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Diurnal Patterns of Energy Balance Components as Influenced by Row Orientations of Potato

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Abstract: Row direction of a crop influences the diurnal patterns of energy balance components of the soil-canopy system of the crop. Attempts were made to compare the diurnal patterns of energy balance components of E-W rows of potato with those of N-S rows at partial cover. The diurnal patterns of energy balance components were considered for the soil, canopy and field, separately. Results of the study revealed that the diurnal patterns of energy balance components of field, soil and canopy were strongly influenced by row orientations. LE, LE_s and LE_c tended to follow the pattern of global radiation of the day of observation. LE_s was the dominant form of water loss in both the E-W and N-S rows. The diurnal pattern of LE_s observed in N-S rows was larger as compared to E-W rows. Diurnal pattern of LE_c from E-W row canopy was larger as compared to E-W row canopy. H showed both positive and negative trends in both the cases. H_s showed positive trends after 09h both in E-W and N-S potato rows indicating that heat flux was towards the soil surface. H_c showed negative trends from 8 to 14h in E-W row canopy and it was 8 to 13h in N-S row canopy.

Key words: Diurnal pattern, energy balance, potato, row orientation, low solar angle

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Introduction

When crops are grown in rows, it produces partial cover at its early stage of growth and thus the open soil surface between rows acts as an important source and/ or sink for the latent heat flux density (Walker, 1984). Penetration of global radiation and net radiation is found to vary with row orientations and cropping seasons (Baten and Kon, 1997). At low solar elevation angles on 35°46"N latitude, penetration of solar radiation is larger at the soil surface between N-S row spaces than that of E-W rows (Baten and Kon, 1997) and thus the rate of evaporation at N-S row spaces must be different from that of E-W row spaces. On the contrary, E-W row canopy intercepts larger solar radiation as compared to N-S row canopy during low solar elevation angles (Baten and Kon, 1997) and thus the rate of transpiration of E-W row canopy must be different from the N-S row canopy. Therefore, the exchange of energy among soil, canopy and surrounding aerial environments of E-W rows would differ from N-S rows and would affect evaporation and transpiration processes of row crops and thereby the patterns of energy balance components.

The patterns of energy balance components of row crops should be evaluated separately both in summer as well as in autumn. Ham *et al.* (1991) evaluated the energy balance components of summer soybeans oriented in N-S rows for field, soil surface and canopy separately. Baten *et al.* (1997) also evaluated the energy balance components of summer soybeans oriented in E-W and N-S rows for field, soil surface and canopy separately. Baten *et al.* (2000) evaluated the day time (total) energy balance components of potato oriented in E-W and N-S rows for field, soil surface and canopy, separately during low solar elevation angles (autumn). To get a complete picture of energy balance components, it is obvious to evaluate the diurnal patterns of energy balance components of any row crop oriented in E-W and N-S directions in autumn. Considering the above views, the present study was undertaken with a view to evaluating the diurnal patterns of energy balance components of E-W and N-S potato rows at partial cover f field, soil and canopy, separately.

Materials and Methods

Experimental conditions: An observation was made at th field of the Faculty of Horticulture, Chiba University, Japa (Latitude 35°46'N and Longitude 139°54'E). Seed tuber of potato of the variety "Nishutaka" were planted on tw plots on September 17, 1996. Each plot was 20m X 20 in size. The plot was prepared by Power-tiller followed b laddering. Potato tubers were planted at a spacing of 0.6 X0.3m. Two row orientations, E-W and N-S, were followed Potato plants were also raised in pots. Pots of 1/3390 were filled with 10kg of air dry soil in each and seeded. T keep the plant growth similar with the field, water wa applied to the pots at a regular interval till October 28. Each pot had a small opening at the bottom so that the exces water was drained out easily. The potato was not applie extra water as sufficient moisture was available due to rai during observation. Standard cultural practices wer followed as and when required.

Instrumentation: Pyranometers (EKO MS 61, S-SR and Ishikawa S-90, Japan) and heat flow plates (EKO, MF 91, Japan) were positioned at 4 equally spaced locations below the potato canopies to measure solar radiation and soil heat flux, respectively, following Baten *et al.* (1996). To measure net radiation (Rn) over the canopy, iron bar was placed at the center of each plot and net radiometers (EKO, CN-11, Japan) were set on the bars at 2.0m height above the soil surface. To observe albedo of potato field, albedo meters (Eko Mr-21, Japan) were set at 1.75m height from the soil surface. Albedo meter was set over bare land near the plot to measure soil albedo. Global radiation was measured with a pyranometer (Eko Mr-21, Japan) positioned at 1.5m above the soil surface. Instruments used in this experiment were carefully calibrated setting in the field. Copper-constantan thermocouple set in "hand made ventilated tube" was used to measure air temperature at the height of 1.0m over the soil surface of the crop field. Relative humidity was also measured at the height of 1.0m over the soil surface of the crop field with the humidity sensor (Tdk Chs-Asp, Japan). Signals from all sensors were recorded every one minute with computer controlled data loggers (Eto Denki Thermodac E, Model 5001A, Japan) and processed later for 1 hour average data by another computer.

Measurements of diurnal patterns of energy balance components: Observations on diurnal patterns of separate energy balance components of potato were made on I) field surface, ii) soil surface below the canopy and iii) canopy surface. Soil and canopy surface together constitute the field surface.

Calculation of field energy balance components: The diurnal pattern of field energy balance components was computed from the following equation:

$$Rn + LE + H + G = 0 \quad \text{..........................} \quad [1]$$

where, Rn, LE, H and G are net radiation, latent heat flux density, sensible heat flux density and soil heat flux density, respectively, all with units Wm^{-2}. In equation [1], fluxes toward the surface were positive, while fluxes away from the surface were negative.
Latent heat flux from the soil (LE_s) and latent heat flux from the canopy (LE_c) were calculated following Baten *et al.* (1997). Thus LE was calculated as:

$$LE = LE_s + LE_c \quad \text{..................................} \quad [2]$$

H was then calculated as a residual from equation [1].

Calculation of energy balance components of the soil surface: The energy balance that accounts for all sources and sinks of energy at the soil surface was calculated as follows:

$$Rn_s + LE_s + H_s + G = 0 \quad \text{...........................} \quad [3]$$

where, Rn_s, LE_s, and H_s are net radiation at the soil surface, soil latent heat flux density and sensible heat exchange between the soil surface and air, respectively, all with units Wm^{-2}. Rn_s at the soil surface was calculated as follows:

$$Rn_s = (1-\alpha_s)\, Rs_s + \epsilon_s (V_{sky}\, \epsilon_{sky}\, \sigma T^4{}_a + (1-V_{sky})\, \epsilon_c\, \sigma T^4{}_c) - \epsilon_s\, \sigma T^4{}_s \quad \text{.................................} \quad [4]$$

where, Rs_s is solar radiation at soil surface, Wm^{-2}, α_s is soil albedo, σ is Stephan-Boltzmann constant and ϵ_s, ϵ_c, and ϵ_{sky} are the emissivities of the soil, canopy and sky, respectively. T_a, T_s and T_c stand for air, soil and canopy temperature, respectively, in Kelvin. Equation 4 assumes uniform temperatures of canopy and soil and no effect of spatial temperature variation on Rs_s (Ham *et al.*, 1991). V_{sky} is the hemispherical view factor of the sky from the soil surface and represents the friction of long-wave sky radiation incident on soil (Ham *et al.*, 1991) which was calculated as follows (Ham, 1980):

$$V_{sky} = \{[L_r - L_c)^2 + Z^2{}_c\,]^{1/2} - Z_c\}/L_r \quad \text{...........} \quad [5]$$

where, L_r is the row width, L_c is the canopy width and Z_c is the canopy height. Soil and canopy temperatures were measured with infrared radiation thermometer (TASCO THI-300, Japan). Canopy and soil emissivity were assumed to be 0.97 and 0.93 (Ham *et al.*, 1991), respectively. Sky emissivity was calculated from water vapor density using equation of Brutsaert (1975) as follows:

$$R_{LD}/\, (\sigma T\,^4{}_a) = \epsilon_{sky} = 1.24\, (e_a\, /\, T^4)^{1/7} \text{...........} [6]$$

where, R_{LD} is total longwave radiation (Wm^{-2}), T_a is air temperature at 1.0m height from the soil surface at the center of the plot, e_a is actual vapor pressure. The complete energy balance of the soil surface was then calculated by rearranging equation [3] as follows:

$$H_s = -(Rn_s + LE_s + G) \quad \text{.........................} \quad [7]$$

Calculation of Energy balance components of crop canopy: The energy balance at the surface of potato canopy was calculated as follows:

$$Rn_c + LE_c + H_c = 0 \quad \text{...........................} \quad [8]$$

where, Rn_c, LE_c and H_c are the net radiation, latent heat flux, and sensible heat flux at the canopy surface, respectively, all in Wm^{-2}. Rn_c was estimated by the following relationship (Kanemasu and Arkin, 1974; Ham *et al.*, 1991).

$$Rn_c = Rn - Rn_s \quad \text{......................................} \quad [9]$$

Hc, was then calculated as a residual by rearranging Eqn. [8] as follows:

$$H_c = -(Rn_c + LE_c) \quad \text{.................................} \quad [10]$$

Additional measurements: Plant height and canopy width were measured at a regular interval of 10 days starting from 40 DAP (Days after planting). Leaf area was measured with a digital leaf area meter (AAM-8, Hayashi Den KOH CO., LTD., NP713.) to calculate leaf area index (LAI). Soil water content at 5 cm depth was determined following gravimetric method and expressed as percent water content. Wind direction and wind speed were measured by a wind vane (Model VF016) and three cup anemometer (Model AF750) of Makino Applied Instruments INc.

Results and Discussion

Observation on diurnal trends of energy balance components as influenced by row orientations of potato was made in a clear sunny day (November 21, 1996). North-West wind was the prevailing wind during observation. Plant height, canopy width and LAI during observation are shown in Table 1. Environmental conditions of the observation day are outlined in Table 2. Fig. 1 shows diurnal patterns of air temperature, relative humidity and wind speed.

Table 1: Height, width and LAI of potato canopy on November 21, 1996

Height (cm)	Height (cm)	Width (cm)	Width (cm)	LAI (m^2m^{-2})	LAI (m^2m^{-2})
E-W	N-S	E-W	N-S	E-W	N-S
46.4±0.5	46.6±0.8	40.2±0.8	40.0±1.2	1.87±0.06	1.89±0.03

Diurnal trends in energy balance components of potato: Fig. 2, 3 and 4 show the diurnal patterns of latent heat fluxes from the field, soil, and canopy of E-W and N-S potato rows on November 21. LE, LE_s and LE_c tended to follow the pattern of global radiation i.e. they produced small values during early and late hours and peak values at mid hours of the day.
Fig. 2a and 2b represent the diurnal patterns of energy balance of the field of E-W and N-S potato rows on November 21. LE of E-W and N-S potato fields tended to follow the pattern of global radiation and net radiation as

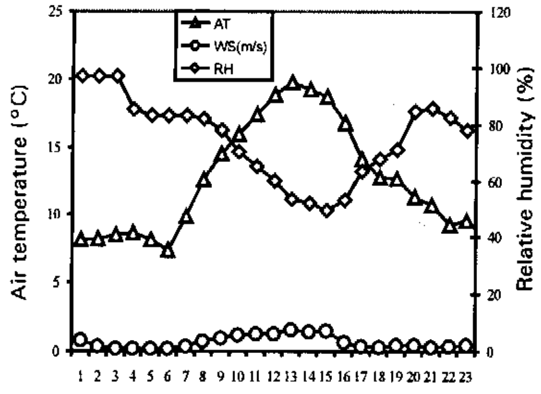

Fig. 1: Air temperature (AT), wind speed (WS) and relative humidity (RH) at 1m height over the crop canopy

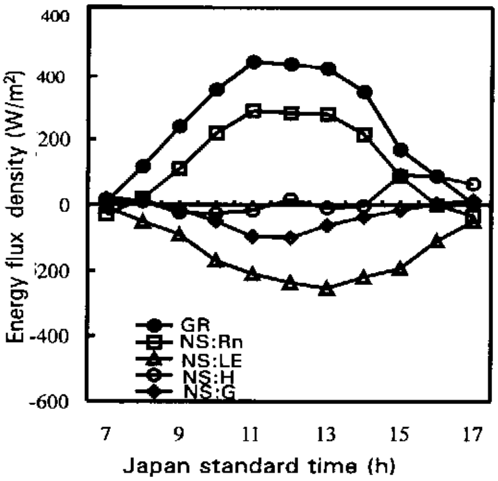

Fig. 2a: Diurnal patter of field energy balance components over N-S potato rows

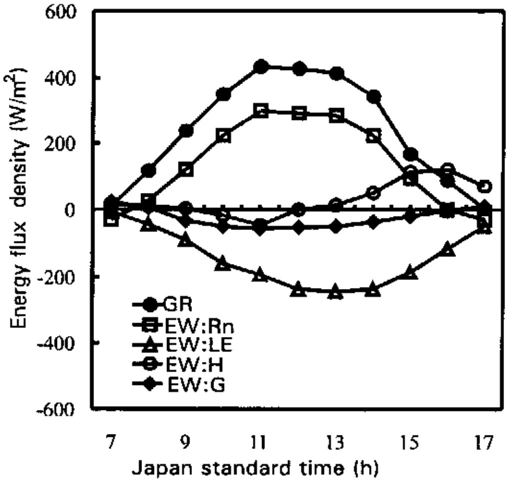

Fig. 2b: Diurnal pattern fo field energy balance components over E-W potato rows

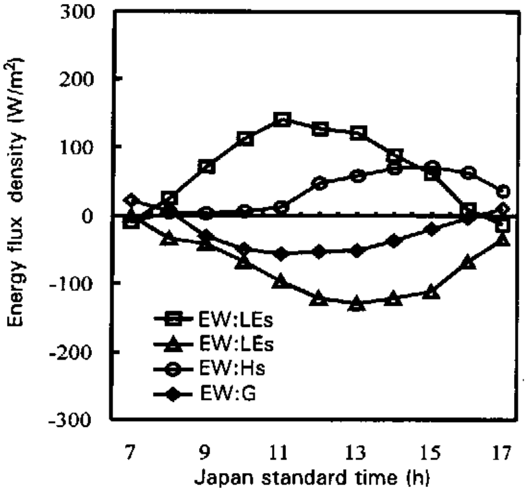

Fig. 3a: Diurnal patter of field energy balance compon over E-W potato rows

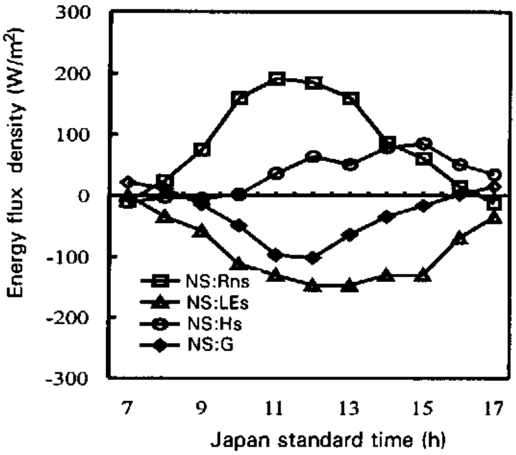

Fig. 3b: Diurnal pattern of soil surface

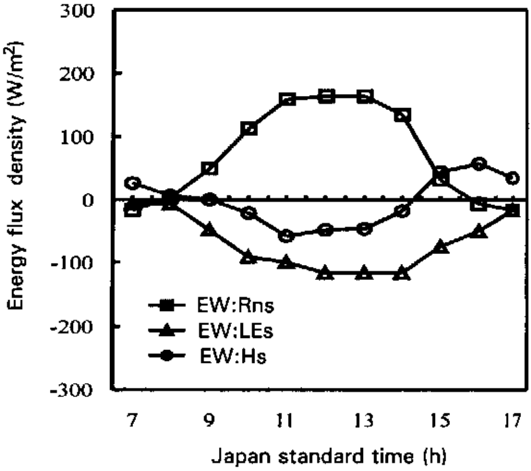

Fig. 4a: Diurnal patter of field energy balance components over E-W potato rows

Table 2: Global radiation (GR), wind speed, relative humidity (RH) and air temperature over the potato canopy on November 21, 1996. It also includes soil moisture at 12:00h

GR (Mjm^{-2})	Wind speed (m/s)			Air Temperature (°C)			RH (%)			Soil moisture(%)	
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	E-W	N-S
9.3	1.6	0.2	1.0	19.7	7.4	15.5	88	49	67	56.2	55.6

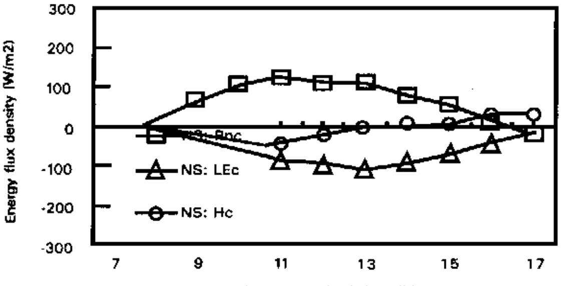

Fig. 4b: Diurnal pattern of canopy energy blanace components of N-S potato rows

well i.e. they produced small values during early and late hours and peak values at the mid hours of the day. Fig. 2a and 2b also show that LE was the dominant form of water loss in both the potato fields oriented in E-W and N-S rows. The sensible heat flux (H) for E-W potato field showed a negative trend before 12:00 h indicating the field (soil + canopy) acted as a source of heat energy which transferred heat to the atmosphere (Fig. 2a) within this period. Again, it (*H*) produced a positive trend after 12:00 h indicating the sensible heat flux was towards the field (soil + canopy) (Fig. 2a). The sensible heat flux observed in N-S row potato field (Fig. 2b) showed negative patterns until 11:00 h and then showed almost an isothermal conditions till 14:00h. After 14:00h it showed a positive trend. The diurnal pattern of G, LE and Rn of E-W potato rows (Fig. 2a) were almost similar to those of N-S potato rows (Fig. 2b) but they varied only in magnitudes.

Fig. 3 represents the diurnal patterns of energy balances of the soil under the canopy of E-W and N-S potato rows on November 21. The sensible heat fluxes showed negative or nearly an isothermal conditions before 09:00 h in E-W rows (Fig. 3a) and 11:00 h in N-S rows (Fig. 3b). After 09:00h in E-W rows in E-W rows and 11:00h in N-S rows, it showed positive trends (Fig. 3a and b) indicating fluxes were towards the soil surface i.e. soil was absorbing sensible heat from the within-canopy air stream within these periods. The diurnal patterns of Rn_s, LE_s and G of N-S rows were larger than those of E-W rows (Fig. 3a and b). On daily basis, LE_s exceeded Rn_s in the E-W rows(Baten *et al.*, 2000). This was due to convective heat from the canopy in addition to wind speed which influenced LE_s and exceeded Rn_s in E-W rows. The energy balance of the soil showed that Rn_s in N-S rows increased rapidly as soil irradiance increased (Fig. 3a and b).

Fig. 4 represents the diurnal patterns of energy balances of the canopy of E-W and N-S potato rows on November 21. The energy balance of the canopy shows that Rn_c of E-W and N-S row canopies (Fig.4a and b) increased with the increase of global radiation (Fig. 2). The larger Rn_c at E-W row canopies caused larger LEc as compared to N-S row canopies (Fig. 4a and b) in addition to other factors like air temperature, relative humidity and wind speed. The sensible heat flux of E-W row canopy on November 21 showed a negative trend from 09:00 h to 14:00 h indication flux was away from the canopy (Fig.4a). The positive H_c indicated that the E-W row canopy absorbs heat before 9:00 h and after 14:00 h (Fig. 4a). H_c form the N-S row canopy (Fig. 4b) showed a negative trend after 8:00 h until 13:00 h indicating sensible heat flux was away from the canopy in this duration. Hc from the N-S canopy showed positive trend before 08:00h and after 13:00h (Fig. 4b) indicating flux was towards the canopy.

LE_s was the dominant form of water loss in both the E-W and N-S rows. Ham *et al.* (1991) reported similar result in irrigated cotton field of N-S rows where they showed that LE_s exceeded LE_c. Before 8:00 h and after 15:00 h *LE_s* was same both in E-W and N-S rows. It was due to shade of canopy and low intensity of light. The diurnal pattern of LE_s observed in N-S rows was larger as compared to E-W rows. It was due to larger soil surface net radiation at N-S row spaces than that of E-W rows (Baten *et al.*, 2000). On the contrary, diurnal pattern of LE_c from E-W row canopy was larger as compared to N-S row canopy. It was due to larger canopy net radiation at E-W row than that of N-S rows (Baten *et al.*, 2000). LE of the potato field was led by the combined effect of LE_s and LE_c.

Due to row-sun geometry at low solar elevation angle in autumn, penetration or transmission of solar radiation at the soil surface between N-S row spaces was larger as compared to E-W row spaces (Mutsaers, 1980; Baten and Kon, 1997). This caused larger Rn_s, G and, LE_s between N-S row spaces than those of E-W rows. On the contrary, interception of solar radiation by E-W row canopy was larger as compared to N-S rows (Mutsaers, 1980; Baten and Kon, 1997). This caused larger Rn_c and LE_c in E-W row canopy as compared to N-S row canopy. These were the reasons behind the variation of moisture and energy balance components between E-W and N-S potato rows.

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References

Baten, M. A., H. Kon and N. Matsuoka, 1996. Spatial variability in micrometeorology at soil surface below a potato canopy with two row orientations. J. Agric. Meteorol., 52: 301-310.

Baten, M. A. and H. Kon, 1997. Comparison of solar radiation interception, albedo and net radiation as influenced by row orientations of crops. J. Agric. Meteorol., 53: 29-39.

Baten, M. A., H. Kon and N. Matsuoka, 1997. Comparisons of moisture and energy balance components as influenced by two row orientations of soybean. J. Agric. Meteorol., 53: 291-300.

Baten, M. A., B.S. Nahar, H. Kon and N. Matsuoka, 2000. Moisture and energy balance components as influenced by row orientations of potato during low solar elevation angles. Pak. J. Bio. Sci., 3: 1644-1647.

Brutsaert, W.,1975. On derivable formula for long-wave radiation from clear skies. Water Resource Res., 11: 742-744.

Ham, J. M., 1980. Soil water evaporation and transpiration from a row crop at partial cover. Ph.D. Diss. Texas A and M Univ., College station, TX (Diss Abstr., 90-27217).

Ham, J. M., J. L. Heilman and R.J. Iascano, 1991. Soil and canopy energy balance row of a crop at partial cover. Agron. J., 83: 744-753.

Kanemasu, E. T. and G. E. Arkin, 1974. Radiant energy and light environment of crops. Agric. Meteorol., 14: 211-225.

Mutsaers, H. J. W., 1980. The effect of row orientation, date and latitude on light absorption by row crops. J. Agric. Sci. Camb., 95: 211-225.

Walker, G. K., 1984. Evaporation from wet soil surfaces beneath plant canopies. Agric. For. Meteorol., 33: 259-264.