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INSTITUTION:	University of Georgia
PROJECT TITLE:	Net CO_2 exchange and soil respiration in peanut ecosystem in response to rainfall variability
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Situation

Agricultural ecosystems, the most active part in global carbon pool, are greatly affected by human activities (e.g. cultivation, irrigation, fertilization), which lead to large variation in the exchange of carbon, water and energy between the land surface and the atmosphere. Agriculture is also highly sensitive to climate variability and weather extremes, such as droughts, floods and severe storms. Climate change scenarios for the North America suggest an increase in mean air temperature and more severe periods of drought (IPCC, 2007). The anticipated increase in both climate variability and extreme events is presumed to adversely affect crop growth and water availability critically influencing the patterns of future agricultural production. An increase in the number of hot days, which attributes to increased potential evapotranspiration and more frequent occurrence of drought periods, will hinder the optimum course of the production process with a direct impact on the yield and quality of crops (Mozny et al., 2009).

Peanut (*Arachis hypogaea* L.) is a major crop grown under both rainfed and irrigated conditions in the southeastern US. Typically, peanut plants have to cope with unfavorable environmental factors such as high temperature, low soil moisture, and high vapor pressure deficit often resulting in drought stress. Drought affects nearly all aspects of plant growth and most physiological processes; however, the stress response depends on intensity, rate, duration, and the stage of plant growth. Water availability is a limiting factor for plant growth in many part of the world and, over long time scales, the local water balance could play a significant role in determining the carbon uptake capacity of the terrestrial surface. An accumulation deficit in soil water can shift the positive absorption of carbon toward negative release into the atmosphere, which can then upset feedback relationships in the evaporative process. Drought also alters the seasonal development of leaf area and changes plant physiology, thus influencing both magnitude and time of maximal CO_2 fixation. Rainfall variability is highly unpredictable and has become a major problem for farmers. In water-limited system, pulses of rainfall are particularly pivotal in controlling plant physiological processes. Rainfall pulses can trigger a cascade of ecosystem responses that affect the cycling of plant nutrient, water, and carbon. These responses ultimately affect the balance of ecosystem respiration and production. Various factors may interact interactively influence plant water relations following pulses of rainfall. For example, plant functional type or species, landscape position, antecedent and environmental conditions, evaporation demand, day since rainfall event, and soil properties all translate rainfall into plant available water. Moreover, the previous research by Huxman et al. (2004) also indicate that along with plant and microbial respiration, the physical displacement of soil CO_2 by water strongly controls whole-ecosystem carbon exchange during rainfall pulse.

To better understand how environmental stress and rainfall variability influences physiological activity in plants, soil and ecosystem, it is necessary to understand gas/water exchange between plant and atmosphere and soil carbon dynamics. Accurate determination of the exchanges of mass and energy between the crop canopy and the atmosphere not only contributes a better understanding of the mechanisms that control on the exchanges, crop productivity, water use efficiency, but also anticipate possible impacts of the climate change scenarios.

Response

In 2009, field experiments were conducted in a rainfed peanut field at Cordele, GA. Peanut field CO_2/H_2O fluxes were monitored using the eddy-covariance technique. The system for measuring eddy-covariance consists of a 3D sonic anemometer (CSAT-3, Campbell Scientific, Logan, UT) and an open path infrared gas analyzer (LI7500, Li-COR Inc., Lincoln, NE) at the height of 1.5 m above the ground surface (Figure 1). The 10 Hz and 30-min averaged data are collected with CR1000 data logger. In order to better understand how the water and carbon fluxes are influenced by key forcing parameters, additional meteorological measurements were continuously monitored at the site, which included net radiation, average soil heat flux from two soil heat flux plates, and soil temperature from thermocouples above each heat flux plate.

All of these variables are recorded in 30 min average. A weather station was also placed at the measurement site, monitoring important environmental parameters such as air temperature, humidity, wind speed and direction, solar radiation and rainfall. In addition, the leaf area index was measured with a plant analyzer (LAI-2000, Li-COR Inc., Lincoln, NE) on weekly intervals.

Soil respiration was continuously measured at two fixed locations using a long-term low-frequency automated soil chamber (Li-8100-101, Li-Cor, Inc., Lincoln, NE: Figure 2) and high-frequency soil CO_2 gradient method (GMP343 soil CO_2 probes, Vaisala Inc., Vantaa, Finland: Figure 3). Soil temperature and moisture were measured with thermocouples, and CS616 soil moisture sensors, respectively. The root-exclusion method was also used to separate soil respiration into autotrophic respiration and heterotrophic respiration. The measurements were conducted weekly using a survey soil chamber (Li-8100-101, Li-Cor, Inc., Lincoln, NE). To eliminate the problem of soil water and soil temperature differences between control plot and root-excluded plot, holes were drilled in the PVC pipes and filled with 35 micron nylon mesh bag. The 35 micron nylon mesh prevented encroachment of roots while still allowing water to pass through.

Figure 1. Sonic anemometer, fast infrared gas analyzer setup for measuring CO_2 exchange and solar panels setup for power support to all instruments.

Figure 2. A long-term low-frequency automated soil chamber (Li-8100-101, Li-Cor, Inc., Lincoln, NE).

Figure 3. High-frequency soil CO_2 gradient method (GMP343 soil CO_2 probes, Vaisala Inc., Vantaa, Finland).

Impact

We assessed the soil CO_2 gradient method for measuring soil CO_2 efflux. A weighted harmonic averaging method, used to estimate the soil CO_2 diffusion coefficient with six models, is verified to yield a better estimate of soil CO_2 efflux, which reasonably approximates the soil CO_2 efflux measured with a soil chamber. In addition, the estimated soil CO_2 efflux obtained by this improved method is well described by an exponential function of soil temperature at a depth of 0.05 m with the temperature sensitivity (Q_{10}) of 1.81 and a linear function of soil moisture at a depth of 0.12 m, which is in general agreement with previous findings. These results suggest that the gradient method is a practical cost-effective means to continuously measure soil CO_2 emissions.

Response of soil CO_2 efflux to rainfall events in agricultural fields is investigated using long-term low-frequency soil CO_2 automated chamber and high-frequency soil CO_2 gradient efflux method measurements. Results show that continuous measurements of can capture on both decreased and increased of F_s response to a drying and rewetting cycle. Moreover, soil CO_2 efflux is controlled by different environment factors. Soil water content is a dominant factor controlling soil CO_2 efflux and Q_{10} values decreased as soil water content decreased during the drying cycle. After rapid rewetting of dry soil, the rain event stimulated soil CO_2 efflux and restored temperature control over soil CO_2 efflux. Moreover, we found that growth stage of peanut also plays a critical role in determining the magnitude of the efflux following rainfall. It is found that the growth stage of the plant is more important than rainfall amount and initial soil moisture in generating soil CO_2 efflux after rainfall. Results from the present study demonstrate that it is imperative to have high-temporal resolution measurements of soil CO_2 efflux to understand total soil CO_2 emissions of an ecosystem and to reduce uncertainties associated with the measurements of soil CO_2 efflux.

During optimum environmental conditions, photosynthetically active radiation (PAR) was the primary driver controlling daytime net ecosystem CO_2 exchange (NEE), accounting as much as 67 to 89% of the variation in NEE. However, soil water content became the dominant factor limiting the NEE-PAR response during the peak growth stage. NEE was significantly depressed when high PAR values coincided with very low soil water content. The presence of a counter-clockwise hysteresis of daytime NEE with PAR was observed during periods of water stress. This is a result of the stomatal closure control of photosynthesis at high vapor pressure deficit and enhanced respiration at high temperature. This result is significant since this hysteresis effect limits the range of applicability of the Michaelis-Menten equation and other related expressions in the determination of daytime NEE as a function of PAR. The systematic presence of hysteresis in the response of NEE to PAR suggests that the gap-filling technique based on a non-linear regression approach should take into account the presence of water-limited field conditions. Including this step is therefore likely to improve current evaluation of ecosystem response to increased precipitation variability arising from climatic changes.

The dynamics of mass and energy exchange between the rainfed peanut canopy and the atmosphere were also assessed. The results show that the partitioning of the available energy and the diurnal pattern of NEE, evapotranspiration (E), and CO_2-water vapor flux ratio (CWFR) depended on growth stage of canopy and environmental condition. The combination of water stress, high temperature, and large vapor pressure deficit, resulting in drought, greatly influenced the partitioning net radiation (Rn) between latent heat flux (λE) and sensible heat flux (H), and the diurnal variation of NEE, E and CWFR.

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. Sensible heat flux 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 was unaffected by drought stress until about mid-morning. After that time, NEE was depressed when the crop was experiencing drought stress. Relatively small stomatal conductance, high air temperature, and large vapor pressure deficit are the most likely causes of this depression of NEE.

Drought stressed plants transpires less than unstressed plants. Midday CWFR 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 CWFR 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 CWFR. The decoupling coefficient (Ω) was evaluated to confirm that when the crop was subjected to drought stress, vapor pressure deficit and surface conductance are drivers controlling evapotraspiration.

Publications

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