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Moisture and Energy Balance Components as Influenced by Row Orientations of Potato During Low Solar Elevation Angles

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Abstract: Attempts were made to compare energy balance and moisture budget components of E-W rows of potato with those of N-S rows at partial cover during autumn of 1996. The energy balance and moisture budget components were considered for the soil, canopy and field, separately. Daily fluctuations of energy and moisture balance of field, soil and canopy were strongly influenced by row orientations. Larger portion of net radiation. (*Rn*), both in E-W and N-S row fields, was partitioned to latent heat fluxes (*LE*). Average *LE* observed in E-W row potato field was lower than that of N-S potato field. Average ratios of *-LE* to *Rn* were found 0.95 and 0.97 for E-W and N-S rows, respectively. Sensible heat flux (*H*) was positive both in E-W and N-S rows. 16 to 17% of Rn partitioned to soil heat flux (*G*) in E-W rows and 21 to 23% in N-6 rows. Average soil net radiation (Rn_s) in N-S rows was about 19% larger than that of E-W rows. On average; latent heat flux density (LE_s) was about 12% larger in N-S rows than that of E-W rows. H_s showed positive values in both the plots. The $-G/Rn_s$ ratios was almost same in both the cases. The average canopy net radiation (Rn_c) and latent heat flux from the canopy (LE_C) of E-W row canopy was 26 and 20% larger than that of N-S row canopy, respectively. H_c showed negative values both for E-W and N-S row canopies.

Key words: Potato, row orientation, low solar elevation angle, energy balance

Introduction

Evaporation and transpiration processes of field crops grown in rows depend on the exchange of energy among soil, canopy and surrounding aerial environment. Evaporation and transpiration should be considered separately to study the *LE* from the crop surface, especially during early stage of growth of row crops (Walker, 1984). It is due to the reason that row crops at its early stage produce partial cover and thus the open soil surface between rows can act as an important source and/or sink for *LE* (Walker, 1984). The views of Walker (1984) are supported by some early and recent reports (Ham *et al*., 1991; Baten and Kon, 1997).

Row orientations of crops are one of the very important agronomic practices observed among growers. N-S row orientation is a popular orientation to the growers, however, they seldom practice E-W row orientation for growing crops without knowing much about radiation environment of row crops. Solar radiation is the most important of all micro climatic elements for the growth and yield of crops. It is the source of power that drives the atmospheric circulation, the only means of exchange of energy between the earth and the rest of the universe (Geiger, 1980). It also provides the main energy inputs to plants, with much of this energy being converted to heat and driving other radiation exchanges and processes (Jones, 1994). In micro meteorological studies, the local area radiation budget measurement is important to study regional energetics and the resulting physical and biological responses (Baldocchi *et al.,* 1981). So, it is very important to study radiation environment in relation energy balance components of crops at various row orientations in details. Solar elevation angles vary with time of a year. At 35°46"N latitude solar elevation is highest (76.91° at 12:00 h) on June 20 and lowest (31°45" at 12:00 h) on December 20. Therefore, during high solar elevation angles, the rays of light are almost parallel to E-W rows (in summer) except midday and during low solar elevation angles, it is parallel to N-S. rows (in autumn). The radiation distribution between row. spaces (soil surface) and over the row canopy during summer was different from that of autumn (Baten and Kon, 1997). Thus, the energy balance components of row crops should be evaluated separately both in summer as well as in autumn. Ham *et al*. (1991) and Baten *et al*. (1997) evaluated energy balance components of soybean row crops for field, soil surface and canopy separately during high solar elevation angles (in summer). To get a complete picture of energy balance components, it is obvious to evaluate energy balance components of any row crop during low solar elevation angles (in autumn). Combined data of summer and autumn could benefit research in crop production, crop biophysics, soil physics, remote sensing, environmental improvement, climate change and agro-ecosystem modeling. Considering the above views, the present study was undertaken to compare the energy balance components of E-W potato rows with those of N-S potato rows during low solar elevation angles in autumn.

Materials and Methods

Experimental conditions: A field experiment was carried out at the field of the Laboratory of Green Space Meteorology, Faculty of Horticulture, Chiba University, Japan (the latitude 35°46'N and the longitude 139°54'E). The soil of the field is light-colored Andosols having loamy texture. Potato seed tubers of the variety "Nishutaka" were planted on two flat plots on September 17, 1996. Area of each plot was 20 m × 20 m. Land was prepared by Power-tiller followed by laddering. Potato tubers were planted at a spacing of 60 cm × 30 cm. E-W and N-S row orientations were strictly followed. Pots of 1/3390a were filled with 10 kg of air dry soil in each and seeded. Water was applied to the pots at a regular interval till October 28. Excess water was drained out from the small opening at the bottom of the pot. The potato was not irrigated as sufficient moisture was available due to rain. Standard cultural practices were followed.

Instrumentation: Pyranometer was used to measure solar radiation and soil heal flux was measured with heat flow plate. 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 under potato canopies following Baten *et al*. (1996). Net radiation (*Rn*) over the canopy was measured with net radiometers (EKO, CN-11, Japan) positioned at the center of each plot, 2.0 m above the soil surface. Albedo meters (EKO MR-21, Japan) were set at 1.75 m height from the soil surface. Albedo meter was also set over bare land near the plot. Global radiation was measured with a pyranometer (EKO MR-21, Japan) positioned at 1.5 m above the soil surface. All instruments were carefully calibrated setting in the field. Air temperature was measured at the height of 1.0 m over the soil surface of the crop field with the copper-constant on thermocouple set in hand made ventilated tube. Relative humidity was also measured at the height of 1.0 m 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 by another computer.

Measurements of separate energy balance: Measurements of separate energy balance were made at three levels of interest, viz. field surface, soil surface below the canopy and canopy surface. The field surface included soil and canopy surface together.

Measurements of field energy balance: The field energy balance was computed from the following equation:

$$Rn + \mathrm{LE} + \mathrm{H} + \mathrm{G} = \mathrm{O} \qquad (1)$$

where, *Rn* is net radiation, *LE* is latent heat flux density, *H* is sensible heat flux density and *G* is soil heat flux density, 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 (*LEs*) and latent heat flux from the canopy (LE_c) were calculated following Baten *et al*. (1997). Thus LE was calculated as:

$$LE = LEs + Lec \qquad (2)$$

H was then calculated as a residual from equation (1).

Energy balance of the soil surface: The energy balance that accounts far all sources and sinks of energy at the soil surface was calculated as follows:

$$Rn_s + LE_s + H_s + \mathrm{G} = \mathrm{O} \qquad (3)$$

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:

$$Rn_s = \frac{(1-\alpha_s)RS_s + \epsilon_s + (V_{sky}\,\epsilon_{sky}\,\sigma T^4)}{+(1-V_{sky})\epsilon_c\,\sigma T^4) - \epsilon_s\,\sigma T^4{}_s} \qquad (4)$$

where, Rs, is solar radiation at soil surface, Wm^{-2}, α_s, is soil albedo, a 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). is the hemispherical view factor of the sky from the sail surface and represents the friction of long-wave sky radiation incident on soil (Ham *et al*., 1991) which was calculated as follows:

$$V_{sky} = \{(L_r - L_c)^2 + Z^2{}_c)^{1/2} - Z_c\}/L \qquad (5)$$

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 TH-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:

$$R_{LD}/\,(\sigma T^4{}_a) = \epsilon_{sky} = 1.24\,(e_s/T^4)^{1/} \qquad (6)$$

where, R_{LD} is total longwave radiation (Wm^{-2}); T_a is air temperature at 1.0 m 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:

$$H_s = -(Rn_s + LE_s + G) \qquad (7)$$

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

$$Rn_c + LE_c + H_c = 0 \qquad (8)$$

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 $\mathrm{W\ m}^{-2}$. Rn_c was estimated by the following relationship (Tanner and Jury, 1976; Ham *et al*., 1991):

$$Rn_c = Rn - Rn_s \qquad (9)$$

Hc, was then calculated as a residual by rearranging Eq. (8) as follows:

$$H_c = -(Rn_c + Le_c) \qquad (10)$$

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

Observations on potato were made on four clear days between

November 06 to 25, 1996. North or North-West wind was the prevailing wind for most of the days of observation. Plant height, canopy width and LAI are shown in Table 1. Environmental conditions of the observation days during autumn are outlined in Table 2.

Daytime Energy balance relationship: Daytime energy balance components of the potato field of E-W and N-S rows are shown in Table 3. *Rn* over E-W and. N-S potato canopies showed variation. It was mainly due to the differences in surface conditions resulting from row orientation (Baten and Kon, 1997). Larger portion of *Rn,* both in E-W and N-S row field, was partitioned to latent heat fluxes as was expected from the available soil moisture content. Average latent heat flux density of E-W soybean field was only 3% larger than that of N-S row potato field. On average, - *LE/Rn* was 95% for E-W soybean field and 97% for N-S potato field (Table 3). *H* was positive both in E-W and N-S rows (Table 3). 16 to 17% of *Rn* partitioned to *G* in E-W rows and 21 to 23% in N-S rows. *G* started to decrease with the increase in canopy cover (Table 3).

Table 4 shows the daytime energy balance components at the soil surface below E-W and N-S potato row canopies. Average Rn_s in N-S rows was about 19% larger than that of E-W rows. On average, *LE,* was about 12% larger in N-S rows than that of E-W rows. The $-LE_s/Rn,$ ratios were larger and *LE,* often exceeded Rn_s in both the cases (Table 4). Similar result was reported for irrigated cotton in summer (Ham *et al.,* 1991). H_s

Table 1: Height, width and LAI of potato canopy duiing the study period of 1996

Date	DAP	Height (cm) E-W	Height (cm) N-S	Width (cm) E-W	Width (cm) N-S	LAI (m^2m^{-2}) E-W	LAI (m^2m^{-2}) N-S
Oct. 27	40	36.3±0.3	36.4±0.4	33.0±0.7	32.0±1.3	1.22±0.06	1.18±0.05
Nov. 06	50	45.0±0.8	45.2±0.8	37.8±1.1	37.2±0.8	1.55±0.08	1.54±0.08
Nov. 16	60	46.4±0.5	46.6±0.8	40.2±0.8	40.0±1.2	1.87±0.06	1.89±0.03
Nov. 20	70	46.5±0.5	46.8±0.8	41.1±1.0	41.3±0.9	1.86±0.03	1.89±0.02

Table 2: Day time global radiation (GR), *wind* speed, relative humidity (RH) and air temperature over the potato canopy. It also includes soil moisture at 12:00 h during observation in autumn of 1996. (Day time (7:00h-17:00h) totals were calculated from detailed measurements integrated over 11 hours data]

Date	GR (MJm^{-2})	Wind speed (m/s)			Air Temp. (°C)			RH (%)			Soil moisture(%)	
		Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	E-W	N-S
Nov. 06	9.6	2.5	0.4	1.3	22.6	13.4	18.8	97	41	70	56.6	54.8
Nov. 19	9.9	1.9	0.1	1.2	18.0	9.6	14.5	64	34	44	57.4	56.9
Nov. 21	9.3	1.6	0.2	1.0	19.7	7.4	15.5	88	49	67	56.2	55.6
Nov. 25	9.3	1.3	0.6	0.9	19.1	8.1	15.2	80	43	55	53.6	52.5

Table 3: Day time (7:OOh to 17:00h) energy balance of potato field during autumn 1996. It includes net radiation (Rn), latent heat flux (LEI, sensible heat flux (11) and soil heat flux (G). Ratios of LE and G to Rn are also included. [Day time (7:OOh-17:00h) totals were calculated from detailed measurements integrated over 11 hours data]

	Rn (MJm^{-2})		LE (MJm^{-2})		H (MJm^{-2})		-G (MJm^{-2})		-LE/Rn		-G/Rn	
Date	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S
Nova 06	6.31	5.98	-5.37	-5.15	0.12	0.51	1.07	1.34	0.85	0.86	0.17	0.22
Nov. 19	6.03	5.75	-5.97	-5.69	0.99	1.26	1.05	1.32	0.99	1.01	0.17	0.23
Nov. 21	5.43	5.12	-5.67	-5.64	1.20	1.70	0.96	1.18	1.04	1.10	0.18	0.23
Nov. 25	5.69	5.37	-4.90	-4.74	0.15	0.49	0.94	1.12	0.86	0.88	0.17	0.21
Average	5.86	5.55	-5.47	-5.30	0.62	0.99	1.01	1.24	0.95	0.97	0.17	0.22

Table 4: Day time (7:00h to 17:00h) energy balance of soil surface of potato field. Ratios of LE_E and *G* to Rn_s are also included. [Day time (7:00h-17:00h) totals were calculated from detailed measurements integrated over 11 hours data]

	Rn (MJm^{-2})		LE_s (MJm^{-2})		H_s (MJm^{-2})		-G (MJm^{-2})		$-LE/Rn_s$		$-G/Rn_s$	
Date	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S
Nov. 06	2.99	3.75	3.36	3.40	1.43	0.99	1.07	1.34	1.12	0.91	0.35	0.35
Nov. 19	2.37	3.23	2.88	3.29	1.56	1.38	1.05	1.32	1.21	1.01	0.44	0.40
Nov. 21	2.65	3.36	2.98	3.44	1.29	1.26	0.96	1.18	1.12	1.02	0.36	0.35
Nov. 25	3.05	3.36	2.35	2.93	0.24	0.69	0.94	1.12	0.77	0.87	0.30	0.33
Average	2.77	3.43	2.89	3.27	1.13	1.08	1.01	1.24	1.06	0.95	0.36	0.35

Table 5: Day time (7:00h to 17:00h) energy balance of crop canopy of potato. Ratio of $LE_s$to Rn_s is also included. (Day time 17;00h -17:00h) totals were calculated from detailed measurements integrated over 11 hours data]

	Rn (MJm^{-2})		LE_s (MJm^{-2})		H_s (MJm^{-2})		$-Le_c/Rn_c$	
Date	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S
Nov. 06	3.31	2.22	2.01	1.74	1.30	0.48	0.61	0.78
Nov. 19	3.66	2.51	3.09	2.39	0.58	0.12	0.84	0.95
Nov. 21	2.78	2.35	2.67	2.20	0.11	0.15	0.96	0.94
Nov. 25	2.54	1.95	2.43	1.18	0.11	0.14	0.96	0.93
Average	3.07	2.26	2.55	2.04	0,52	0.22	0.84	0.90

showed positive values in both the plots indicating absorption of the sensible heat by the soil from the upper air, which provided energy for LE_s. The $-G/Rn_s$, ratio was almost same in both the cases.

Table 5 shows daytime energy balance components of E-W and N-S potato row canopies. The average Rn_c of E-W row canopy was 26% larger than that of N-S row canopy. Similar was the case for LE_c *of* E-W row canopy, which was also 20% larger as compared to N-S row canopy. On average, 84% of *Rn* was partitioned to LE_c. for E-W row canopy and 90% for N-S row canopy (Table 4). The H_c. showed negative values both for E-W and N-S row canopies (Table 5) indicating sensible heat flux was away from the canopy.

Ratios of *LE* to *Rn* of our study were almost similar to those of Ritchie (1971) and Ham *et al.* (1991). Ratios of LE_s to Rn_s and LE_c to Rn_c of our study were also nearly similar to those of Ham *et al.* (1991). These indicate that pot lysimeter method could be used to measure evaporation and transpiration in case of small fetch when soil moisture is not limited. Results reveal that the trends in energy balance components observed in E-W and N-S soybean rows in summer (high solar elevation angle) are different from those of E-W and N-S potato rows in autumn (low solar elevation angle). Thus, the above results also suggest that both E-W and N-S row orientations as well as high (Baten *et al*., 1997) and low solar elevation angles should be taken into consideration when evaluating the energy and water balance of sparse crops.

Results reveal that the trends in energy balance components observed in E-W and N-S soybean rows in summer are different from those of in E-W and N-S potato rows in autumn. Field energy balances were observed to be different from the soil and canopy surface energy balances. Therefore, separate energy balance measurement should be done for soil and canopy as well.

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References

Baldocchi, D.D., S.B. Verma and N.J. Rosenberg, 1981. Mass and energy exchanges of a soybean canopy under various environmental regimes. Agron. J., 73: 706-710.

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

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

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

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

Geiger, R., 1980. Heat Budget of the Earth's Surface as the Basis of Micrometeorology. In: The Climate near the Ground, Geiger, R. (Ed.). Harvard University Press, Cambridge, pp: 5-43.

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

Jones, G.H., 1994. Plants and Microclimate-A Quantitative Approach to Environmental Plant Physiology. 2nd Edn., Cambridge University Press, Cambridge, Pages: 428.

Ritchie, J.T., 1971. Dryland evaporative flux in a subhumid climate: I. Micrometeorological influences. Agron. J., 63: 51-55.

Tanner, C.B. and W.A. Jury, 1976. Estimating evaporation and transpiration from a row crop during incomplete cover. Agron. J., 68: 239-243.

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