This is the final report for the 2014 peanut project. The goal of this project is to examine the physiological responses of different peanut cultivars to water stress or drought conditions. This is the first step in identifying the surrogate traits of drought tolerance and their underlying molecular controls. This should help guide the development of the desired breed of peanut varieties.

1. Experimental Methods and Data Processing

(1) Experiments

Two different peanut cultivars, GA-06G and Tifguard, were selected for this project following the suggestion of Prof. Peggy Ozias-Akins whose expertise lies in peanut breeding and genomics.

With the assistance of two county agents, two rainfed peanut fields with the two cultivars were identified. One field with peanut GA-06G was in Newton County, GA and another field with peanut Tifguard was in Webster County, GA, about 22 miles apart from...
each other. Both fields were in general flat and met eddy-covariance measurement requirements.

An eddy-covariance system consisting of a sonic anemometer CSAT3 (Campbell Scientific Inc., Logan, UT) and a fast-response CO2/H2O analyzer Li-7500 (Li-Cor Biosciences, Lincoln, NE) was set up on a tripod at 1.5 m above the ground in each field (Fig. 1). The system measured automatically three-dimensional wind components, temperature, and concentration of water vapor and carbon dioxide in 10 Hz. The data were collected to estimate peanut field evapotranspiration and CO2 exchange with the atmosphere that indicates canopy respiration (with night data) and photosynthesis (with daytime data). That information is used to identify genetic traits responsible for drought resistance.

Meanwhile, soil CO2, soil temperature and soil water content at various depths were also simultaneously monitored with soil CO2 probes GMP343 (Vaisala, Finland), thermocouples and water content reflectometers CS616 (Campbell Scientific Inc., Logan, UT) in each field (Fig. 2). Leaf area index in each field was measured with a plant canopy analyzer LAI-2000 (Li-Cor Biosciences, Lincoln, NE) each week. In addition, an automated weather transmitter WXT510 (Vaisala, Finland) was set at the non-irrigated field to measure wind speed and direction, air temperature and humidity, and rainfall. The fields were visited weekly to service the instrumentation and to download data.

(2) Calculations and Data processing

Eddy-covariance data were separated in 30-min runs. Data points characterized by abnormal “automatic gain control” (AGC) values from the open-path H2O/CO2 gas analyzers (Li-7500) or by abnormal diagnostic values from the sonic anemometer (CSAT3)
were rejected. Spikes in the time series data were detected and removed according to Vickers and Mahrt (1997). A coordinate rotation using the planar fit method (Wilczak et al., 2001) was applied to the sonic anemometer data in order to remove tilt errors. Linear trend was removed from individual 30-min runs. From the resulted time series of fluctuations, eddy-covariance and turbulent fluxes of CO₂, water vapor and energy were calculated and examined. The Webb-Pearman-Leuning (WPL) correction for density effects due to heat and water vapor transfer (Webb et al., 1980) was applied to correct the calculated fluxes of CO₂ and water vapor.

2. Results and discussion

2.1 The behavior of CO₂ fluxes, evapotranspiration, and water-use efficiency of peanut varieties O6G and Tifguard

In general, daily variation of CO₂ fluxes presents large negative values in day time and small positive values at night (Fig. 3), corresponding daytime photosynthesis and nocturnal respiration respectively. Evapotranspiration rate is usually much larger daytime than in nighttime conditions (Fig. 4), and its daytime variation during daytime is mainly associated with solar radiation and soil water content. Water use efficiency (WUE), or the ratio of CO₂ flux to evapotranspiration, possesses usually the largest early morning and then decreases with time in the morning and varies less in the afternoon (Fig. 5). These findings are in general agreement with the results of experiments in 2013.

From the middle of August (DOY 225) to early September (DOY 245) 2014, both O6G and Tifguard or both cultivars presented smaller CO₂ fluxes and evapotranspiration when compared to the days before and after the above period, resulting in lower water use.
efficiency. Soil measurements show long time lower soil water content (Fig. 6) and relative higher soil temperature (Fig. 7) during this period. All information indicates that peanut experienced water stress (or drought) in the period. However, the rain at O6G field on DOY 233-234, indicated by the increase of soil water content and the decrease of soil temperature (Fig. 6 & 7), releases the water stress in the field and peanut CO₂ flux and evapotranspiration partially recovered (Fig. 3 & 4). After 5-6 days, the peanut O6G experienced water stress again.

2.2 Response of peanut CO₂ fluxes, evapotranspiration, and water use efficiency to water stress

The behavior of the photosynthetically active radiation (PAR) daily variation with time indicates clear day without clouds and rainy days. Based on the radiation (photosynthetically active radiation) (PAR) data measured at the nearby Plains weather station (Fig. 8) and soil water content measured at each peanut field (Fig. 6), the following days with clear skies are found for further analysis:

(1) DOY 207-208 for both fields before water stress
(2) DOY 225-228 for peanut O6G field in water stress
(3) DOY 237-238 and 240-241 for peanut Tifguard in water stress, and
(4) DOY 248 for both fields after water stress

To explore the influence of water stress to peanut CO₂ fluxes (Fc), evapotranspiration (E), and water-use efficiency (WUE), their daytime variations (08-18 hours EST) on the above-stated selected days with clear skies before, in, and after water stress were plotted in Fig. 9 and 10 for peanut cultivar O6G and Tifguard, respectively.
Before water stress, both cultivars present daytime temporal variation of CO₂ flux and evapotranspiration with peaks around noon, while their water-use efficiency (WUE) has the largest values at around 8 AM and decreases rapidly in the morning with little change in the afternoon.

During the period with water stress, CO₂ flux and evapotranspiration of the both cultivars are smaller than those before water stress. They increase with time to around 10 AM, with small difference from those before water stress. Then they decrease with time, showing larger difference from those before water stress. At the worst time around 14 PM, CO₂ fluxes are in small positive values, meaning that the photosynthesis becomes so weak due to water stress that CO₂ absorbed with photosynthesis is less than CO₂ released through peanut plant respiration and soil respiration. The difference becomes smaller in late afternoon as water stress is gradually released for the decrease in solar radiation and air temperature. Though water use efficiency is also smaller than that before water stress, it varies with time in a similar rule to that before water stress. It presents the largest value at around 8 AM and decreases rapidly with time in the morning. It does not change much in the afternoon. However, WUE before water stress decreases after 16 PM while WUE in water stress increase during that time. The former is because rapid decrease in PAR and slow decrease in air temperature during that time lead to rapid decrease in photosynthesis and slow decrease in evapotranspiration. The latter is because of gradual release of water stress from the decrease in solar radiation and air temperature.

CO₂ flux, evapotranspiration, and water use efficiency after the water stress are very similar to those before water stress, in both their values and their variation with time, indicating that peanut plants have gradually recovered from the influence of water stress.
The averages of peanut CO₂ fluxes, evapotranspiration, and water-use efficiency during 12-16 PM on the same selected days before, in, and after water stress are listed in Table 1. It can be seen that, CO₂ fluxes, evapotranspiration, and water-use efficiency of peanut cultivar O6G in water stress decrease to 18%, 56%, and 29% of those before water stress, respectively. For the cultivar Tifguard, the reduction in these values becomes 6%, 39%, and 15% respectively. The ratio of water-use efficiency (WUE), i.e. the ratio of carbon uptake fluxes to that of evapotranspiration indicates that water stress has more influence on photosynthesis than evapotranspiration for both cultivars, leading to a decrease in water use efficiency. After water stress, they recovered to about 75% and above of those before water stress.

2.3 Influence of water stress on the relationship of photosynthesis with photosynthetically active radiation

A diurnal variation of CO₂ fluxes of peanut cultivar Tifguard and O6G with photosynthetically active radiation (PAR) has been examined. It can be seen that water stress seriously influences the diurnal variation. In water stress conditions, CO₂ fluxes in the afternoon are much smaller than those in the morning in the same photosynthetically active radiation (PAR) conditions, i.e., the hysteresis effect occurs. Fig. 11 is an example on 8/20/2014 (DOY 232, just before the above-stated rain at O6G field on DOY 233) in water stress conditions, showing hysteresis. Light saturation point for photosynthesis becomes lower in stronger water stress conditions. This reflects plant stomatal closure, the response of plants to water stress and high temperature conditions. The result agrees with the report by Pingintha et al. (Biogeosciences, 2010).
Fig. 12 is another example on 8/28/2014 (DOY 240, after the above-stated rain at O6G field on DOY 233) in water stress conditions, also showing the hysteresis effect. However, due to rain at the field of peanut O6G, the CO₂ fluxes of peanut O6G on DOY 240 were larger than those of Tifguard. This is different from the day of DOY 232 when Tifguard presented larger CO₂ fluxes (Fig. 11). Thus, only a comparison between the before drought/stress periods, during, and after the drought/stress periods can be best made within the same cultivar and less so across cultivars, unless the two fields have the same soil type and the same microclimate, microclimate on the same day. Fig. 13 is an example on 9/5/2014 (DOY 248), showing that the hysteresis effect had disappeared, which indicates that peanut had recovered from water stress.

3. Summary and Conclusions

In this project, two peanut cultivars O6G and Tifguard were tested for their physiological response to water stress. CO₂ fluxes, evapotranspiration, and water use efficiency were measured at the field scale using the eddy-covariance method. Results show that all evapotranspiration, carbon assimilation by peanut plants through photosynthesis, and water-use efficiency of the both cultivars severely impacted by water stress. Photosynthesis is more sensitive to and affected by water stress than evapotranspiration, which lead low water use efficiency in water stress conditions. Photosynthesis presents the hysteresis effect in water stress conditions, indicating that light saturation point for photosynthesis becomes low with water stress. Due to different conditions at the two fields, especially rainfall, it is difficult to conclude the difference in the response to water stress between the two cultivars. This will be improved with an experiment with different peanut cultivars grown in adjacent fields so that they experience the same environments. The response of water use efficiency of different
peanut genotypes to different drought conditions would help find the peanut genotypes tolerant to water stress/drought. Hysteresis in the amount of CO2 captured by the peanut following drought is real and substantial and it varies with cultivar. This is a topic that has been first brought to light by Pingintha et al and should receive a closer attention specially in the light that it is likely to modulate the peanut yield. Considering an increasingly drier climate and increased water use restrictions, its relevance to peanut productivity is likely to grow in importance.
Table 1. Averages and ratios of peanut CO₂ fluxes (Fc), evapotranspiration (E), and water use efficiency (WUE) during 12-16 PM on DOY 207-208 before water stress (BWS), DOY 225-228 in water stress (IWS), and DOY 248 after water stress (AWS) with clear skies for peanut cultivar O6G and Tifguard

<table>
<thead>
<tr>
<th></th>
<th>Before water stress (BWS)</th>
<th>In water stress (IWS)</th>
<th>Ratio (%) (IWS/BWS*100)</th>
<th>After water stress (AWS)</th>
<th>Ratio (%) (AWS/BWS*100)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>O6G</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fc (mg/m²/s)</td>
<td>-1.016</td>
<td>-0.188</td>
<td>18.5</td>
<td>-0.748</td>
<td>73.6</td>
</tr>
<tr>
<td>E (g/m²/s)</td>
<td>0.133</td>
<td>0.075</td>
<td>56.4</td>
<td>0.13</td>
<td>97.7</td>
</tr>
<tr>
<td>WUE (mg CO₂/g H₂O)</td>
<td>-7.645</td>
<td>-2.221</td>
<td>29.1</td>
<td>-5.782</td>
<td>75.6</td>
</tr>
<tr>
<td><strong>Tifguard</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fc (mg/m²/s)</td>
<td>0.862</td>
<td>0.05</td>
<td>5.8</td>
<td>-0.695</td>
<td>80.6</td>
</tr>
<tr>
<td>E (g/m²/s)</td>
<td>0.144</td>
<td>0.056</td>
<td>38.9</td>
<td>0.147</td>
<td>102.1</td>
</tr>
<tr>
<td>WUE (mg CO₂/g H₂O)</td>
<td>-6.01</td>
<td>-0.886</td>
<td>14.7</td>
<td>-4.683</td>
<td>77.9</td>
</tr>
</tbody>
</table>
Fig. 1 Installation of eddy-covariance system in the rainfed peanut field
Fig. 2 Installing soil CO₂ probes, thermocouples, and water content reflectometers in peanut fields
Fig. 3 Comparison of 30-min CO₂ fluxes (mg CO₂ m⁻² s⁻¹) between two peanut cultivars GA-O6G (green) and Tifguard (blue)
Fig. 4 Comparison of 30-min evapotranspiration (g H₂O m⁻² s⁻¹) between two peanut cultivars
GA-O6G (green) and Tifguard (blue)
Fig. 5 Comparison of 30-min water use efficiency (mg CO₂/g H₂O) between two peanut cultivars GA-O6G (green) and Tifguard (blue)
Fig. 6 Comparison of 30-min average volumetric soil water content at the depth of 5 cm between two fields of peanut cultivars GA-O6G (red) and Tifguard (green)
Fig. 7 Comparison of 30-min average soil temperature at the depth of 5 cm between two fields of peanut cultivars GA-O6G (red) and Tifguard (green)
Fig. 8 Daily variation of photosynthetically active radiation (PAR) measured at the nearby Plains weather station
Fig. 9 Variation of CO2 fluxes (Fc), evapotranspiration (E), and water use efficiency (WUE) during daytime (08-18 hours EST) on DOY 207-208 before water stress (BWS, blue points), DOY 225-228 in water stress (IWS, red point), and DOY 248 after water stress (AWS, green points) for peanut cultivar O6G.
Fig. 10 Same as Fig. 9, but for peanut cultivar Tifguard, and red points representing DOY 237-238 and 240-241 in water stress (IWS)
Fig. 11 Diurnal variation of CO₂ fluxes of peanut cultivar Tifguard (red) and O6G (green) with photosynthetically active radiation (PAR) on 8/20/2014 (DOY 232) in water stress condition, with the arrows showing the direction of time change. It shows the hysteresis effect.
Fig. 12 Diurnal variation of CO₂ fluxes of peanut cultivar Tifguard (red) and O6G (green) with photosynthetically active radiation (PAR) on 8/28/2014 (DOY 240) in water stress condition, with the arrows showing the direction of time change. It shows the hysteresis effect.
Fig. 13 Diurnal variation of CO₂ fluxes of peanut cultivar Tifguard (red) and O6G (green) with photosynthetically active radiation (PAR) on 9/5/2014 (DOY 248), with the arrows showing the direction of time change. It does not show the hysteresis effect, which indicates that peanut had recovered from water stress.