Dimensions and orientation of runoff trenches for minimizing water loss

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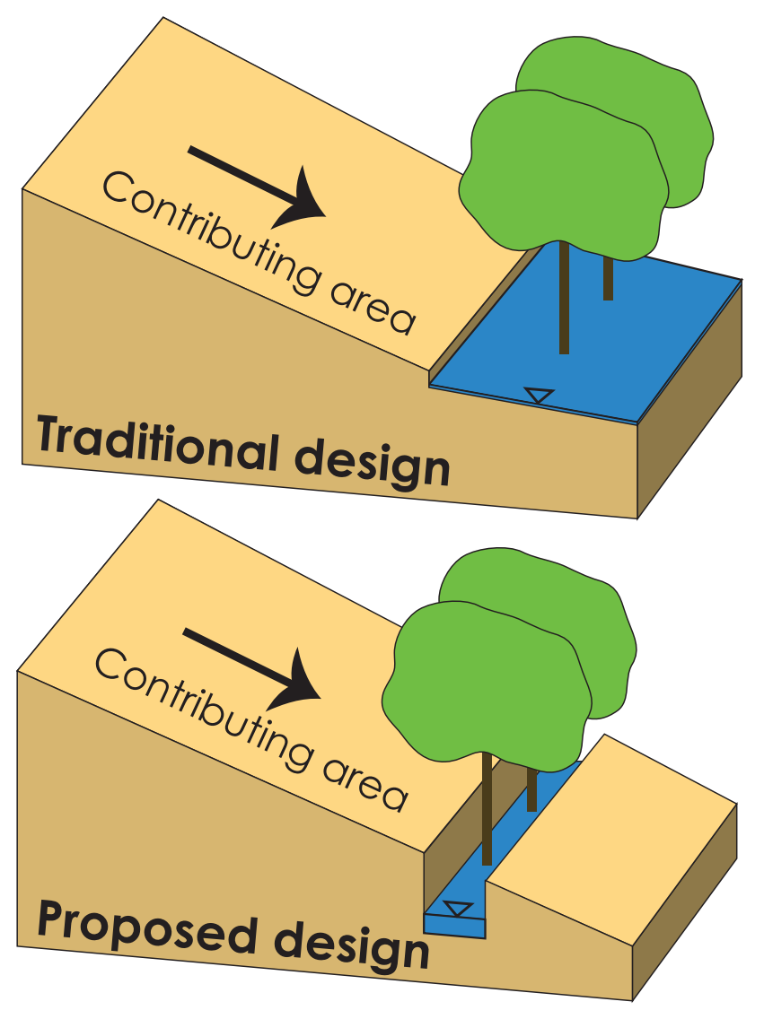
Rationale

Micro-catchment water harvesting systems are designed to collect runoff water generated on a given area (contributing area) and store it in the soil profile of an adjacent shallow infiltration basin. Conservation of the harvested water in the soil can be achieved by minimizing the non-productive water losses, i.e., direct evaporation and deep percolation. By replacing the shallow infiltration basin with a trench, the solar radiation flux reaching the bottom of a wet trench will be dramatically reduced, thus direct evaporation from the soil surface will be reduced.



Objective

Optimally design trench dimensions and orientation for minimizing solar radiation load (prime driver of soil evaporation) on the expected wet soil surface within the trench by modeling solar radiation regime within the trench

Radiation model description

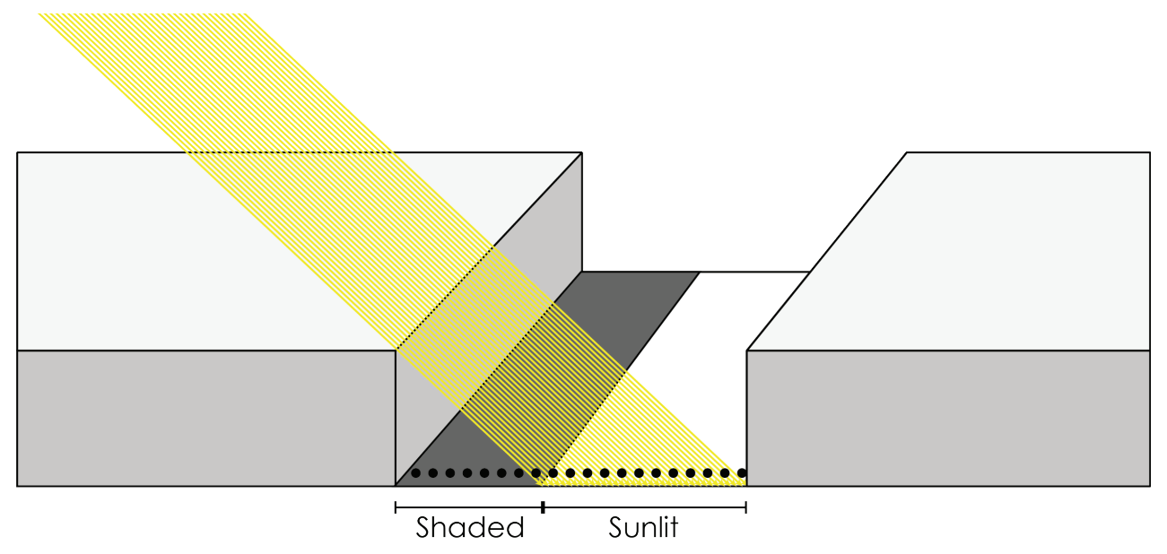
Radiation models were primarily developed for either urban or agricultural applications -

Models designed for agricultural studies	**Models designed for urban studies**
☒ usually don't account for reflected solar radiation from horizontal surfaces	☑ usually account for reflected solar radiation from horizontal surfaces
☑ frequently compute radiation at multiple points below the canopy	☒ frequently compute "average" radiation fluxes for a single site located midway in the canyon

Approach - combine the pros and avoid the cons of both approaches

Assumption - the length of the trench is infinite, no crop is present and secondary reflection is negligible.

Direct solar radiation



Depends on:

☐ Sun's elevation and azimuth angles

☐ Trench orientation and dimensions

1. Define shaded and sunlit areas

$$L = \text{depth}\frac{\cos(\theta)}{\tan(\varphi)}$$

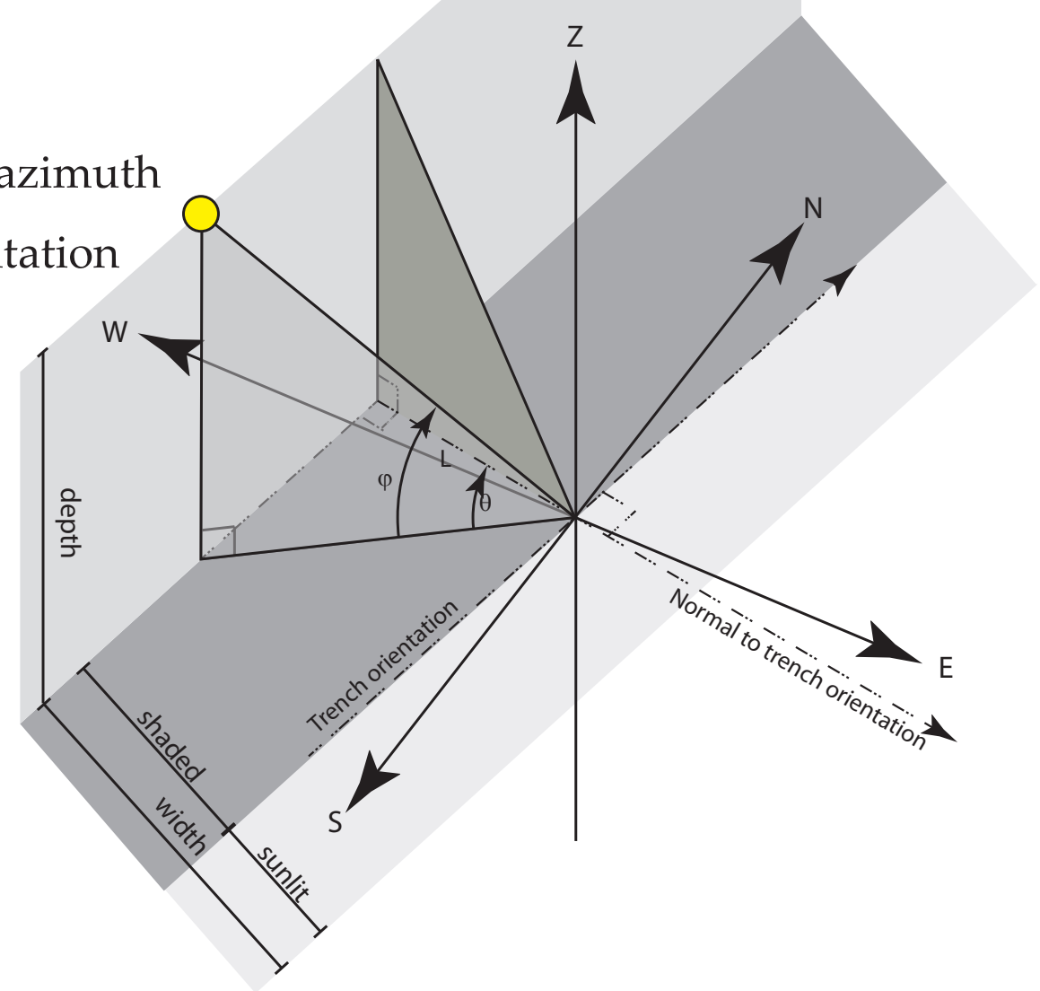
depth = trench depth

θ = the angle between the solar azimuth and the normal to trench orientation

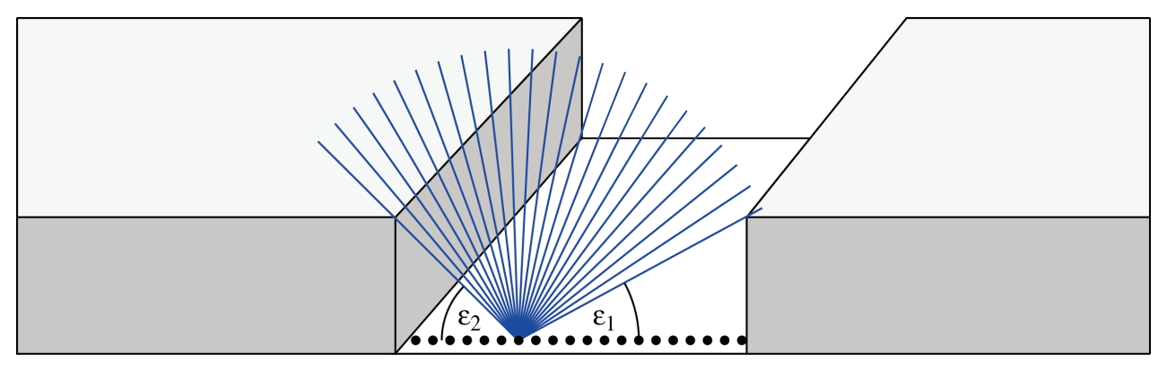
φ = solar elevation angle

2. Compute direct radiation at each point on a transect perpendicular to the direction of the trench (wall-to-wall)

$$RAD_{dir_i} = \begin{cases} RAD_{dir} & \text{if sunlit } (x_i < L) \\ 0 & \text{if shaded } (x_i \geq L) \end{cases}$$

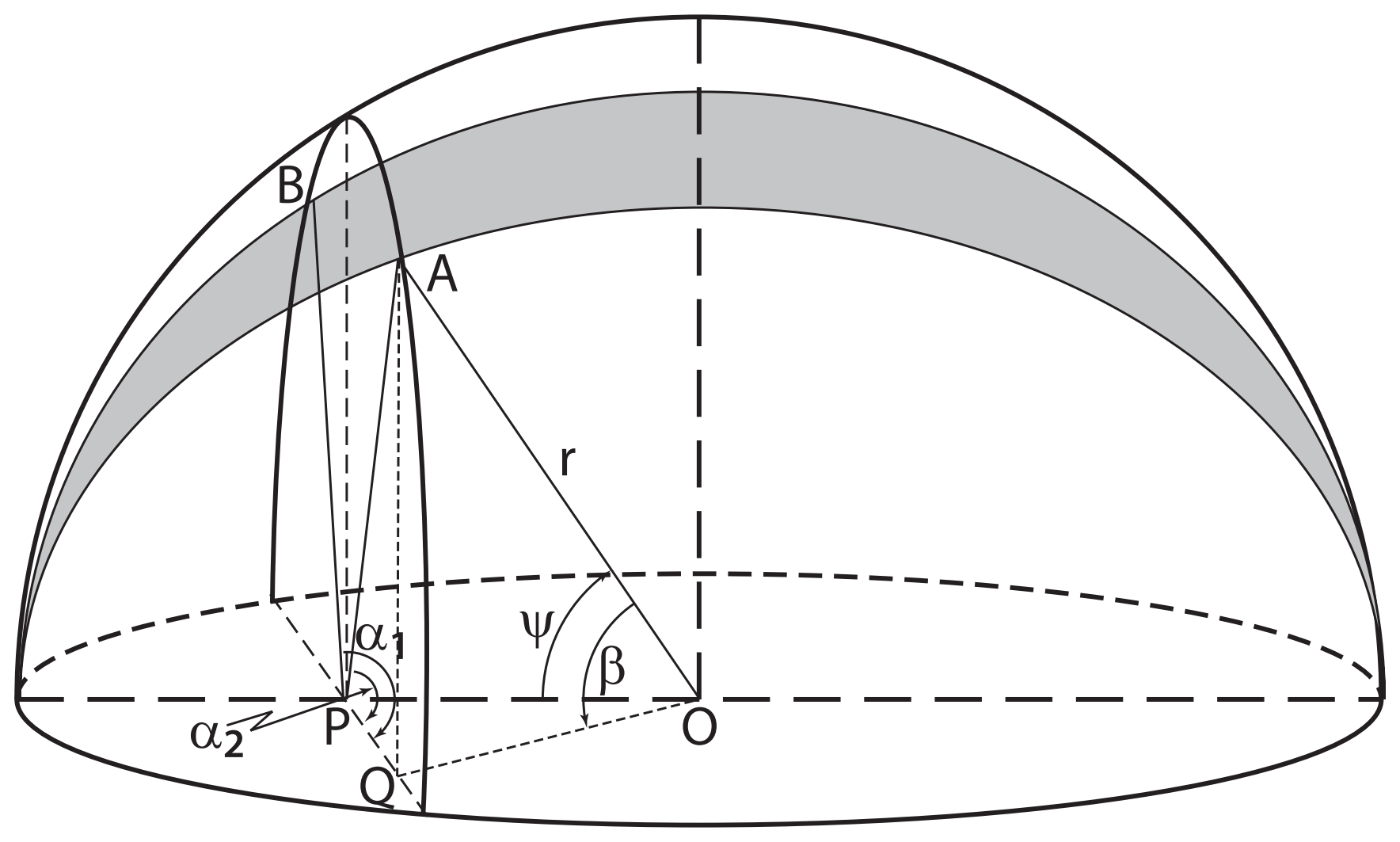


Diffuse solar radiation



Depends on:

☐ The veiw angle from each point to the sky



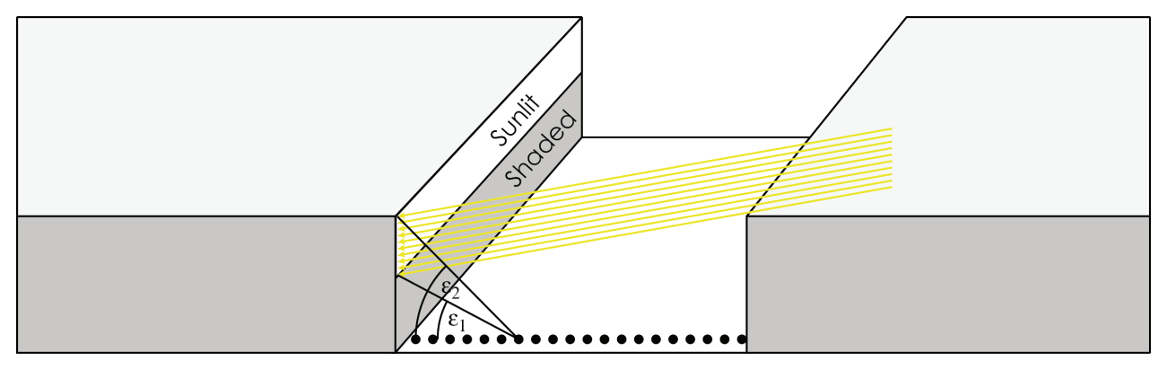
The diffuse radiation reaching O emanating from a slice of the upper hemisphere with angle BPA is

$$\Omega_S = \int_{\varepsilon_1}^{\varepsilon_2}\int_0^{\pi} \Omega \sin^2\psi \sin\alpha \, d\psi \, d\alpha = \Omega r^2 [\cos\varepsilon_1 - \cos\varepsilon_2]^{\pi}/_2$$

Diffuse solar radiation at each point

$$RAD_{diff_i} = RAD_{diff}\frac{\cos\varepsilon_{1_i} - \cos\varepsilon_{2_i}}{2}$$

Reflected solar radiation



Depends on:

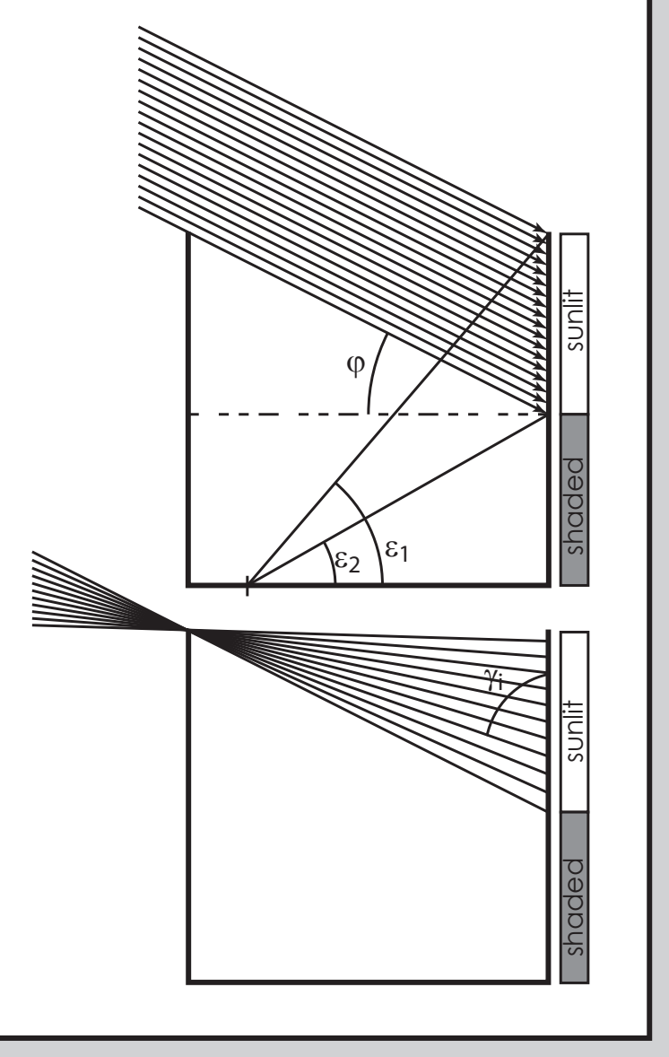
☐ Wall albedo

☐ View angle of the wall from each point

$$RAD_{ref_i} = \rho W_{RAD} = \rho (W_{dir_i} + W_{diff_i})$$

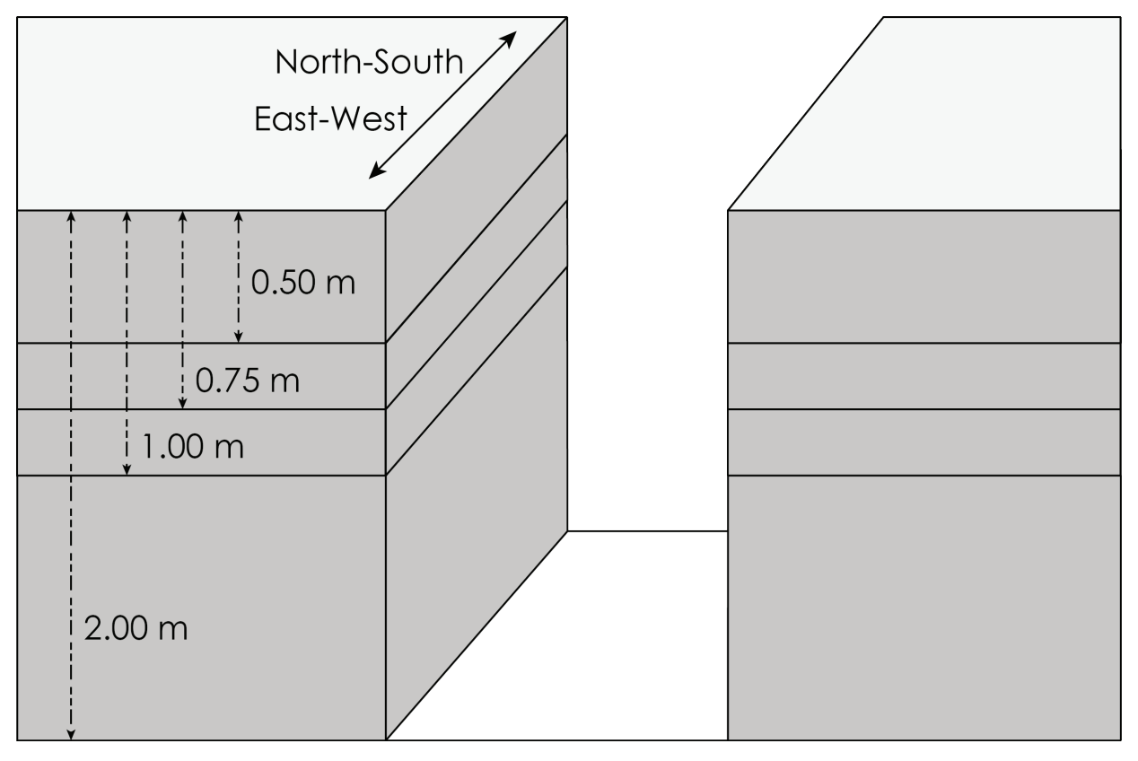
$$W_{dir_i} = RAD_{dir}\cos\varphi\frac{\cos\varepsilon_{1_i} - \cos\varepsilon_{2_i}}{2}$$

$$W_{diff_i} = \left(1 - \frac{\cos\varepsilon_{1_i} + \cos\varepsilon_{2_i}}{2}\right)\int_{\pi/2-\varphi}^{\pi/2}\frac{1-\cos\gamma}{2}\,d\gamma$$



Assumption – The trench walls are Lambertian reflectors

Simulations



☐ Location - Sede-Boqer campus, (30º 51′ 33″ N 34º 46′ 42″ E)

☐ Input data - global, diffuse, and direct radiation

☐ Time - 1 Jan-31 Dec 2010 @ 10min intervals

☐ Trench orientations - north-south (N-S) and east-west (E-W)

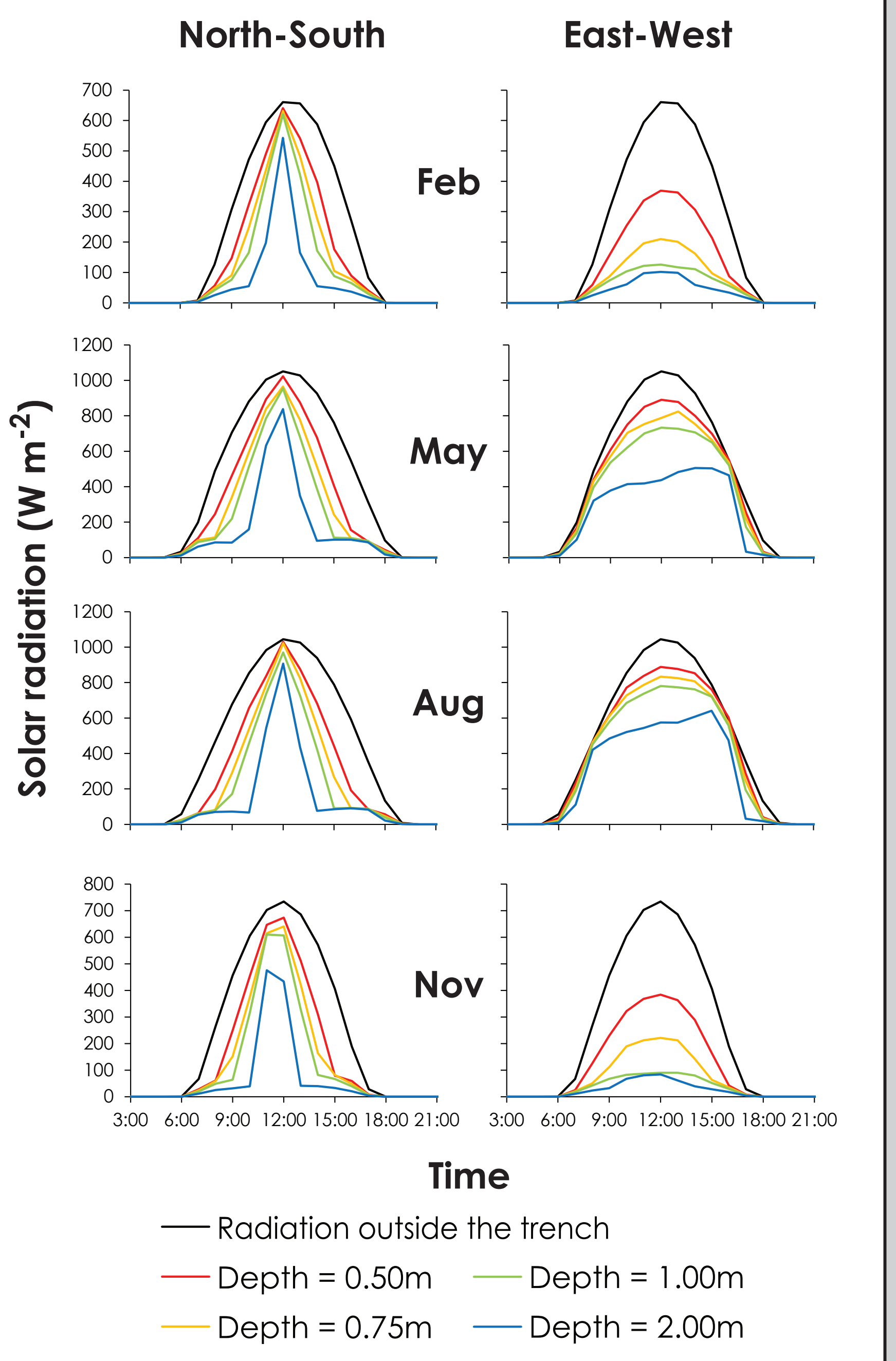
☐ Trench width - 1.0 m

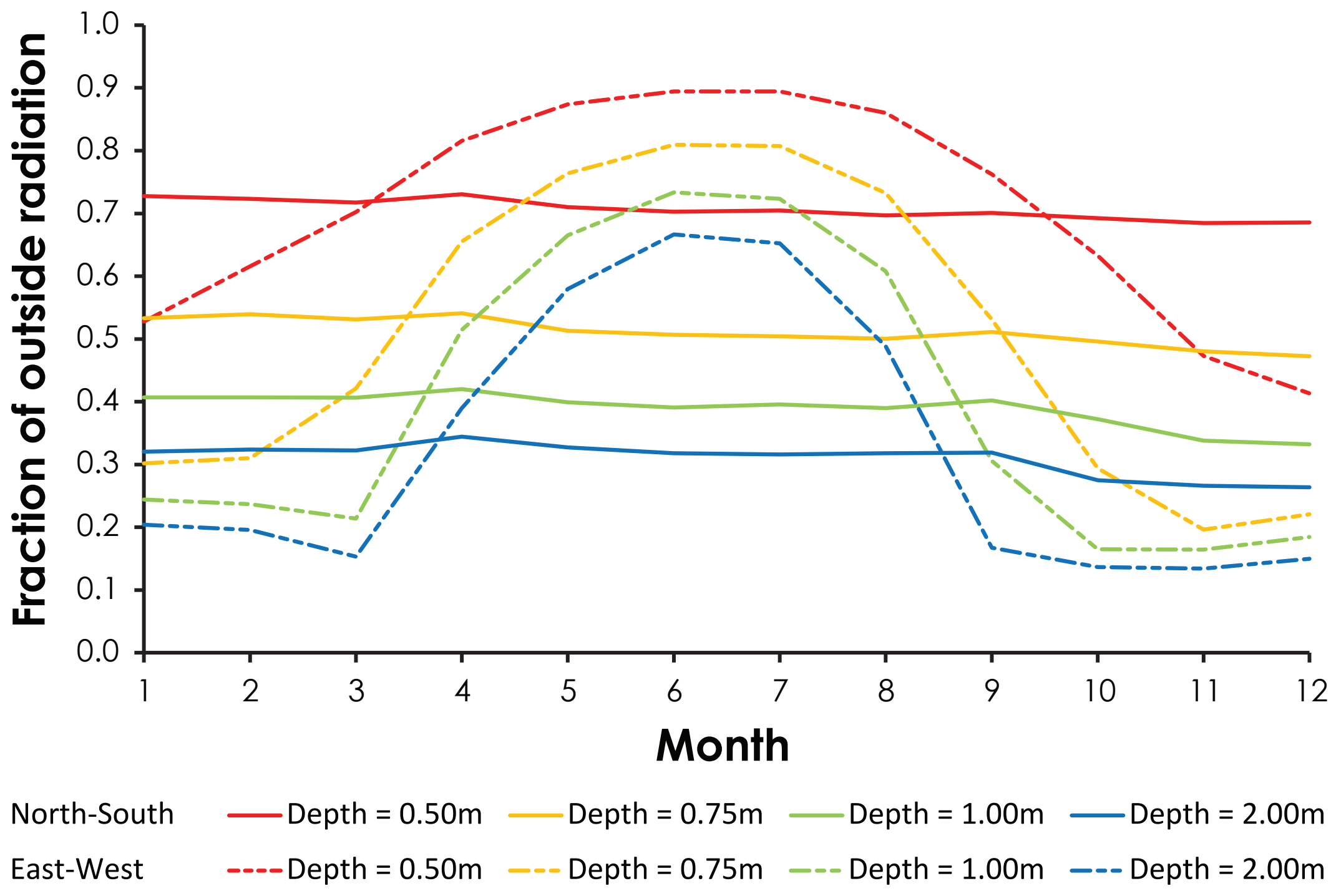
☐ Trench depths - 0.5, 0.75, 1.0, 2.0 m

Results

1. Different diurnal patterns of trench radiation for the N-S and E-W orientations were observed, with a sharp and short peak in the N-S orientation and a lower and wider peak in the E-W orientation.

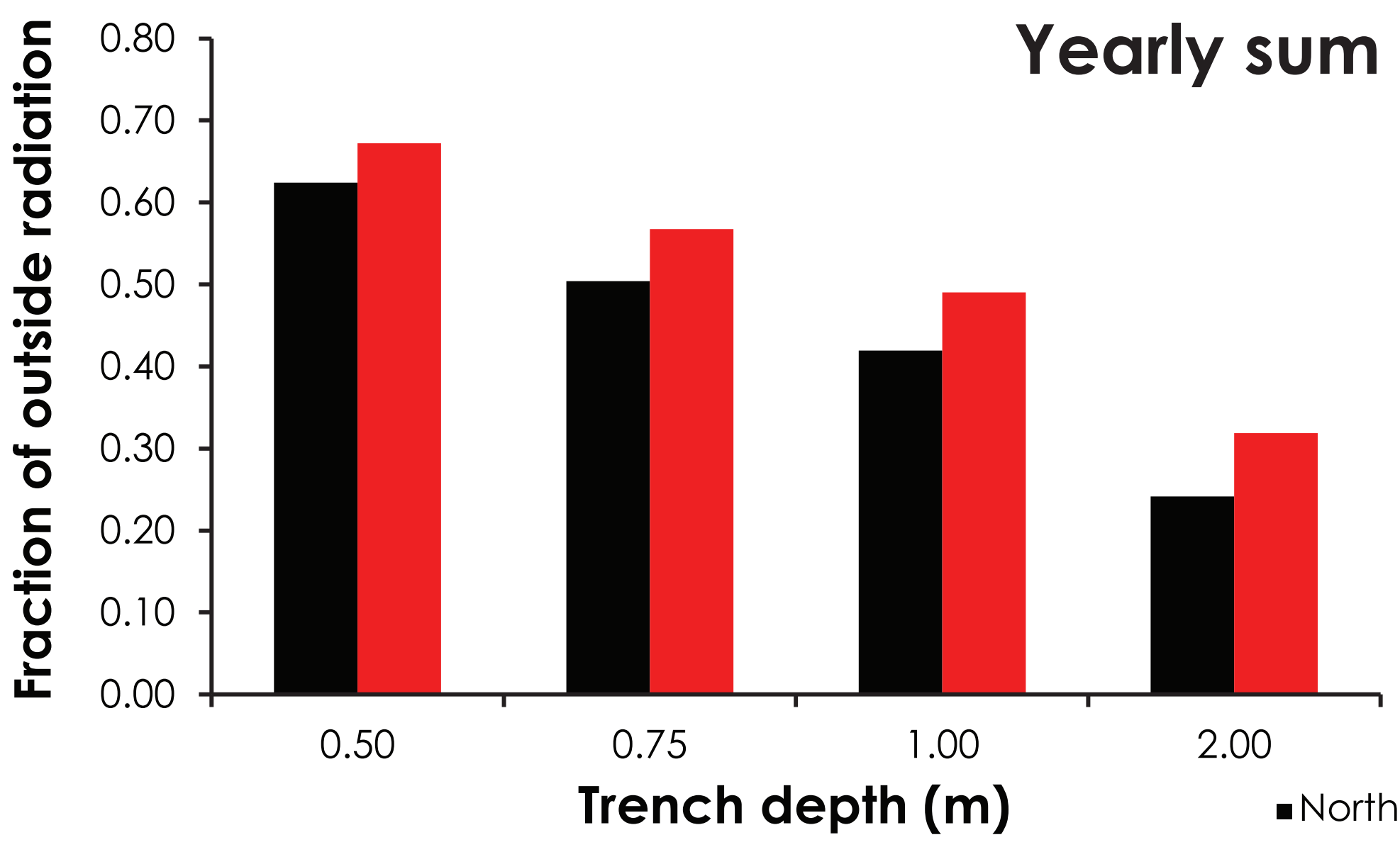
2. In the N-S orientation little difference in the diurnal pattern of trench radiation throughout the year was observed, while in the E-W orientation seasonal differences in the diurnal pattern were more apparent.

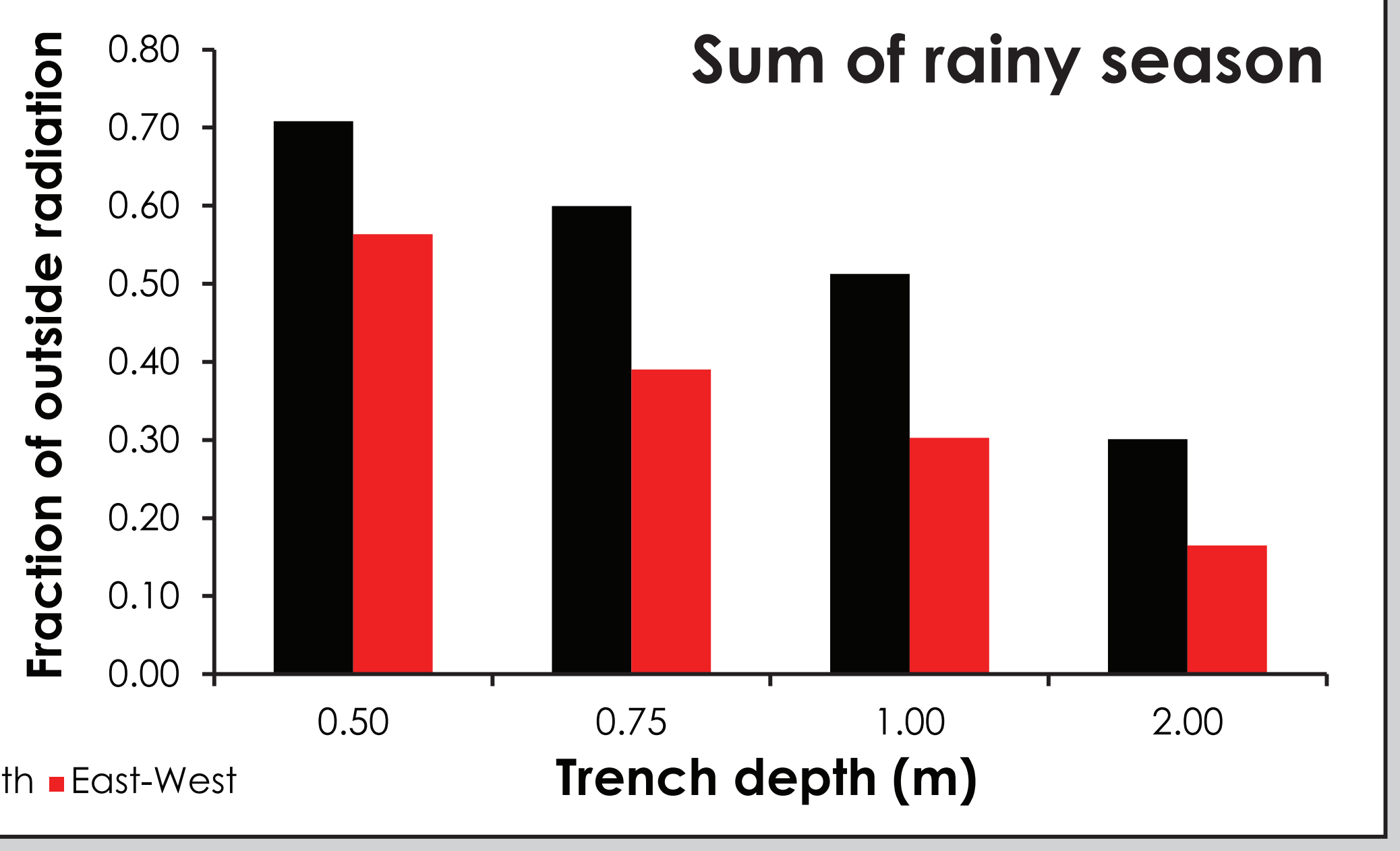




3. The fraction of radiation reaching the bottom of the trench averaged over the width compared to the radiation outside the trench in the N-S orientation was constant throughout the year, changing only as a function of trench dimensions, while in the E-W orientation this fraction changed as a function of both trench dimensions and day of year.

4. The yearly total of trench radiation in the E-W orientation was larger than in the N-S orientation, but smaller when considering only the rainy season (November-March).





Conclusions

1. **Radiation flux reaching the bottom of the trench decreases with trench depth**
2. **Trench orientation affects the radiation flux reaching the bottom of the trench**
3. **Radiation flux reaching the bottom of a 1m wide and 1m deep trench was ~70% lower than the radiation received on a similar area on the soil surface**
4. **For an area with Mediterranean rainfall regime an E-W orientation is preferable and will probably result in a reduction of direct evaporation**