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EFFECTS OF TURBULENCE-INDUCED LIGHT FLUCTUATIONS ON PHOTOSYNTHESIS IN ALFALFA

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1. INTRODUCTION

Light environment in crop canopies is variable at different time scales. Faster light fluctuations, due to the shaking and bending of foliage induced by wind, produce sunflecks in canopies. Winds can greatly increase the contribution of sunflecks to total photosynthetically active radiation (PAR) in the canopy. Light fluctuations have been shown to affect photosynthetic efficiency at leaf scales, through photosynthetic induction and post-illumination CO_2 fixation (Pearcy, 1990).

The objectives of this study are to investigate effects of wind on mean light penetration and sunflecks in alfalfa and their effects on photosynthesis at a canopy scale.

2. METHODS

Measurements were made at an alfalfa field near Richmond in Utah, in days with clear skies during the summers of 2000 and 2001. PAR values were observed at three heights in the canopy. 17 micro quantum sensors (Apogee Instruments Inc, Logan, UT) were at an upper level, 17 sensors at a middle level, and 12 sensors at the lower level. Incident total and diffuse PAR were monitored above the canopy with LI-190SA quantum sensors (LI-COR Inc., Lincoln, NE). Fluxes of CO_2, sensible heat and latent heat over the canopy were measured using eddy-covariance method, with a CSAT3 3-D sonic anemometer (Campbell Scientific Inc., Logan UT), and a LI-7500 CO_2/H_2O analyzer (LI-COR). All light and turbulence sensors were sampled at 10 or 20 Hz, depending upon the day. Net radiation was measured with a net radiometer (REBS Inc, Seattle, WA) calibrated against a CNR1 (Kipp & Zonen). Soil heat flux was determined with heat flow transducers and thermocouples. Soil CO_2 efflux was measured with a LI-6400 portable system, leaf area index was determined using the LI-2000 canopy analyzer, and soil water content was measured gravimetrically.

Properties of light in the canopy and the relationship with wind were analyzed as follows: (1) Penetration of light was calculated, and temporally and spatially averaged. (2) Sample frequency histograms of light intensity were analyzed, and a beta probability density function was applied to simulate the probability distribution of light fluctuation in the canopy. (3) FFTW, "Fastest Fourier Transform in the West", was used to compute power spectra.

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30-minute average fluxes of sensible heat, latent heat and CO_2 were calculated, and various corrections were made with methods given by Webb et al. (1980) and Massman (2000). The results indicated energy balance closure values of 0.7-0.8, suggesting an underestimation of fluxes. Further correction was done with the assumption that the Bowen Ratio was correctly measured, and the energy closure was forced as described by Twine et al., (2000).

3. RESULTS AND DISCUSSION

30-minute mean penetration of light at different levels in the canopy was mainly related to solar zenith angle (Fig. 1).

Frequency histograms of light were often U-shaped, especially when wind was larger than 2.5 m/s (Fig. 2). This indicates that light in the canopy changed quickly between small and large values in the presence of wind. Frequency histograms of light were well simulated with beta distribution.

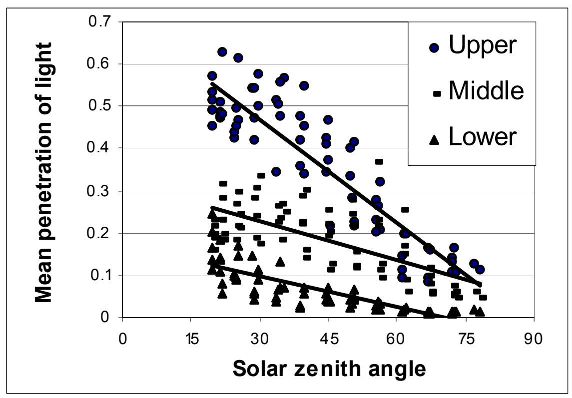

Fig. 1. Effect of solar zenith angle on the mean penetration of light in the canopy.

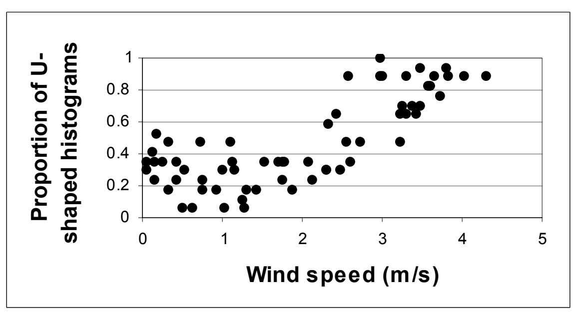

Fig. 2. Effect of wind speed on the proportion of U-shaped frequency histograms of light at the upper level (LAI = 1.2).

Power spectral analyses of PAR showed that total variance of light increased as wind speed increased. The prominent spectral peak ranged from 1 to 2 Hz at LAI of 1.8, and high frequency contribution increased as wind speed increased (Fig. 3), which is similar to results of Tong (1996). Spectra at winds of 5.5 m/s exhibited large values at high frequencies (Fig. 3).

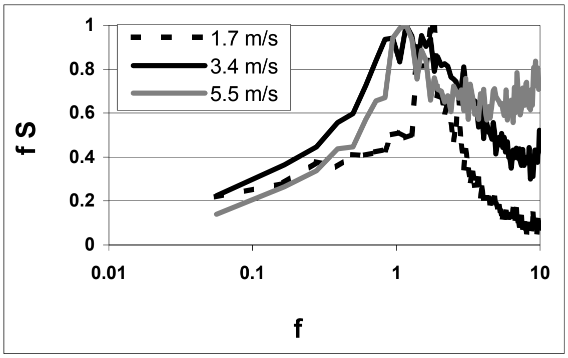

Fig. 3. Power spectra of PAR at height where LAI=1.8 during different wind conditions.

During clear days, sensible heat flux was upwards in the morning and downwards in the afternoon (Fig. 4), indicating advection. CO_2 flux varied with PAR, and was as large as 38 μmol m^{-2} s^{-1}. Under similar PAR levels, CO_2 flux (Fc) decreased as turbulence (U_*) increased (Fig. 5). This may have resulted from clumping of foliage. Multiple regression equation from data on July 5-7, 2000 is

$Fc = 137.27-23.05LN(PAR)+4.187U_*$ (R^2 = 0.954)

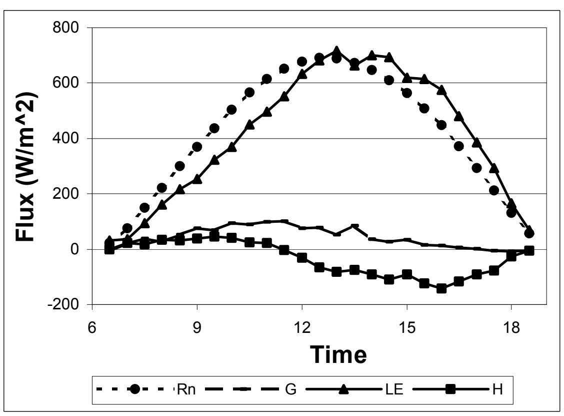

Fig. 4. Fluxes of sensible heat (H), latent heat (LE), soil heat (G) and net radiation (Rn) on July 5, 2000.

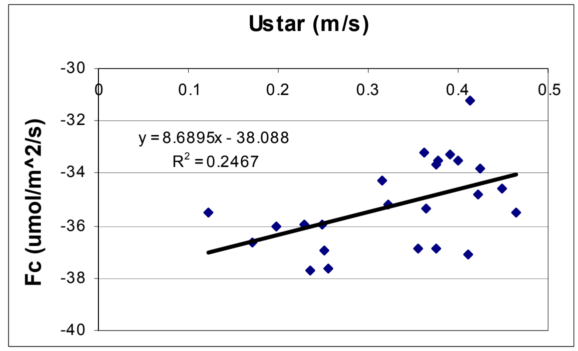

Fig. 5. Effect of turbulence on CO_2 flux over alfalfa canopy, PAR=1740-1920 μmol m^{-2} s^{-1}, July 5-7, 2000.

4. CONCLUSIONS

Wind alters the light regime in the canopy, and induces U-shaped frequency histograms, that are simulated by beta distributions.

Turbulence increased the high frequency contributions to variance of light.

CO_2 flux over canopy was related to both PAR and turbulence intensity. As turbulence increased at similar light levels, the flux decreased.

5. FUTURE WORK

A sophisticated canopy model, CUPID, will be employed to estimate the canopy photosynthesis that would occur under steady-state light with the same average value of fluctuating light. These values will be compared with the measured CO_2 flux under windy conditions indicate the effect of sunflecks on canopy photosynthesis.

6. REFERENCES

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