Energy flux and water use efficiency measurements in a maize and soybean cropping system

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Introduction

The agricultural sector is one of the crucial sectors heavily impacted on by the consequences of water scarcity. Climate models have shown that climate change alone will decrease global crop production by 9 % by year 2050 [1]. Erratic rainfall patterns are likely to impact on poorer communities depending on rainfed agriculture. These communities will be left to face potential hunger as their crops fail to give sufficient yields. On the other hand, commercial farmers are likely to face increased costs of water for irrigation due to restrictions and high cost of available fresh water. The challenge faced by agrometeorologists and hydrologists globally is therefore an increased need for climatic information and various products to accurately quantify water use by various crops. There is also a need for testing various remote sensing products, crop models and modern climate monitoring equipment. The observed total evaporation *ET*, yield and water use efficiency for maize and soybean crops showed good agreement with AquaCrop model outputs.

Materials and methods

Micrometeorological and meteorological measurements over two cultivated plots (maize and soybeans) for season 2012-2013 were collected at Baynesfield Estate (near Richmond), KwaZulu-Natal, South Africa (Fig. 1). Each plot was instrumented with eddy covariance (EC) system (Fig. 2) from which turbulent fluxes of CO_2, latent energy *LE*, sensible heat *H* and momentum were measured continuously after seedling emergency until harvesting. The observed *ET*, water use efficiency and crop yields were compared to the outputs from the FAO AquaCrop model.

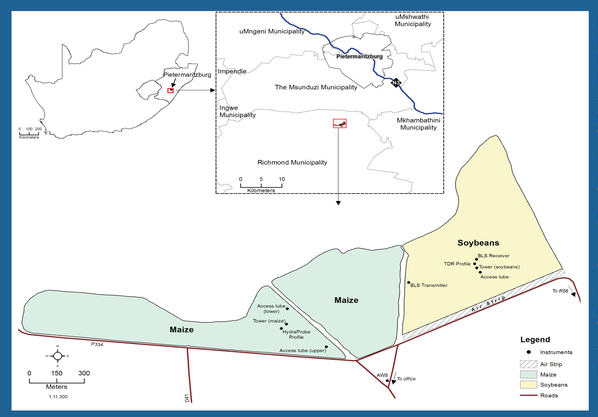

Fig. 1 Shows the study site (part of Baynesfield Estate) about 12 km from Pietermaritzburg. The Baynesfield Estate is 9300 ha and currently under a mixed farming regime. Some land is under irrigation with portions rainfed. The two experimental sites used are collocated with each having a fetch greater than 100 m in all directions. These sites have been cultivated for more than a decade and have similar climatic conditions, soil properties and topography.
The cropping at the Estate is characterized by a maize-soybean rotation.
The lands lay fallow from the last day of harvesting to the beginning of each planting season.

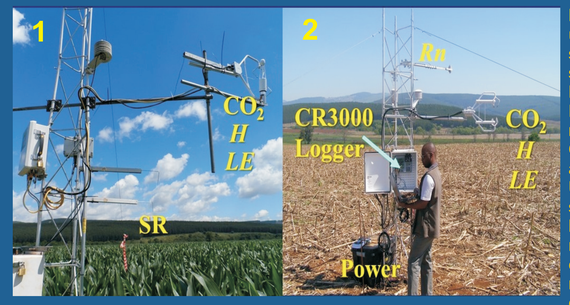

Fig. 2 Shows the instrumentation masts used at each site: (1) maize and (2) soybean (before germination).The soybean site was instrumented with an EC 150 system (Campbell Scientific Inc., Logan, Utah, Nebraska, USA) while the maize site was instrumented using CSAT3 sonic anemometer coupled with an LI7500, LICOR, Lincoln, Nebraska, USA. The maize residue at the soybean site is the evidence of crop rotation between the two sites. The surface renewal method (SR) was used for comparison purposes. Data were recorded using CR 5000 and 3000 dataloggers.

Results and discussion

Energy flux measurements from the EC systems were used to determine *ET* as a residual of the shortened energy balance. The net irradiance was the dominant component followed by the latent and sensible heat components (Fig. 3 (a) and (b). The observed and modelled *ET* for the entire growth season for soybeans was 365.20 and 422.50 mm, respectively. The AquaCrop model over estimated *ET* by 15.6 %. The observed and modelled soybean yields were 5.28 and 5.40 t ha^{-1}, respectively. The observed and modelled soybeans yield showed a good agreement as the model over estimated by 2.3 %. For maize, the observed and modelled *ET* for the entire growth season was 322.66 and 396.20 mm, respectively. The AquaCrop model over estimated *ET* by 22.8 %. As for the yield, the observed and modelled were 22.70 and 19.30 t ha^{-1}, respectively. Here, the model underestimated the yield by 15%. Maize (PAN 3Q222) showed a high WUE (4.89 kg m^{-3}) than the soybeans (PAN 1666R) (1.28 kg m^{-3}). The latent heat was the dominant energy balance component for both maize and soybeans during growth stages. Soybeans had a higher LAI than the maize until maturity and it was drastically reduced as the plants dried up (Fig. 4).

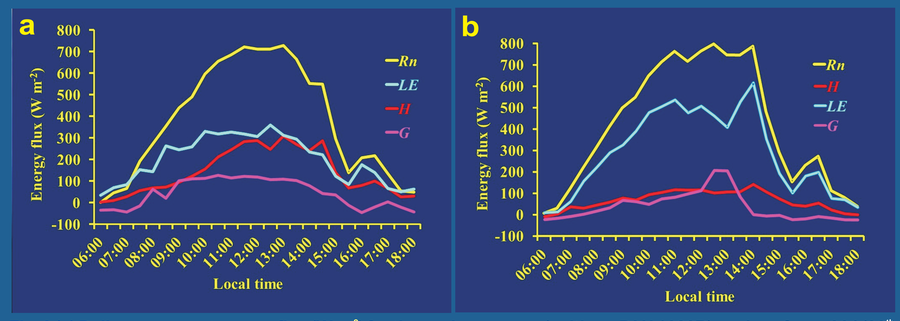

Fig. 3 (a) Daily component energy flux (W m^{-2}) for the soybean crops (cultivar: PAN 1666R) on day of year 364 (30th December 2012. The total evaporation for the day was 3.64 mm.
(b) Daily component energy flux (W m^{-2}) for the maize crops (cultivar: PAN 3Q222) for the same day and the total evaporation for the crop was 4.79 mm.

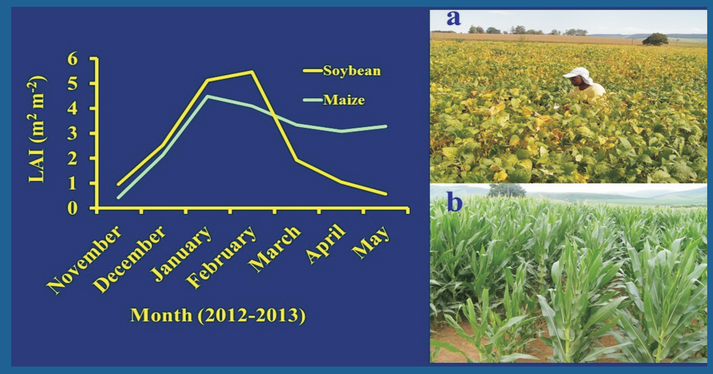

Fig. 4 Shows the leaf area index (LAI) (m^2 m^{-2}) of the soybean (a) and maize (b) crops during the study period (2012 - 2013). A plant canopy analyzer (LAI-2200) (LICOR) was used to measure LAI. The LAI was determined every two weeks from plant germination to harvesting. The periodical observation of plant leaf colour was used to determine the onset of senescence.

Conclusions

The eddy covariance method gave reliable total evaporation during the 2012-2013 growing season. The yield, *ET* and WUE were comparable to AquaCrop model outputs.

While EC is regarded as a standard method of estimating fluxes, the skill required to operate the instruments is not freely available making it unattractive for routine use.

Crop models like AquaCrop may be used as agronomic research tools as well as for management purposes and the model is capable of giving comparative results.

References

1. Rost, S., Gerten, D., Hoff, H., Lucht, W., Falkenmark, M., Rockström, J. (2009). Global potential to increase crop production through water management in rainfed agriculture. Environmental Research Letters, 4(4), 1-9.

Acknowledgements

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