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ARTICLE

Evaluation of Soil Water Tension Trigger Levels for Optimizing Peanut (*Arachis hypogaea*) Yield and Irrigation Water Use Efficiency

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ABSTRACT

Irrigation technologies have provided the ability for growers to effectively manage crops. In recent years, soil moisture sensors have provided more precise soil moisture readings for continued improvement of irrigation decisions. Trigger level irrigation research was first performed on corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.), but southeastern crop growers often include peanut (*Arachis hypogaea* L.) in crop rotations. Therefore, research was performed on peanut to determine how differing soil water tension (SWT) trigger levels affected peanut yield. Soil water tension sensors connected to a real-time data logger were used to test irrigation trigger levels in peanut plots during the 2018 and 2019 growing seasons at the University of Georgia (UGA) Stripling Irrigation Research Park (SIRP) in Camilla, Georgia. Nine different treatments were implemented, which included 20, 30, 40, 50, 60 kPa SWT, USDA-ARS Irrigator Pro, UGA Checkbook, 50% UGA Checkbook, and rainfed. Twenty-seven plots were established in a randomized complete block design with three replications. At the conclusion of this study, it was determined that there were no differences on yield within year, but year had an effect on peanut yield ($P < 0.05$), and treatment within year had a significant effect on irrigation water use efficiency (IWUE) ($P < 0.05$).

INTRODUCTION

Georgia peanut growers contribute to producing over 50 percent of the total United States (U.S.) peanut supply annually and Georgia is ranked first in the nation for total peanut production (USDA ERS, 2021). As shown in the U.S. Peanut Production Map (Figure 1), peanut thrives in the southeast because of the soil type, long growing season, and environment in the region. The sandy loam soils provide the ability to include peanut in crop rotations, which typically include cotton and corn. In 2019, Georgia peanut producers planted 273,000 hectares and half of the hectares planted were grown under pivot irrigation (USDA, 2021; Monfort, 2019). Over time, there has been an increase of the number of crop hectares in Georgia being planted under irrigation. The shift to irrigate more crops, rather than relying on rainfall, can be attributed to research performed in the late 1900s that found that higher yield, quality, and net return could be achieved with added moisture (Lamb *et al.*, 1997; Lamb *et al.*, 2004). When comparing Figure 2 and Figure 3, the coloration between the maps indicates that there has continuously been an increase in irrigated peanut hectares in the state of Georgia. As shown in Figure 3 (Szydzik, 2021), total irrigated peanut hectares have continued to increase throughout the 2000s. An increase of 74,000 hectares of peanuts planted under irrigation occurred in just 10 years and is projected to continue in the future. Lamb *et al.* (1997) discovered that peanut has unique physiological capabilities that capture and efficiently use water to produce a crop, but yield potential is decreased when peanut does not receive adequate water at key growth stages: the late flowering and pod formation stages (Zhang *et al.*, 2021).

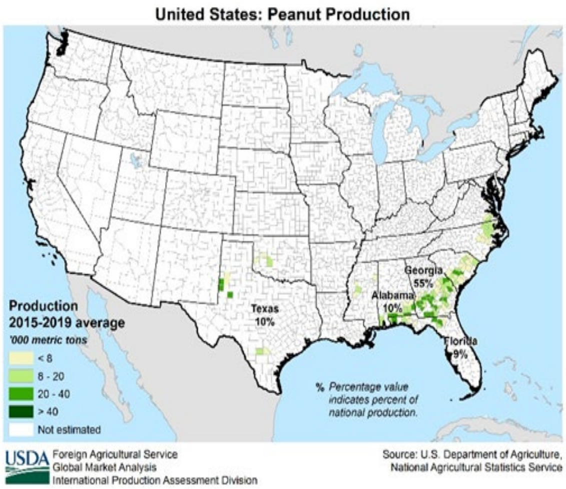

Figure 1. 2015-2019 percent value of peanut production averages in the United States (USDA, 2022).

The soil type that dominates the southern coastal plain of the United States is sandy loam, which has a high sand content and low silt, clay, and organic matter. With these properties, the soil drains rapidly and causes low soil water holding capacity (SWHC) or soil moisture retention (USDA, 2022; Zhang *et al.*, 2021). Agronomic efforts to improve SWHC have been performed in research, but there are constraints on this, so improving the effectiveness of irrigation is vital to the continued improvement of peanut yield and quality. Studies have found that scheduled irrigation results in a higher quality and higher value crop (Lamb, *et al.*, 2010).

In 2019, Porter *et al.* identified weekly water requirements of peanut throughout the season to better understand where peak water usage occurred for a peanut crop (Table 1). As delineated as days after planting (DAP), the peak water requirements occurred at 75 days and decreased in the later part of the season. Agronomically, the peanut crop would be at peak pod development which normally coincides with the hottest portion of the growing season in the southeast with peak temperatures and humidity.

Previous research in other regional crops indicated that irrigation scheduling tools can aid in decision making by providing growers information based on predicted and/or historical records (Camp *et al.*, 1985; Migliaccio *et al.*, 2015; Vellidis *et al.*, 2016; Porter 2021). One example includes the utilization of the UGA Checkbook irrigation recommendations (Table 1). This method provides irrigation recommendations based on historic weather data and uses the DAP data to estimate peanut phenological stages associated with water consumption trends (Porter, 2021; UGA Peanut Production Guide, 2022).

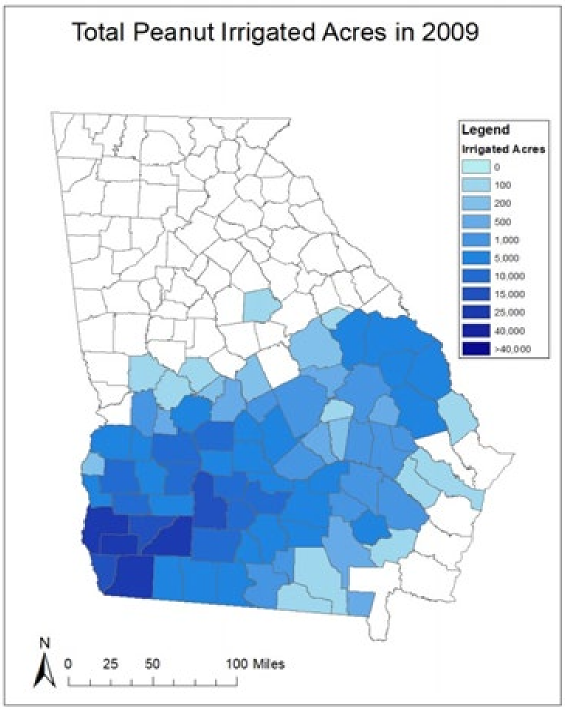

Figure 2. Irrigated peanut acres in 2009 (Szydzik, 2021).

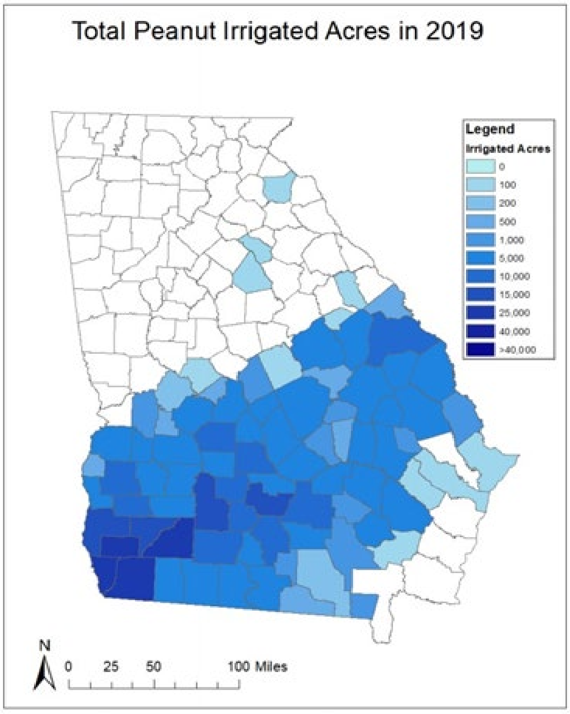

Figure 3. Irrigated peanut acres in 2019 (Szydzik, 2021).

Table 1. UGA Checkbook peanut irrigation schedule

Days after planting	Irrigation applied per week
	mm
1 – 7	3
8 – 14	8
15 – 21	10
22 – 28	13
29 – 35	20
36 – 42	23
43 – 49	28
50 – 56	33
57 – 63	38
64 – 70	41
71 – 77	41
78 – 84	38
85 – 91	36
92 – 98	33
99 – 105	31
106 – 112	25
113 – 119	20
120 – 126	18

Sensor-based irrigation scheduling utilizes concepts that have been established in prior research, such as appropriate irrigation trigger levels, soil type, and crop growth stage, to precisely provide irrigation to peanut based on the readings from the physical soil moisture sensors placed in field (Irmak *et al.*, 2014). Irrigator Pro is an example of a web-based irrigation scheduling tool that recommends irrigation by corresponding the available water in the soil and the daily water needs of the crop based on its growth stage (IrrigatorPro, 2022).

The main objective of this study was to determine the effects on peanut yield for over- and under-irrigating peanuts as determined by Soil Water Tension (SWT) data. The main objective was met by applying irrigation when the thresholds as defined by SWT were met for a range of soil water tension levels as defined as wet to dry for a sandy loam soil type (Irmak *et al.*, 2014). At the end of the season, total irrigation applied, irrigation water use efficiency, and yield were evaluated to determine the optimal peanut irrigation method for maximizing yield and productivity.

MATERIALS AND METHODS

This two-year study was conducted during 2018 and 2019 at the University of Georgia's Stripling Irrigation Research Park (SIRP) near Camilla, GA. Peanuts were planted on May 11, 2018 and May 6, 2019, respectively. Nine treatments were implemented under a variable rate lateral irrigation system (Valmont Omaha, NE) into a randomized complete block design with three replications per treatment for a total of 27 plots. Treatments included 20, 30, 40, 50, 60 kPa SWT, a UGA Checkbook method, a modified UGA Checkbook method (meaning that 50% of the weekly water required by the Checkbook was applied), Irrigator Pro, and rainfed. Each plot was 7.3 m (8 rows) wide by 12.8 m long with a minimum 8-row lateral border and 12-meter vertical buffer between plots and replication blocks to prevent overspray of the irrigation system. The soil water tension was monitored hourly by custom built probes that had WaterMark (Irrometer Company, Inc., Riverside, CA) SWT sensors connected to an internal UGA Server that provided real-time soil moisture data. Data from the WaterMark SWT sensors were collected and used to make irrigation decisions each day at 07:00 am for each treatment. Irrigation was only applied to the rainfed treatment in this study to promote germination/emergence and activate herbicides.

Each SWT value tested was determined by the researched SWT trigger point of 45 kPa, which is recommended for sandy loam soil (Irmak, 2015a). Two SWT probes were placed in two of the three treatment replications at depths of 10, 20, and 40 centimetres to reflect the soil moisture content at varying depths. The 07:00 am, SWT data for each treatment was compiled into an Excel file to compute weighted averages which reflected the current rooting depth for each treatment. The weighted average approach was applied to the sensor depths to reflect root growth, development, and water usage. This approach was developed based on past observations and discussions with peanut physiologists on peanut root growth over time. The weighting on sensors depths occurred as follows: 0-40 days after planting (DAP), 80% on the 10 cm depth, 20% on the 20 cm depth, and 0% on the 40 cm depth, 41-60 DAP, 60%, 30%, and 10% on the 10, 20 and 40 cm depths respectively, 61-140 DAP, 40%, 40%, and 20% on the 10, 20, and 40 cm depths respectively. When the treatment trigger level was reached for the weighted depth average for the two probes in each treatment, 19 mm of irrigation were applied to all plots of the treatment. This was repeated for all treatments except for the UGA Checkbook, 50% UGA Checkbook and Irrigator Pro. For the UGA Checkbook and 50% UGA Checkbook the recommended amount of irrigation was compiled by the day of the week and applied after rainfall was subtracted, and this amount was divided in half for the 50% UGA Checkbook method. For Irrigator Pro, the nodes from each sensor depth were averaged and entered into the appropriate depths in the online version of Irrigator Pro. Once Irrigator Pro recommended irrigation, 19 mm of irrigation were applied.

Upon desired pod maturity being reached, the center two rows of each plot were dug on September 27, 2018 and September 19, 2019 and were harvested using a Colombo two-row plot combine (Colombo North America, Adel, GA) on October 2, 2018 and September 23, 2019, respectively. Using a hanging scale, weights of the peanuts harvested were collected in each plot. Yield data were calculated based on plot size and weight.

For data analysis, yield, Irrigation Water Use Efficiency (IWUE, calculated by subtracting non-irrigated yield from the treatment yield and dividing that value by the amount of irrigation applied) and adjusted revenue data (or gross revenue, which is (yield * the loan rate) - the irrigation system costs) were analysed in JMP 16.1 (SAS, 2021) using a Tukey adjustment for multiple comparisons at an alpha level of 0.05.

RESULTS AND DISCUSSION

Rainfall data were collected from the University of Georgia Weather Network (UGA-AEMN) and monthly rainfall amounts are shown in Table 2. In 2018, there was a total rainfall amount of 1875 mm and 1305 mm in 2019 (Table 2). The historical yearly average rainfall for Camilla, GA is 1320 mm, concluding 2018 received 555 mm more rainfall than the average (UGA-AEMN). The 2018 growing season was from May 11 until harvest on October 2; during that season there was a total rainfall accumulation of 830 mm, while the 2019 growing season was from May 6 until September 23 and received 510 mm of rainfall, with an average growing season rainfall of 603 mm.

Table 2. 2018 and 2019 monthly rainfall.

Month	Rainfall		
	2018	2019	Long Term Average
	----------	mm	----------
January	89	123	136
February	169	68	142
March	104	84	139
April	129	108	135
May	131	87	109
June	229	121	129
July	218	156	139
August	233	122	127
September	19	26	99
October	168	129	96
November	139	58	105
December	247	223	133
Total	1875	1305	1489

Seasonal yield and IWUE were analysed to find the optimal irrigation SWT trigger level for peanut in loamy sand soils in peanut. Additionally, adjusted revenue was calculated to determine total income after irrigation costs (which are application costs * number of irrigation applications based on the UGA Extension Enterprise Budget) were deducted. Seasonal yield, IWUE, and adjusted revenue of each irrigation treatment for 2018 and 2019 are presented in Tables 3 and 4. There were no differences between irrigated treatments for yield within year for both 2018 and 2019. However, mean yield for 2019 was greater when compared to 2018 (6736 kg ha^{-1} vs. 5592 kg ha^{-1}, $P < 0.0001$). The reduction of peanut yield in 2018 is most likely attributed to the excessive rainfall events during most of the growing season. Similar results were recorded in a study evaluating peanut yields in irrigated peanut fields compared to rainfed (Lamb *et al.*, 2004).

Unlike the seasonal yield, year and treatment had an effect on peanut IWUE. In 2018, The 40 kPa irrigation treatment had the greatest IWUE but was not different from the 50 kPa and Irrigator Pro scheduling treatments (498 kg ha^{-1} mm^{-1} vs. 435 kg ha^{-1} mm^{-1}, $P = 0.2874$; 498 kg ha^{-1} mm^{-1} vs. 472 kg ha^{-1} mm^{-1}, $P = 0.9680$). The use of the UGA Checkbook recommendations resulted in the lowest IWUE in 2018 (203 kg ha^{-1} mm^{-1}, $P < 0.05$). While there were no significant differences in yield during 2018, the numerically greatest yields did not produce the greatest IWUE either. Additionally, there were no significant differences in adjusted revenue, however, the treatments which had the greatest IWUE, numerically had the greatest return on investment. In 2019, the 20 kPa, and the full and reduced UGA Checkbook recommendations resulted in the lowest IWUE of peanut (155 kg ha^{-1} mm^{-1}, 178 kg ha^{-1} mm^{-1}, 150 kg ha^{-1} mm^{-1}; $P < 0.05$). The 60 kPa treatment had the significantly greatest IWUE followed by the 40 kPa treatment and they also resulted in the highest adjusted revenue, along with the 50 kPa treatment though they were not statistically different from all other treatments except from the 20 kPa treatment. While there were no differences in yield within each season, the differences between IWUE suggests that there are optimal SWT thresholds that can maximize IWUE in peanut. These data suggest that while overwatering peanut may not affect yield, or did not in this study, it did have a significant impact on IWUE. While there were not significant differences in adjusted revenue during 2018, there were differences during 2019, a year that did not have as high of a rainfall amount negating treatment differences. This suggests that overwatering peanut does not maximize yield, but it also reduces IWUE and profitability. Careful consideration should be used when determining irrigation scheduling triggers for peanut to avoid over-irrigation and wasting of irrigation water.

Table 3. 2018 peanut irrigation treatment, yield, IWUE, and adjusted revenue.

Treatment	Irrigation Applied	Yield	IWUE	Adjusted Revenue
	mm	kg ha^{-1}	kg ha^{-1} mm^{-1}	dollars ha^{-1}
20 kPa	159	6554	330c[a]	1870
30 kPa	140	6421	329c	1641
40 kPa	102	6613	498a	1865
50 kPa	121	6771	435ab	1918
60 kPa	121	6570	407bc	1785
Checkbook	235	6333	203d	1626
50% Checkbook	150	6464	321c	1731
Irrigator Pro	102	6300	472ab	1763
Rainfed	64	6156	n/a	2061

[a]Means in columns followed by different letters are different, no letter indicates no significant difference ($P < 0.05$).

Table 4. 2019 peanut irrigation treatment, yield, IWUE, and adjusted revenue.

Treatment	Irrigation Applied	Yield	IWUE	Adjusted Revenue
	mm	kg ha^{-1}	kg ha^{-1} mm^{-1}	dollars ha^{-1}
20 kPa	386	7361ab[a]	155f	1860b
30 kPa	290	7558ab	212de	2108ab
40 kPa	176	7594a	352b	2236a
50 kPa	233	7673a	275c	2256a
60 kPa	137	7277ab	449a	2267a
Checkbook	400	7393ab	178ef	1990ab
50% Checkbook	335	7188ab	150f	1941ab
Irrigator Pro	252	7079ab	234cd	2010ab
Rainfed	64	6584b	n/a	2012ab

[a]Means in columns followed by different letters are different. No letter indicates no significant difference. ($P < 0.05$).

SUMMARY AND CONCLUSIONS

Peanut is an important row crop in Georgia and across the Southeast US. Water usage in peanut is crucial in obtaining optimal yields at the end of the growing season. To achieve these goals, there are several irrigation methods which are available to growers. This study evaluated nine irrigation treatment thresholds to determine the affect they had on yield, IWUE, and adjusted revenue. There were differences in yield between years, but not by treatment within year. However, there were significant differences within year by treatment for IWUE. These data suggest that while there may not be a yield penalty for over-irrigating peanut there is an IWUE and profitability penalty. Thus, it is strongly suggested that growers select an advanced and validated irrigation scheduling method for peanut to avoid over-application of irrigation water, reductions in IWUE and profitability.

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