18] reported that when clay content is low, as it occurs in loamy-sandy soil, its water content has a greater effect on EC. Accordingly, the higher EC value in CM soil as compared to that in PM and C soil was due to its better capability in transmitting the incoming water as well as holding the underlined soil water.

The capability of mulch in conducting and transmitting heat from soil to atmosphere or vice versa was a key factor affecting the temperature change in the underlined soil. For instant, the lower capacity of PM, as compared to CM and bare soil, in transmitting heat from soil to atmosphere might increase its underlined soil temperature [3, 10, 33]. In contrast, although C plot or bare soil tended to deliver heat from soil to atmosphere more effective than CM and PM plot, it absorbed more heat from solar radiation directly resulting in its higher soil temperature than the two former plots. Furthermore, an effective soil temperature reduction by CM, mainly in hot-summer condition, allowed crop to be healthy grown, since leaf and root of the crop are sensitive to hot temperature [36–38].

4.3 Water Flow Pattern

The unsaturated hydraulic conductivity (K_{us}) represents the dynamic of water in its soil profile [6, 31]. Having knowledge of K_{us} will then help us in quantifying water and nutrient budget within certain growing field including lettuce crop to support its appropriate irrigation scheduling [2, 20, 48, 51] as well as to determine its optimal dosage of fertilizer applied [12, 16, 39]. The fitting volumetric water content for entire mulches-covered soils showed the results that were comparable to that of [14, 32, 55]. This suggests that such fitted parameters is acceptable for predicting the water characteristics and hydraulic conductivity [51] as well as modelling water flow in the lettuce growing soils under various mulches coverage.

4.4 Cotton Mulch Application for Better Soil-Water Management

According to the quantified soil water balance, it was realized that the cotton mulch was sufficiently effective in maintaining the underlined soil water available to crop. The mulch was not only able to transmit and redistribute the water input from either rainfall or irrigation within soil profile, but also could prevent the upward water loss by either evaporation or deep percolation. Such condition might in turn keep the soil temperature in suitable condition for suitable crop growth [36–38]. Furthermore, the cotton mulch was easily biodegraded in soil, which contributed to significant improvement of soil physical properties and organic matter [22, 37, 38], hence soil water holding capacity. Although the plastic mulch is almost as effective as the cotton mulch in supporting optimal *ET* rate and preventing soil loss by deep percolation [56], it has negative impact on reducing soil water storage, due to its lower transmissibility to water input. The plot covered by the plastic mulch might then result in higher temperature within its soil profile compared to that covered by the cotton mulch. In contrast, the zero mulch might allow more water to infiltrate and percolate into the deeper profile, thus reduces its soil water holding capacity as well as *ET* rate.

The information on the soil water balance in the lettuce growing plot under various mulches coverage was essentially required to support its better water management, including irrigation scheduling and fertilizer application to enhance yield of the crop grown [24, 30, 49]. The soil water balance represented the dynamic movement of water within the crop and its surrounding environment over a cultivation period. The effective water uptake by the crop was determined based on its water used efficiency (*WUE*) coefficient, which was calculated as the ratio of the total aboveground dry matter weight of the crop to the cumulative amount of water required for *ET* process [21]. Concerning this study, it was expected that the CM plot might have *WUE* higher than PM plot, since the former had higher fresh and dry matter compared to the latter, although both ET value were relatively similar. The high yield of the crop in CM plot was affected by the typical characteristic of the cotton mulch, which was transmissible to water input from either rainfall or irrigation resulting in appropriate soil water availability and temperature for better crop growth. Furthermore, the CM application had benefit to suppress weeds in the growing field up to 89%, mainly in hot condition or summer [36, 37].

5 Conclusions

The distribution pattern of soil physicochemical properties in the lettuce growing soil under various mulches coverage such as cotton mulch, plastic mulch, and zero mulch was characterized and modelled with help of 5TE moisture sensor data and Hydrus-1D analysis. The field with cotton mulch had higher soil water content as well as soil water holding capacity as compared to that with plastic and zero mulch, resulted in good soil water and nutrients availability (indicated by high EC value), and suitable soil temperature, of which those were never seen in other mulches-covered field. The application of the cotton mulch, mainly in hot-summer condition, might in further contribute to high water use efficiency as well as optimum yield of the crop, and effective weeds suppression.

Acknowledgments. This study was funded by Ehime University – JSPS Joint Project for Practical Training in Agriculture held in Ehime University, Japan. We thank to Ms. Moyuri Kinebuchi and other members of the Laboratory of Soil Fertility Science, Ehime University, Japan for their help in conducting field experiment.

Authors' Contributions. The first author is the main researcher conducting the field experiment, laboratory analysis and modelling of soil properties and water movement, and then writing the article. The second, third, fourth, and fifth authors support discussion and peer-review of the articles. The seventh author supports the research fund (EU-JSPS joint project) and facilitates the field and laboratory experiment.

References

1. Aladesanwa, RD, Adigun AW 2008: Evaluation of sweet potato (Ipomoea batatas) live mulch at different spacings for weed suppression and yield response of maize (Zea mays L.) in southwestern Nigeria. Crop Prot., 27, 968–975.
2. Andreu L, Hopmans JW, Schwankl LJ 1997: Spatial and temporal distribution of soil water balance for a drip-irrigated almond tree. Agric. Water Manag., 35, 123–146.
3. Anikwe MAN, Mbah CN, Ezeaku PI, Onyia VN 2007: Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (Colocasia esculenta) on an ultisol in southeastern Nigeria. Soil Tillage Res., 93, 264–272.
4. Asagi N, Uen,o H, Kinebuchi M, Sano S, Shimizu K, Kanke F, Oomori T, Fukuda N 2008: Nutrient dynamics in lettuce growing soil with cotton waste mulch. Crop Sci. Soc. Jpn., 45, 80–81.
5. Babalola O, Oshunsanya SO, Are K 2007: Effects of vetiver grass (Vetiveria nigritana) strips, vetiver grass mulch and an organomineral fertilizer on soil, water and nutrient losses and maize (Zea mays L.) yields. Soil Tillage Res., 96, 6–18.

6. Chen S, Zhang, Chen X, Shi P 2009: The impact of land use and land cover changes on soil moisture and hydraulic conductivity along the karst hillslopes of southwest China. Environ. Earth Sci., 59(4), 811–820.
7. Cook HF, Valdes GSB, Lee HC 2006: Mulch effects on rainfall interception, soil physical characteristics and temperature under Zea mays L. Soil Tillage Res., 91, 227–235.
8. Dahal RK, Hasegawa S, Nonomura A, Yamanaka M, Nishino K 2008: Failure characteristics of rainfall-induced shallow landslides in granitic terrains of Shikoku Island of Japan. Environ. Geol., 56(7), 1295–1310.
9. Dahiya R, Ingwersen J, Streck T 2007: The effect of mulching and tillage on the water and temperature regimes of a loess soil: Experimental findings and modeling. Soil Tillage Res., 96, 52–63.
10. Diaz-Pe´rez, JC, Gitaitis R, Mandal B 2007: Effects of plastic mulches on root zone temperature and on the manifestation of tomato spotted wilt symptoms and yield of tomato. Sci. Hortic., 14, 90–95.
11. Doring TF, Brandt M, Heb J, Finckh MR, Saucke H 2005: Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. Field Crops Res., 94, 238–249.
12. Gallardo M, Jackson LE, Schulbach K, Snyder RL, Thompson RB, Wyland LL 1996: Production and water use in lettuces under variable water supply. Irrig. Sci., 16(3), 125–137.
13. Farmanullah K, Sato K, Takase K 1998: Effect of soil cohesion on critical flow for riil initiation under different slope conditions. Pak. J. Biol. Sci., 1(4), 244–247.
14. Fujimaki H, Inoue M, Konishi K 2004: A multi-step inflow method for estimating hydraulic conductivity at low pressure under the wetting process. Geoderma, 120, 177–185.
15. Hartsock NJ, Mueller TG, Thomas GW, Barnhisel RI, Well. KL, Shearer, SA 2000: Soil Electrical Conductivity Variability, In: Robert PC(ed) Proceeding of 5th International Conference on Precision Agriculture. ASA Misc. Publisher, ASA, CSSA, and SSSA, Madison, WI.
16. Jackson LE, Strivers LJ, Warden BT, Tanji KK 1994: Crop nitrogen utilization and soil nitrate loss in a lettuce field. Fertil. Res., 37(2), 93–95.
17. Jin K, Cornelis WM, Schiettecatte W, Lu J, Yao Y, Wu H, Gabriels D, de-Neve S, Cai D, Jin J, Hartmann R 2007: Effects of different management practices on the soil–water balance and crop yield for improved dryland farming in the Chinese Loess Plateau. Soil Tillage Res., 96, 131–144.
18. Kachanoski, RG, Gregorich EG, van-Wesenbeeck IJ 1988 : Estimating spatial variations of soil water content using no contacting electromagnetic inductive methods. Can. J. Soil Sci., 68, 715–722.
19. Kinebuchi M, Ueno H, Asagi N, Sano S, Shimizu K, Kanke F, Oomori T, Fukuda N 2008: Application effects of cotton waste mulch on growth and yield of summer sowing lettuce. Crop Sci. Soc. Jpn,. 45, 78–79.
20. Leenhardt D, Lafolie F, Bruckler L 1998: Evaluation irrigation strategies for lettuce by simulation: 1. Water flow simulations. Eur. J. Agron., 8, 249–265.
21. Mastrorilli M, Katerji K, Rana G, Steduto P. 1995: Sweet sorghum in Mediterranean climate: radiation use and biomass water use efficiencies. Ind. Crops Prod., 3, 252–260.
22. Moreno MM, Moreno A 2008: Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop. Sci. Hortic., 116, 256–263.
23. Nishikawa Y 1991: Application of supercritical fluid extraction/supercritical chromatography to pesticide residue analysis. Anal. Sci., 7, 567–572.
24. Pathak H, Aggrawal PK, Roetter R, Karla N, Bandyopahaya SK, Prasad S, van-Keulen H 2003: Modelling the quantitative evaluation of soil nutrient supply, nutrient use efficiency, and fertilizer requirements of wheat in India. Nutr. Cycl. in Agroecosyst., 65(2), 105–113.

25. Rabary B, Sall S, Letourmy P, Husson O, Ralambofetra E, Moussa N, Chotte JL 2008: Effects of living mulches or residue amendments on soil microbial properties in direct seeded cropping systems of Madagascar. Appl. Soil Ecol., 39, 236–243.
26. Razafubdrabe BHN, He B, Inoue S, Ezaki T, Shaw R 2010: The role of forest stand density in controlling soil erosion: Implications to sediment-related disasters in Japan. Environ. Monit. Assess., 160, 337–354.
27. Rhoades JD, Corwin DL 1981: Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. Soil Sci. Soc. Am. J., 45, 255–260.
28. Rhoades JD, Manteghi NA, Shouse PJ, Alves WJ 1989: Soil electrical conductivity and soil salinity: new formulations and calibrations. Soil Sci. Soc. Am. J., 53, 433–439.
29. Ritter A, Hupet F, Unoz-Carpena R, Lambot S, Vanclooster M 2003: Using inverse methods for estimating soil hydraulic properties from field data as an alternative to direct methods. Agric. Water Manag., 59, 77–96.
30. Sangare K, Compaore E, Buekert A, Vanclooster M, Sedogo MP, Bielders CL 2012: Field-scale analysis of water and nutrient use efficiency for vegetable production in a West African urban agricultural system. Nutr. Cycl. in Agroecosyst., 92(2), 207–224.
31. Shinomiya Y, Takahsihi K, Kobiyama M, Kubota J 2001: Evaluation of the tortuosity parameters for forest soils to predict unsaturated hydraulic conductivity. J. For. Res., 6, 221–225.
32. Takeshita Y, Kohno I 1993: Evaluation of Closed-Form Analytical Models for Predicting Unsaturated Soil Hydraulic Properties. In: Memoirs of The Faculty of Engineering, Okayama University, Okayama, Japan, 28(1), 61–69.
33. Tarara JM, Ham JM 1999: Measuring sensible heat flux in plastic mulch culture with aerodynamic conductance sensors. Agric. For. Meteorol., 95, 1–13.
34. Tolk JA, Howell TA, Evett SR 1999: Effect of mulch, irrigation, and soil type on water use and yield of maize. Soil Tillage Res., 50, 137–147.
35. Topp GC, Davis, JL, Anna AP 1980: Electromagnetic determination of soil water content: Measurement in coaxial transmission line. Water Resour. Res., 16, 574–582.
36. Ueno H, Miyoshi Y, Yamashita Y, Kanke F, Oomori T, Fukuda N 2008: Effects of Mulching with No-Woven Fabric Sheet Made of Cotton Wastes on Growth of Cabbage. In: Proceeding of International Conference on Sustainable Agriculture, Hokkaido University, Sapporo, Japan, 2008.
37. Ueno H 2010a: Improvement of Plant Production and Soil Quality by Recycling Bilogical Waste in Local Area for Sustainable Agriculture, in: Proceeding of The 3rd GEN Network International Seminar, Bali, Indonesia, Aug. 7–8, 2010.
38. Ueno H, Mori M, Michioka M, Adachi M, Yamashita Y, Ishikake K, Yamashita J, Sugimoto H 2010b: Application effect of cotton mulch seeding method on nutrient dynamics in rice paddy field. In: Proceeding of ASA, CSSA, and ASSA. 2010 International Annual Meeting, Long Beach, CA, Oct. 31–Nov. 4, 2010.
39. Wang HJ, Huang B, Shi XZ, Darilek JL, Yu DS, Sun WX, Zhao YC, Chang Q, Oborn I 2008: Major nutrient balances in small-scale vegetable farming systems in peri-urban areas in China. Nutr. Cycl. Agroecosyst., 81(3), 203–218.
40. Whalley WR 1993: Consideration on the use of time-domain reflectrometry (TDR) for measuring soil water content. Soil Sci., 44, 1–9.
41. Wijaya K, Nishimura T, Kato M 2003: Estimation of dry bulk density of soil using amplitude domain reflectrometry probe. J. Jpn. Soc. Soil. Phys., 95, 63–73.
42. Wijaya K, Nishimura T, Kato M, Nakagawa M 2004: Field estimation of soil dry bulk density using amplitude domain reflectrometry data. J. Jpn. Soc. Soil. Phys., 97, 3–12.
43. Wijaya K, Kuncoro PH 2008: Application of dielectric constant method to predict spatial variability of soil permeability on potato field. J. Inov., 1(2), 67–77.

44. Wijaya K., T. Nishimura, B.I. Setiawan, and S.K. Saptomo. 2010. Spatial Variability of Soil Saturated Hydraulic Conductivity in Paddy Field in Accordance to Subsurface Percolation. Paddy Water Environ, 8: 113-120, doi: https://doi.org/10.1007/s10333-009-0190-x.
45. Wijaya, K. and P. Arsil. 2012. Kajian Sifat Fisik Tanah, Erosi, dan Produktivitas Kentang pada Beberapa Tipe Guludan dan Penutupan Mulsa. Seminar Nasional PERTETA 2012 (Presentasi Oral dengan Prosiding, ISBN: 978–602–17199–0–9). Malang, Indonesia, 30 November - 2 Desember 2012.
46. Askari, M., F.A. Ahmad, A.M. Mohd Sayuti, C.B.S. Teh, Suhartono, H. Saito, Z. Yusop, and K. Wijaya. 2013. Field Estimation of Infiltration Models under Oil Palm Plantation: Stemflow and Throughfall Areas. International Conference on Sustainable Rural Development (Invited Speaker with Proceeding, ISBN: 978–979–99046–5–2). Purwokerto, Indonesia, 25–26 August 2013.
47. Wijaya, K., Ardiansyah, P.H. Kuncoro, and T. Nishimura. 2015. Simple Prediction Model for Potato Yield Based on Water and Nutrient Availability in Soil with Different Fertilizers and Biochars Application. National Seminar of Purwokerto Muhammadiyah University (Oral Presentation with Proceeding, ISBN: 978–602–14930–3–8). Purwokerto, Indonesia, 26 September 2015.
48. Wijaya, K., P. H. Kuncoro, and P. Arsil. 2019. Dynamics of soil physical and chemical properties within horizontal ridges-organic fertilizer applied potato land. In IOP Conference Series: Earth and Environmental Science, 255 012024.
49. Wijaya, K., P.H. Kuncoro, Ardiansyah, P. Arsil, and H. Aryani. 2019. Spatial distribution of soil water content in potato horizontal-ridge profile under various ridge dimensions. In IOP Conference Series: Earth and Environmental Science, 406(1), 012025.
50. Wijaya, K., M. Masrukhi, P.H. Kuncoro, A. Sudarmaji, S.B. Sulistyo, A. Syariffianto. 2020. Pengaruh Kombinasi Mulsa-Pupuk Terhadap Erosi Tanah pada Lahan Kentang dengan Aplikasi Bio-Arang dan Guludan Horizontal. Jurnal Keteknikan Pertanian Tropis dan Biosistem, 8(22): 84-94.
51. Wijaya, K., P.H. Kuncoro, T. Nishimura, and B.I. Setiawan. 2020. Assessing saturated hydraulic conductivity from the dielectrically-predicted dry bulk density. Agricultural Engineering International: CIGR Journal, 22(3): 43-50.
52. Wijaya, K., A. Mustofa, A. Hardanto, E. Sumarni, A. Sudarmaji, dan S.B. Sulistyo. 2021. Pengaruh Jadwal Irigasi dan Dosis Pupuk Organik Terhadap Sifat Fisik Tanah dan Pertumbuhan Serai Wangi. Jurnal Keteknikan Pertanian Tropis dan Biosistem, 9 (3), 262-271.
53. Xie ZK, Wang YJ, Li FM 2005: Effect of plastic mulching on soil water use and spring wheat yield in arid region of northwest China. Agric. Water Manag., 75, 71–83.
54. Yamanaka T, Yonetani T 1999: Dynamic of the evaporation zone in dry sandy soils. J.Hydrol. 217,, 135–148.
55. Yang H, Rahardjo H, Leong EC, Fredlund DG 2004: Factor affecting drying and wetting soil-water characteristic curve of sandy soils. Can. Geotechnol. J., 41, 908–920.
56. Zhou LM, Li FM, Jin SL, Song Y 2009: How two ridges and the furrow mulched with plastic film affect soil water, soil temperature and yield of maize on the semiarid Loess Plateau of China. Field Crops Res., 113, 41–47.