QUANTIFYING ENERGY BALANCE COMPONENTS AND ESTIMATING MAIZE EVAPOTRANSPIRATION UNDER WIDE AND NARROW RUNOFF STRIPS

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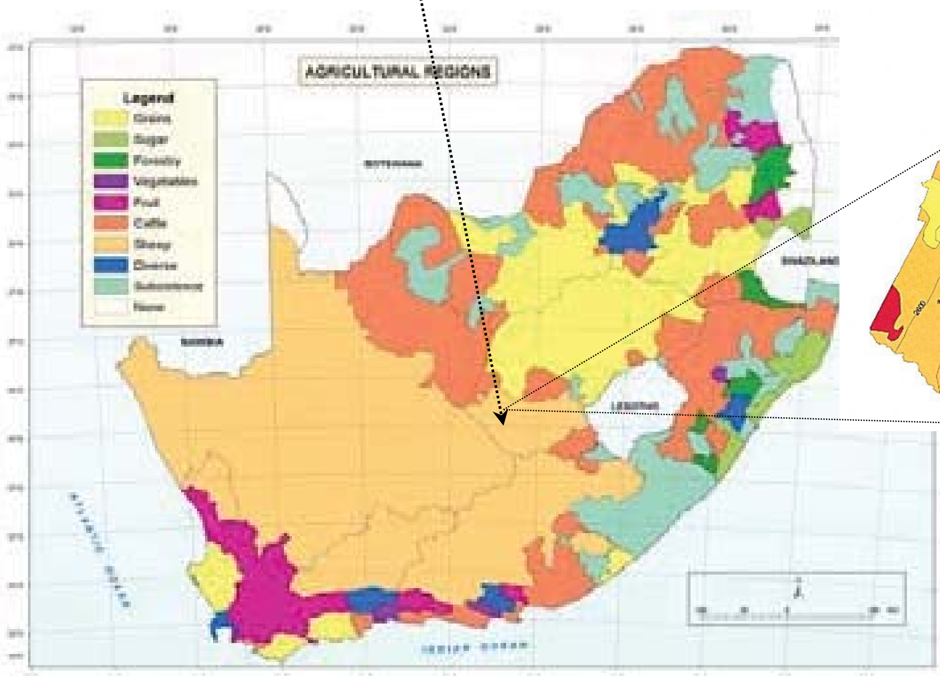
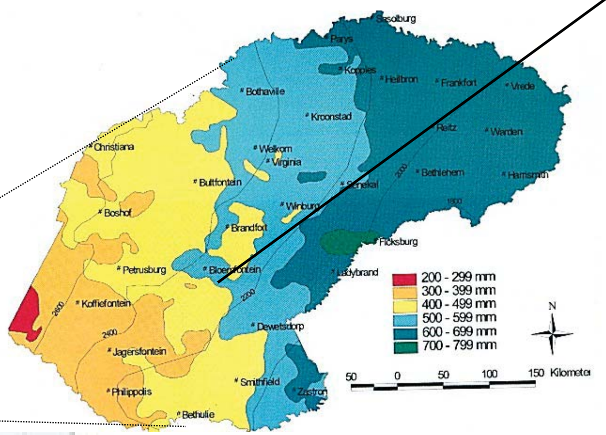
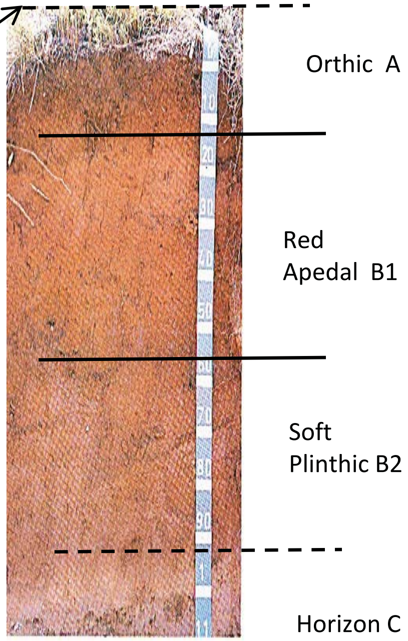
LANDBOUWETENSKAPPE

ECOTOPE

◊ Climate — Semi-arid area
◊ Soil — Fine sandy loam
◊ Topography — 1%







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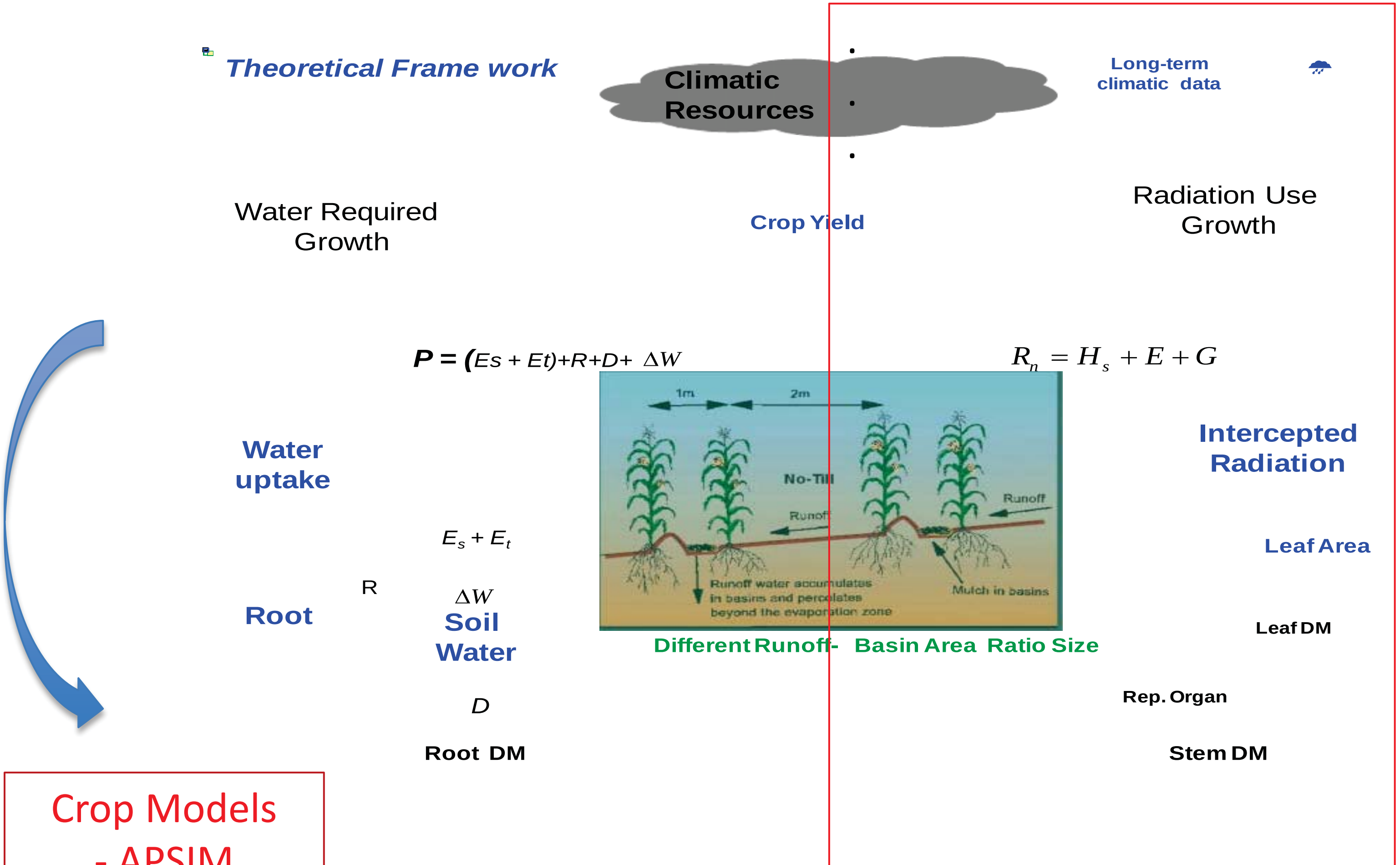
OVERALL PROJECT OF WATER & ENERGY BALANCE UNDER IN-FIELD RAINWATER HARVESTING (IRWH)

Latent Heat **- - - - - crucial component to balance both water and energy and controlled by the environmental and biological processes**



Crop Models
- APSIM
- AquaCrop

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MOTIVATION

- In dry land farming the soil evaporation accounts
  - for approximately 30% - 50% of the total loss of precipitation (wallace, 1991)
  - a value can exceed 50% in sparsely cropped farming system , such as IRWH
  - in semi-arid of South Africa 60%-85% of the rainfall, (Bennie et al., 1994) and for maize crop 30% of the total evapotransiration
- Considerable proportion of the rainwater that would be used for growth and vegetation development is lost.
- Better understanding of evapotranspiration is crucial for
  - more efficient use of rainwater under limited precipitation
  - determining management strategies to conserve water

OBJECTIVE

- To quantify the components of the energy balance and to compare available energy so as to estimate ET for maize crop under IRWH.

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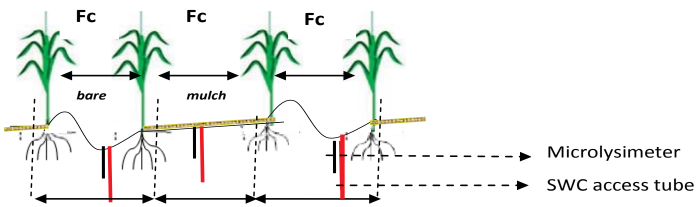
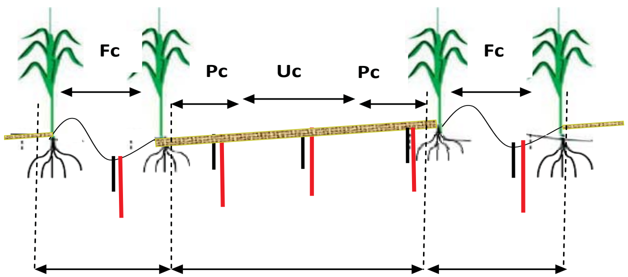
MEASURMENTS

a) Narrow Runoff Strip (RSL-1)



b) Wide Runoff Strip (RSL-3)



❑ Net radiation	NR-LITE-L Net Radiometer
❑ Soil heat flux	Plates of CN3 type
❑ Wind speed	Three-cup wheel Sentry Anemometer
❑ Temp. & Humidity	HMP50 Probes (PRT & Vaisala) sensors
❑ Soil temp.	Thermocouples (0.51 mm)
❑ Soil water content	ECH2O Probe Sensors

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$$Rn - G = Hs + LE$$

(Rosenberg et al., 1983)

Bowen ratio method

$$LE = (Rn - G)/(1 + \beta)$$

Aerodynamic method

$$Hs = \rho C_p k^2 \frac{(\theta_1 - \theta_2)(u_2 - u_1)}{\{ln[(z_2 - d)/(z_1 - d)]\}^2} (\Phi_m \Phi_h)^{-1}$$

(Monteith & Unsworth, 1990)

MO Similarity Parameter

(Malek, 1993 & Arya 2001)

Neutral & Stable	$\zeta_m = R_i/1 - 5R_i$	$0 \leq R_i < 0.25$
Unstable	$\zeta_m = R_i$	$R_i < 0$

Stability Factors

Stable (*Ri* > 1)	$\Phi_m^2 = \Phi_h = \Phi_w = (1 - 5\zeta)^{-1}$	$\zeta \geq 0$	$F = (1 - 5\zeta)^2$
Unstable (*Ri* < 0)	$\Phi_m = \Phi_h = \Phi_w = (1 - 15\zeta)^{-1/2}$	$\zeta \geq 0$	$F = (1 - 15\zeta)^{-1}$

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Soil heat flux (G)

$$G_{sf} = G_{0.08} + C_s \frac{dT_s}{dt} dz$$ (Hanks & Ashcroft, 1980)

Modelling of net radiation (Rn)

$$Rn = [(1-\alpha)Rs \times FC_{eff}] - [(1-V_{sky})\epsilon_s \sigma T^4 / BLAR]$$

$$\alpha = \alpha_c - (\alpha_c - \alpha_s) exp(0.75BLAR)$$ (Oguntunde & van de Giesen, 2004)

$$\alpha_s = \alpha_{sw} + \alpha_{s\theta}$$

$$\alpha_{s\theta} = 0.01[(exp0.00358\theta^{1.5}) - 1]$$ (Song, 1998)

$$\theta = \arccos(sin\emptyset sin\delta) + (cos\emptyset cos\delta)\left[\frac{\pi}{12} - (t - t_o)\right]$$

$$V_{sky} = [\{(L_R - L_c)^2 + h_c^2\}^{1/2} - h_c]/L_R$$ Ham et al., 1991

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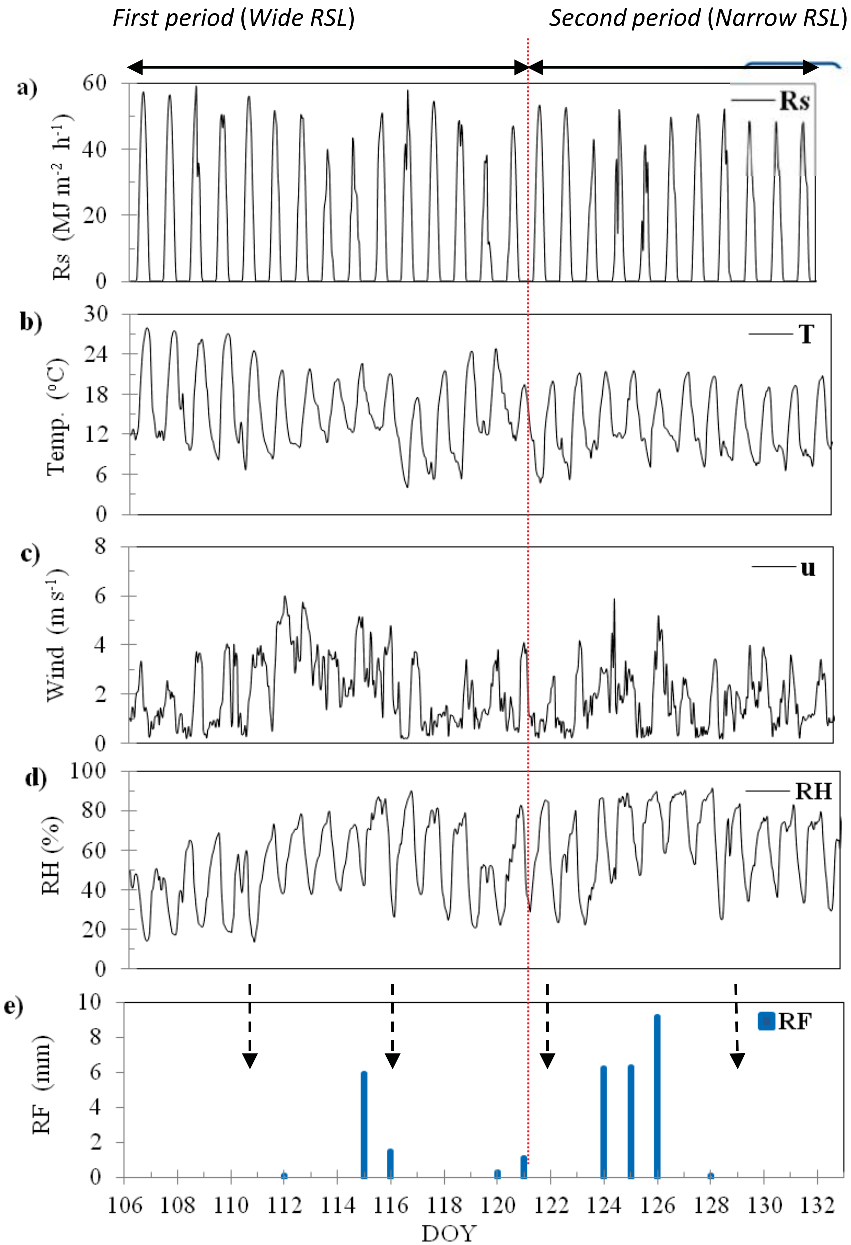
Weather variables during measurement periods

- During late growth stage (Autumn)
- *Rs* decrease slightly over the measuring period resulting higher daily mean *T* on 1st period
- Wind was weaker in 2nd period compared to 1st
- *RH* values indicating a typical semi-arid conditions with low during day & high during night
- *RH* slightly higher in the second period compare to 1st period (64% vs. 53%)
- Because of more rain & longer rain durations (21.9mm vs. 8.9mm)
- Resulted lower ETo in the 2nd period compared 1st



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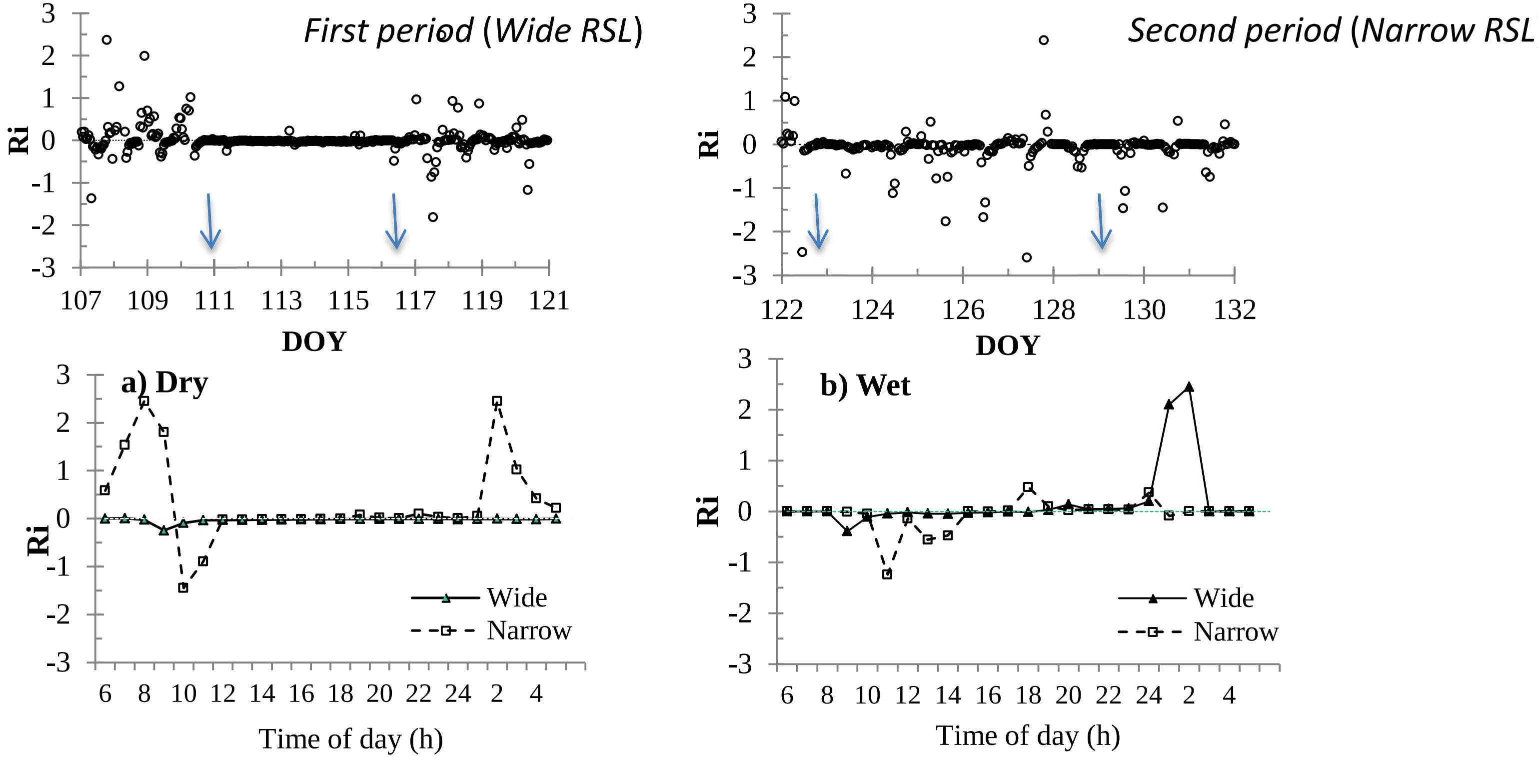
Atmospheric stability

◊ Within and above canopy behaviour of T and u is very complex and often characterize by atmospheric stability parameters



◊ According to Ri criterion, the 1st period had lower *Ri* compared 2nd period

◊ Despite these difference, it was argued there are days that met the stability requirement during dry and wet conditions for wide and narrow RSL treatments.

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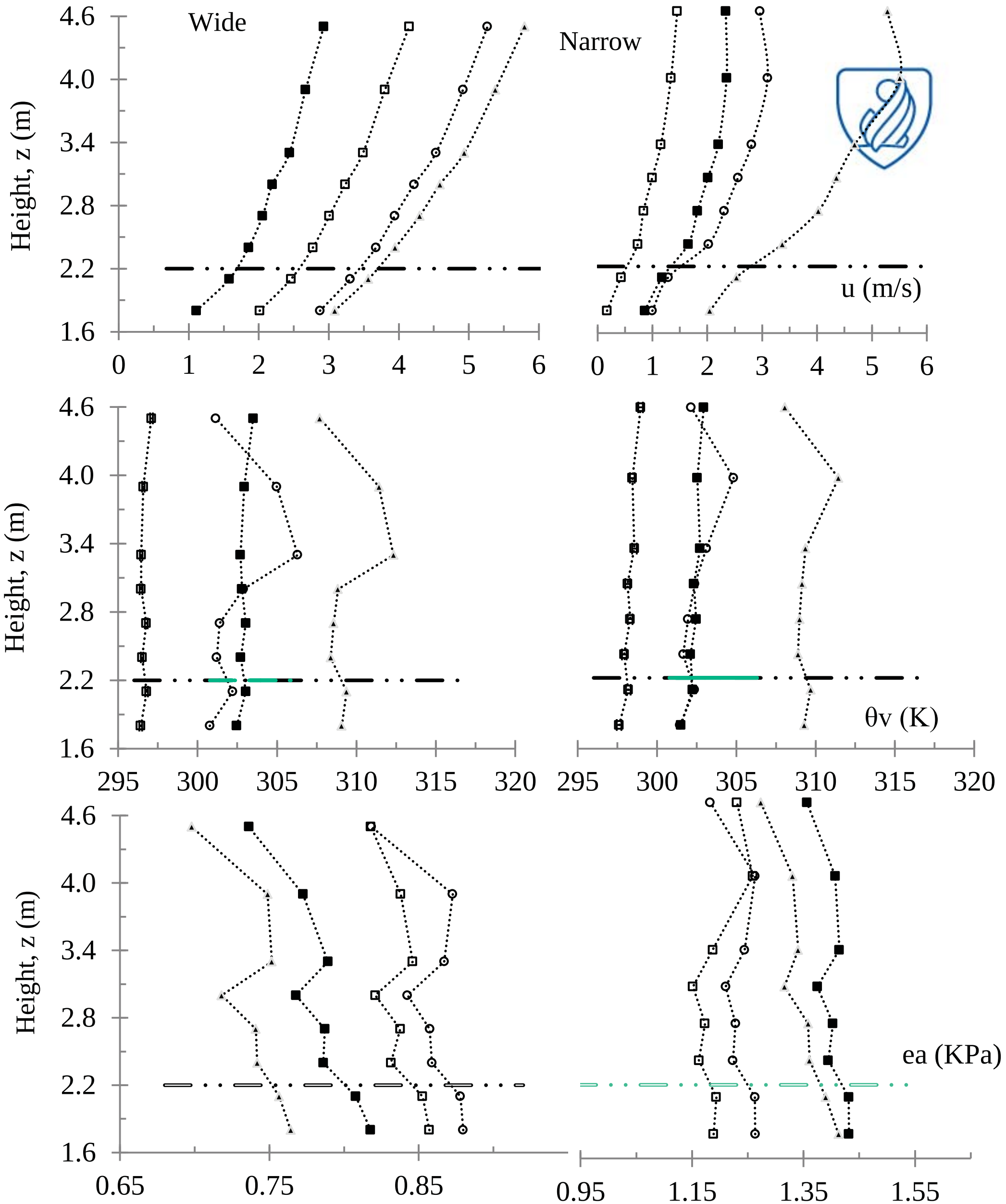
Profiles within & Above canopy



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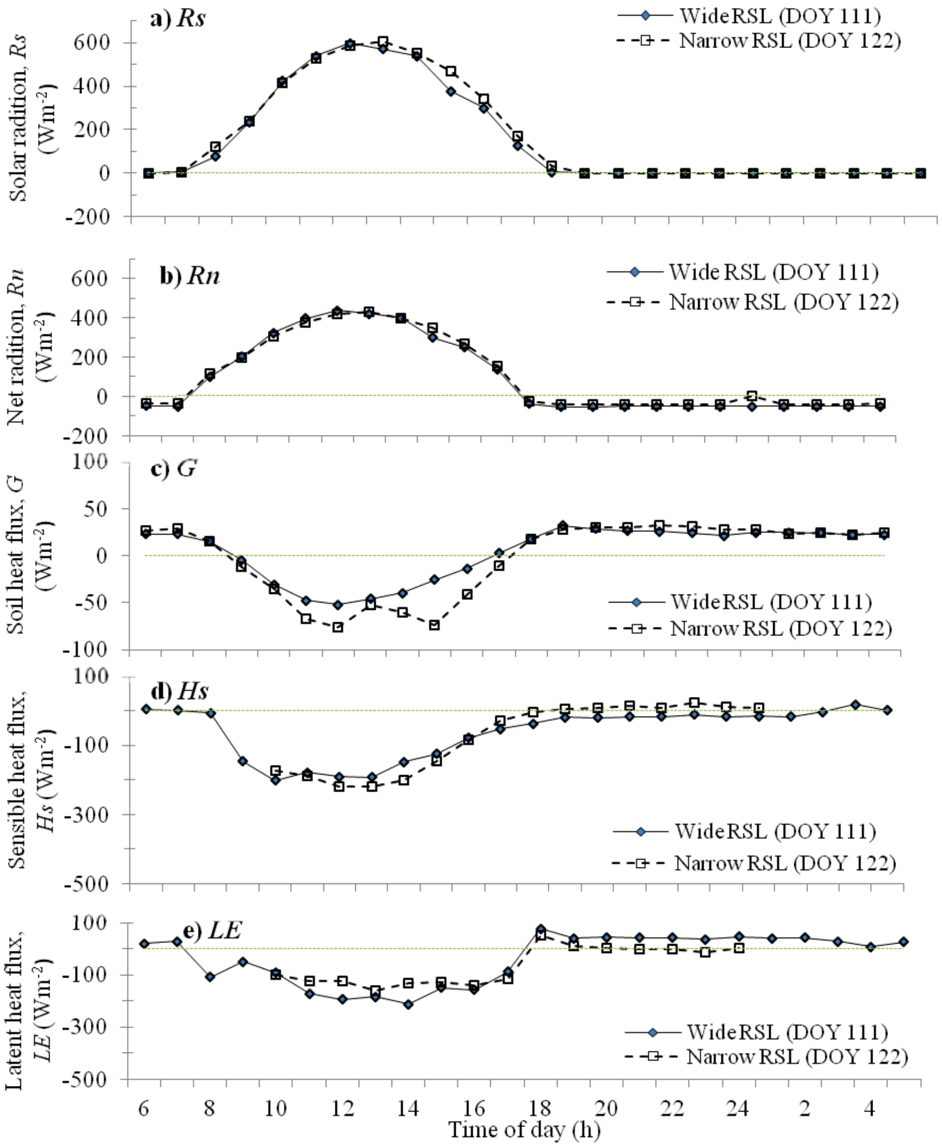

Dry Days Diurnal Pattern

- ◊ Rs are similar in both wide and narrow RSL
- ◊ Rn showed little variation during midday & afternoon

Soil heat flux (G)

Wide	smooth with high at midday ($52 Wm^{-2}$)
Narrow	variable with large peak values ($76 Wm^{-2}$)

Daytime
Wide < Narrow

Nighttime
Wide ≈ Narrow

- ◊ Low plant population (Lower BL-ratio) allowed more radiant energy to reach soil surface
- ◊ In narrow RSL more energy transmitted & less energy partitioned into LE &Hs

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Sensible Heat (Hs)

- Around midday Narrow RSL > Wide RSL
- Nighttime the Narrow Hs more towards the soil showing direct exchange of heat from canopy to surface
- During morning sharp increase of Hs in wide indicating the open surface of the runoff releasing heat to the atmosphere
- After midday more heat left Narrow than Wide

Latent Heat (LE)

- Around midday β remained higher ($\beta = \approx 1$)
  more than half (55%) of available energy used for evaporating water in wide
- Wide RSL most energy was partition to LE ($\beta \leq 1$) include advection afternoon (high wind speed 4 – 6 ms^{-1})
- Narrow RSL large portion of energy was partitioned to Hs ($\beta >> 1$) & conditions are non advective

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Wet Days Diurnal Pattern

- ❑ *Rs* and *Rn* had large values for wide with a dip at mid day due to cloud.

Soil heat flux (G)

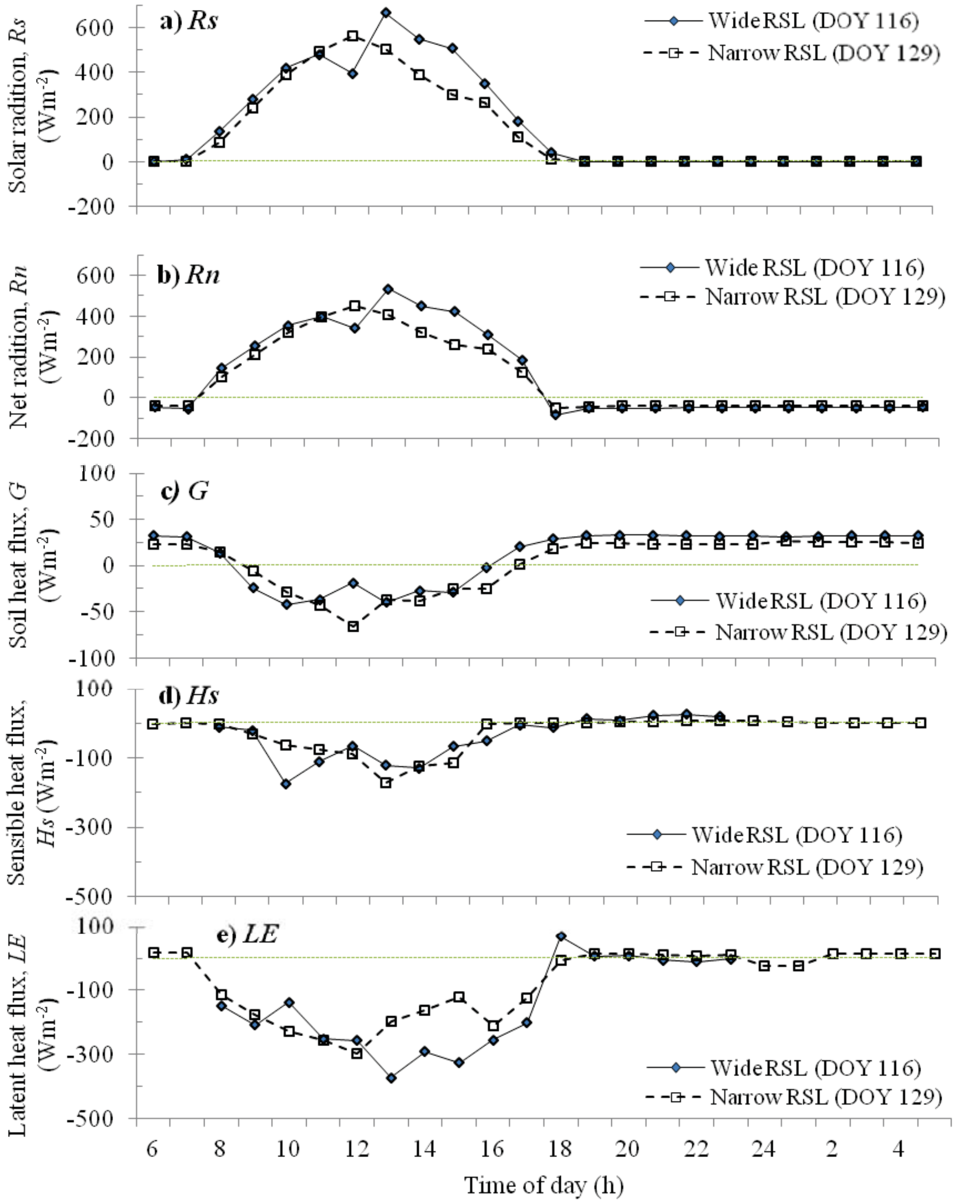
- ❑ Wide slightly more than Narrow except under cloud conditions at midday & afternoon

- ❑ At night G was positive & Wide greater than Narrow by 25%, indicating more heat energy was going towards the wide runoff

Bowen ratio partitioning (Hs/LE)

- ❑ Unlike dry, the wet days Hs & LE not similar
- ❑ Hs comprises small portion of the energy balance (β < 0.5) under moderately wind condition

- ❑ Wide RSL accounted for most energy consumption
- ❑ Narrow RSL LE reduced during afternoon (little evidence of sensible advection)



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From the analysis of diurnal course - - -

- *Rn* after rain days was more variable than on dry days due to canopy shading and albedo effect

- *G* in dry/wet & wide/narrow represent significant form of energy balance

- Wetting of the soil surface in the wide runoff soil surface alter surface energy balance and micro climate in the canopy because of reduced albedo and increased radiant energy

- Considering local advection of heat and water vapour within air space in the uneven row widths inherent in the system of IRWH

- Favourable for horizontal advection from hot, dry bare runoff area to relatively cool wet plant canopy in the basin area, specially under windy conditions.

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Midday basis Available Energy Partitioning

- ❑ During dry days the Hs is the large portion of available energy (β ≥ ≈1) and reveres on wet days
- ❑ The mean values of β was double on dry compared to wet (0.97 vs. 0.48)

Treatments	*Rs* (Wm^{-2})	*Rn-G* (Wm^{-2})	*Hs* (Wm^{-2})	*LE* (Wm^{-2})	EF (LE/(Rn - G))	β (Hs/LE)	ET (mmd^{-1})
Soil condition							
Dry (DOY 111 & 122)	536.3	338.8	152.2	157.9b	0.46b	0.97	1.20b
Wet (DOY 116 &129)	484.9	362.1	106.7	253.2a	0.69a	0.48	2.51a
LSD	ns	ns	ns	47.1	0.07	ns	0.41
Runoff strip							
Wide (DOY 111 &116)	521.4	373.7a	132.8	240.9a	0.64a	0.63	2.16a
Narrow (DOY 122 &129)	499.6	327.1b	126.1	170.2b	0.52b	0.83	1.55b
LSD	ns	41.7	ns	40.7	0.08	ns	0.37
CV%	13.8	12.2	38.8	23.5	13.9	58.7	24.2

Fraction of available energy , EF (LE/(Rn-G)):

- ❑ Wet conditions are more efficient than dry (69% vs 49%
- ❑ Wide RSL is also being effective than Narrow RSL (64% vs 52%)

Therefore;

- ❑ Higher ET occurred from wide RSL (2.16 mmd^{-1}) relative to narrow RSL (1.55 mmd^{-1})
- ❑ ET was lower under dry conditions for both wide and narrow (1.57 vs. 2.74 mmd^{-1} & 0.82 vs. 2.28 mmd^{-1})
- ❑ Regardless of weather conditions (dry/wet), the available evaporative surfaces (soil and leaf) much higher under wide RSL

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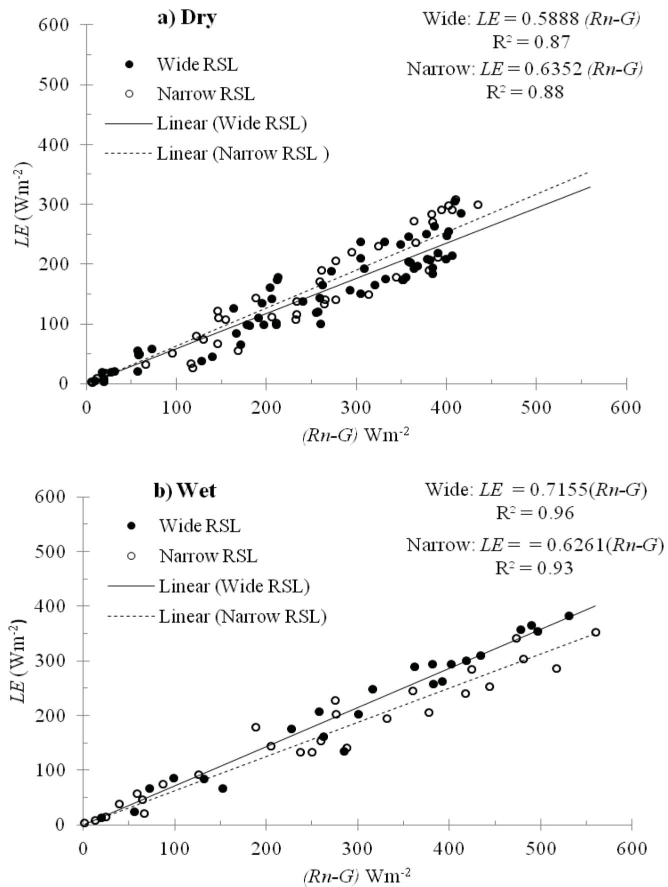
Partitioning of available energy (Rn-G)

- The paired relationships were highly significant differences for wide/narrow and dry and wet



- During dry period the narrow RSL used more available energy (64% vs. 59%)

- During wet period, Wide RSL had much higher available energy partitioned to LE than narrow (72% vs. 63%)

- Results from both wide and narrow RSL showed a dependence of ET on the amount of available energy during both dry and wet conditions.

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CONCLUSION

- *Rn* simulation was satisfactory with inclusion of albedo and canopy factors and measured G showed variation during dry/wet conditions on both wide/narrow RSL

Thus contribution of Rn & G under IRWH had an influence in partitioning Hs and LE

- The wide-wet was able to convert 75% of the available energy into evaporative power. The wide RSL with higher BL-ratio contribute to greater transpiration and cause loss of more energy by evaporation.

- The local advection from the wide runoff area enhanced more ET from the crop rows of the basin area.

Hence LE consumed more energy and as a result wide RSL was more efficient converter of available energy to on that also promotes more biomass production.

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In many cases the biophysical properties are well understood & the ability of increase yield proven , but still lack of the wide spread energy balance studies & remains mystery that needs more research

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Thank You
Dankie

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