SUMMARY AND CONCLUSIONS

This research presents a unique data set of carbon dioxide exchange over the rainfed peanut fields in response to drought stress. Eddy-covariance method and micrometeorological measurements were successfully used to study fluxes of mass, heat and momentum, while the soil CO_2 gradient method was used to estimate the emissions of soil to the atmosphere.

In Experiment 1 presented the dynamics of mass and energy exchange between the rainfed peanut canopy and the atmosphere. The sub-experiment 1 shows that the partitioning of the available energy and the diurnal pattern of net ecosystem CO_2 exchange (*NEE*), evapotranspiration (*E*), and ecosystem water use efficiency (*EWUE*) depended on growth stage of canopy and environmental condition. The combination of water stress, high temperature, and large *VPD*, resulting in drought, greatly influenced the partitioning net radiation (*Rn*) between λE and *H*, and the diurnal variation of *NEE*, *E* and *EWUE*.

When the crop was not experiencing drought stress, more than 60% of *Rn* was consumed by λE. Only 50% of *Rn* was consumed by λE when the crop was experiencing drought stress. *H* was a very minor part in *Rn* when the crop was not subject to drought stress and become the main consumer of *Rn* when the crop was subject to drought stress. Carbon dioxide flux or net ecosystem CO_2 exchange (*NEE*) was unaffected by drought stress until about mid-morning. After that time, *NEE* was

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depressed when the when the crop was experiencing drought stress. Relatively small stomatal conductance, high air temperature, and large *VPD* are the most likely causes of this depression of *NEE*.

Drought stressed plants transpires less than unstressed plants. Midday *EWUE* on the days when the crop was experiencing drought stress was lower than when the crop was not experiencing drought stress. However, during the crop was subject to drought stress, no difference in *E* between morning and afternoon was observed but a lower *EWUE* values in the afternoon as compared to morning. Leaf wilting in the upper canopy level allows the light penetrate in the lower layers of the canopy thus determining high *E* and responsible for the reduction in *EWUE*.

The further study on the key factors controlling daytime *NEE* in sub-experiment 2 found that *PAR* was the primary climatic factor controlling daytime *NEE*, accounting for 67 to 89% variations of *NEE* during peanut growing season. However, the model Michaelis-Menten describing *NEE* during daytime as a function of *PAR* could not be used during a peak growing stage, indicating that other environmental variables became proportionally more important in controlling *NEE*. It was found that for very low soil water content ($SWC < 0.04$ m^3 m^{-3}), *NEE* was significantly decreased when *PAR* exceeded 1300 μmol photons m^{-2} s^{-1}. The results inferred that *SWC* was the dominant factor limiting the *NEE-PAR* response of peanut during the peak growing stage.

Pronounced hysteresis in *NEE* was observed in both non-stress and water-stress conditions as a function of *PAR*. However, the magnitude of hysteresis was larger for the water stress days than the non-stress days. It was found that 95% of

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variation in g_s was explained by the changes in *VPD* on the water-stress days, indicating strong stomatal control of CO_2 exchange. The stomatal limitation during water-stress period resulting from high *VPD* is responsible for a large hysteresis loop, which in turn leads to the failure of the Michaelis-Menten function to describe *NEE-PAR* relationship.

In experiment 2, the soil CO_2 gradient method was used to study soil CO_2 efflux. While there have been recent studies examining the feasibility of the soil gradient method, sub-experiment 1 provides an assessment of the soil gradient method utilizes weighted harmonic averaging in the calculation of the soil CO_2 diffusion coefficient. This averaging takes into account the factors influenced by the natural spatial variations in textural properties in the soil profile and non-uniform vertical distribution of soil water content. Results show a better agreement with soil chamber measurements when the weighted harmonic averaging is used. Furthermore, the six different models were compared in estimating the relative gas diffusion coefficient and the estimated soil CO_2 efflux using the soil gradient method was found to differ between 3 and 173% from the mean of soil CO_2 efflux values across all five collars obtained using the soil chamber method depending on the choice of the model used. This clearly demonstrates that the choice of the relative gas diffusion coefficient model is critical when using this method. However, further work using the weighted harmonic averaging of soil CO_2 diffusion coefficient should examine transient water content conditions such as after rainfall.

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For the purpose of minimizing errors potentially leading to a low correlation between soil CO_2 efflux data obtained using the soil chamber method and the soil gradient method, the authors recommend that the soil CO_2 concentration be measured at several depths to provide more CO_2 efflux values at various soil levels to allow the determination of the CO_2 efflux at the surface. In the author’s experience, I recommend using a minimum of three CO_2 concentration measurements in a vertical profile. The assumption that the soil CO_2 concentration linearly decreases with soil depth is invalid when soil CO_2 is greater in shallow soil than deeper soils such as during a sudden rain event during a long dry summer. In this situation, the author recommends that the CO_2 concentration above the soil surface be measured.

Since the variation in soil texture and water content in soil profile influence the calculations of the soil CO_2 diffusion coefficient, I envision that the availability of more accurate soil temperature and water content sensors installed adjacent to the soil CO_2 concentration probe array will improve the accuracy of the estimates of the coefficient. Further studies in a larger experimental site and multipoint measurements of the soil CO_2 gradient method are recommended to provide spatial heterogeneity of the soils. However, the initial cost of installation may be higher than that of the ordinary chamber method. The implication from the present study is to combine both the soil chamber method and the soil gradient method, i.e., to get an average of soil CO_2 efflux through multi-spatial samples with the soil chamber method and correct the continuous point soil CO_2 efflux measurement of the soil gradient method based on the linear relationship between the soil CO_2 effluxes from each method.

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The functional relationships of soil CO_2 efflux to soil temperature and soil moisture with the improved method were well described using exponential and linear equations, respectively. The results indicate that the soil temperature measured at the depth of 0.05 m was the most suitable to examine the measured relationship between soil CO_2 efflux and temperature, confirming previous findings. These results further attest to the potential of using the soil gradient method as a cost-effective means to measure soil CO_2 emissions.

Moreover, continuous half-hourly measurements of soil CO_2 efflux using the soil CO_2 gradient method made at a rainfed peanut field in 2007 in Unadilla, Georgia were used to examine the responses of soil CO_2 efflux to drying and rapid rewetting of soil in sub-experiment 2. During drying condition, soil CO_2 efflux and soil CO_2 concentration decreased as *SWC* decreased and T_s increased. The response of soil CO_2 efflux to rapid rewetting of soil due to rain is complex. Immediately after the rain stopped, the soil CO_2 efflux decrease by 17% lower than the efflux before rain and gradually decreased and reached at the lowest values of 47% lower than the efflux before rain at an hour after rain stopped. The presence of the decreasing in soil CO_2 efflux after rain attributed to a decrease in soil diffusivity since we observed the decrease in soil diffusivity in the top soil layer from 6.49 $mm^2\ s^{-1}$ before rain to 5.07 $mm^2\ s^{-1}$ immediately after rain stopped. After soil CO_2 efflux reached its minimum, soil CO_2 efflux dramatically increased and peaked two days after rain stopped and then decreased gradually. The enhanced emissions of soil CO_2 after rain in this site was likely caused by trigger of microbial activity and by enhancing mineralization of organic constituents after the prolonged dry condition and rapid rewetting events.

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In sub-experiment 2 assessed the effect of drying and rapid rewetting of soil on the sensitivity response of soil CO_2 efflux to T_s and *SWC* found that during the drying period when *SWC* was less than the permanent wilting point (0.042 $m^3\ m^{-3}$), soil CO_2 efflux decreased dramatically (up to 80%) and *SWC* took over control of soil CO_2 efflux. After rapid rewetting of dry soil, rain event stimulated soil CO_2 efflux and restored temperature control over soil CO_2 efflux, even though *SWC* in the surface layer was low. During drying condition, the temperature sensitivity of soil CO_2 efflux (Q_{10}) declined with decreasing *SWC*.

In conclusion, the present study clearly demonstrates that further studies of water-limited ecosystems are needed in order to develop improved models accounting for the extreme environmental conditions such as drought to reliably predict the long-term *NEE* of these ecosystem and estimate their contribution to the global carbon balance. Moreover, it is imperative to have continuous measurement of soil CO_2 efflux to understand total soil CO_2 emissions of an ecosystem. In the future, many regions of the globe may experience higher mean annual temperatures and greater intra-annual variation in timing of precipitation events. Under these scenarios, we would expect many surface soils to experience more frequent drying and rewetting events. Neglecting the effect of drying and rapid rewetting of soil on soil CO_2 efflux in modeling study, one would definitely raise an uncertainty in predicting future carbon emission from soils.

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