Peanut Response to Crop Rotation, Drip Tube Lateral Spacing, and Irrigation Rates with Deep Subsurface Drip Irrigation

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ABSTRACT

Long term crop yield with various crop rotations irrigated with subsurface drip irrigation (SSDI) is not known for US southeast. A SSDI system was installed in 1998 on Tifton loamy sand soil with five crop rotations, two drip tube lateral spacings, and three irrigation levels. Crop rotations ranged from continuous peanut (*Arachis hypogaea* L) to four years between peanut. Laterals were installed beneath each crop row (0.91-m) and alternate row middles (1.83-m). Crops were irrigated daily at 100, 75 and 50% of estimated crop water use. Laterals spaced at 1.83 m had the same yield as laterals spaced at 0.91-m in nine out of ten years. The 50, 75, and 100% irrigation treatments averaged 3263, 3468, and 3497 kg/ha, respectively. There was no yield difference between the 75 and 100% irrigation treatments implying 25% water savings. Crop rotation affected peanut yield seven out of eight years and continuous peanut had lowest yield across all years. As time between peanut crops increased peanut yield increased. Irrigation treatment had no effect on total sound mature kernels (TSMK). Lateral spacing affected TSMK 20% of the time and crop rotation affected TSMK 90% of the time. Continuous peanut rotation had the lowest TSMK with higher TSMK occurring as time between peanut crops increased. There was no evidence of any one crop rotation negatively affecting kernel size distribution except for continuous peanut. When using SSDI, it is possible to save 25% irrigation water, install drip laterals in alternate row middles, and rotate with peanut every three years without negatively affecting peanut yield or grade.

Key Words: subsurface drip irrigation, crop rotation, lateral spacing, pod yield, kernel size distribution.

Peanut production covers just over 322,000 ha in the tri-state area of Alabama, Florida, and Georgia with only 28% of these acres being irrigated (USDA, 2009). Only 10% of the total irrigated hectares in Georgia were irrigated using drip, trickle or micro-sprinkler while Florida has over 220,000 ha using some type of drip or trickle irrigation (USDA, 2009). Due to the expense of drip system installation, it is assumed that most of these drip systems are on high value vegetable crops. It is unknown, if or how many, of these drip or trickle systems may be used to grow peanut or other traditional row crops such as cotton (*Gossypium hirsutum* L.) or corn (*Zea mays* L.).

Economic simulations showed that subsurface drip irrigation (SSDI) would be more profitable for small areas (<30 ha) because of its lower investment per unit land area and lower pumping costs compared to fixed or towable center-pivot systems. As emphasized by Bosch *et al*. (1998) and O'Brien *et al*. (1998), SSDI systems have a near-static cost per hectare compared with overhead sprinkler systems (center pivots), where per hectare cost decreases as the length of the system increases covering more area. Overhead sprinkler irrigation systems are the most common in the tri-state area, because they are easy to assemble, durable, do not require elaborate filtering systems, and familiarity with operation and maintenance. One major concern with overhead sprinkler systems is that once water exits an overhead sprinkler system, its fate may be affected by environmental conditions such that water may not hit the intended target but be lost due to wind and evaporation before it reaches the soil surface and becomes available for crop use. Thus, subsurface drip irrigation has the potential to provide consistently high yields while conserving soil, water, and energy. Some of the major benefits of drip irrigation include precise placement of water and chemicals, low labor requirements, and reduced runoff and erosion compared with overhead sprinkler system. These SSDI systems have the capability of frequently supplying water to the root zone thereby reducing the risk of cyclic water stress typical of other irrigation systems. Research has indicated that crop yield and quality may be increased and that SSDI can be used on cotton (Bucks *et al*., 1988; Henggeler, 1988, Nuti *et al.,* 2006, Dougherty *et al*., 2009), and corn (Mitchell, 1981; Mitchell and Sparks, 1982; Powell and Wright, 1993).

These SSDI systems are adaptable to various field sizes and shapes making them an important

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Table 1. Description of crop rotation for irrigation research at Sasser, Georgia.

Rotation	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
pppp[a]	p	p	p	p	p	p	p	p	p	p
pcpc	p	c	p	c	p	c	p	c	p	c
mpmp	m	m	p	m	p	m	p	m	p	m
cmpc	p	c	m	p	c	m	p	c	m	p
cmmp	m	p	c	m	m	p	c	m	m	p

[a]Abbreviations: p, peanut; c, cotton; m, corn.

economic consideration, especially in the southeast. This economic advantage is further evident when considering the option to design a SSDI system to effectively cover an irregularly shaped field that would not be totally covered with a sprinkler type system (Bosch *et al*., 1998). With proper SSDI designs these systems can provide sufficient water to different fields according to the area, soils, and crop species.

Drip tube laterals have been installed at 0.2- and 0.3-m soil depths (Bucks *et al.,* 1986; Tollefson, 1985; Phene *et al*., 1987; Camp *et al*., 1989) on cotton, corn, fruits, and vegetables. Drip laterals have been spaced at 1, 2, and 3 m apart with yields decreasing as lateral spacing increased to greater than 2 m (French *et al*., 1985; Lamm *et al.,* 1992; Powell and Wright, 1993; Camp *et al.,* 1997; Enciso *et al*., 2005). Drip tubing was buried or laid on the soil surface at various lateral spacings, i.e., every row or alternate row furrows, in continuous cotton or cotton-corn-peanut rotations (Camp *et al*., 1993; Camp *et al*., 1997; Dougherty *et al*., 2009; Sorensen *et al*., 2008). In continuous cotton with alternate row lateral spacing, there was year to year variability due to climatic patterns, but irrigated cotton yields were greater than nonirrigated yields especially in dry years (Dougherty *et al.,* 2009). A comparison of alternate row spacing versus every-row lateral spacing indicated no yield differences with either continuous cotton, or cotton-corn-peanut rotations (Camp *et al.,* 1993; Camp *et al*., 1997; Sorensen *et al.,* 2008).

With increasing concern for water conservation in the tri-state region (Alabama, Georgia, and Florida), the use of SSDI due to the greater irrigation efficiency of these systems, may be of great interest to individual growers, water and environmental conservancy agencies, and policy making agencies. There is little long term peanut yield response data with SSDI in the southeast to make management recommendations. Therefore, the objectives of this research were to determine the long-term yield response of peanut to: 1) three irrigation rates, 2) two lateral spacings, and 3) five crop rotations using SSDI over a 10-year period.

Materials and Methods

The research site was located in Terrell County near Sasser, GA on a Tifton sandy loam soil (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 2 to 5% slope. A SSDI system was installed in 1998 on non-irrigated farmland that consisted of three irrigation levels, five crop rotations, two drip tube lateral spacings, and three replications for a total of 90 individual plots. Cotton had been planted two years prior to installing the SSDI system. Land ownership had changed such that long term crop rotations were not available and the current owner had not raised peanut since 1993. A 6.8 ha area rectangle was divided into three equal areas referred to as tiers. There were alley-ways (12.2 m minimum) between tiers, at the sides, and crop row ends for equipment turn areas. Each SSDI tier (38 m by 274 m) was randomly assigned an irrigation level. A SSDI tier consisted of three blocks (replications), five crop rotations, and two thin-wall drip lateral spacings for a total of 30 plots per tier. The irrigation levels were 100%, 75% and 50% of estimated crop water use (Sorensen *et al.*, 2001).

The five crop rotations included continuous peanut (PPP), cotton-peanut (CP), corn-peanut (MP), cotton-corn-peanut (CMP), and a cotton-corn-corn-peanut (CMMP) (Table 1). All crops were planted on a 0.91-m row spacing in a single row pattern. The two drip tube lateral treatments had drip tubes installed underneath each crop row (narrow, 0.91-m) and in alternate crop row furrows (wide, 1.83-m). Each narrow row subplot had six crop rows with one drip tube lateral installed under each row and was replicated three times across each tier (replication per block). Each wide row subplot had 10 crop rows with five drip tube laterals installed in alternate crop row middles and replicated three times, one replication in each block. Sorensen *et al*. (2001) describes in detail the treatments, irrigation system design criteria, and irrigation control. The thin-wall drip tube (Super Typhoon, Netafim Irrigation, Inc., Fresno, CA; www.netafim-usa.com) had a wall thickness of 0.254 mm and emitters spaced every 46 cm with a

Table 2. Peanut planting and harvest dates, rainfall, irrigation, and cultivar selected by year for irrigation research at Sasser, Georgia.

Year	Planting	Harvest	Rainfall	Irrigation level 100%	Irrigation level 75%	Irrigation level 50%	Cultivar[a]
			mm	mm	mm	mm	
1998	11 May	16 Sep	579	242	182	117	GG
1999	12 May	13 Sep	453	328	251	171	GG
2000	11 May	25 Sep	330	304	232	161	GG
2001	08 May	12 Sep	397	359	272	211	GG
2002	07 May	11 Sep	292	178	128	89	GG
2003	09 May	08 Sep	651	242	189	139	GG
2004	06 May	10 Sep	546	199	151	101	GG
2005	03 May	09 Sep	701	238	178	119	GG
2006	01 May	22 Sep	429	479	260	240	GG
2007	03 May	12 Sep	391	386	290	194	GG

[a]Abbreviation: GG, Georgia Green.

flow rate of 1.5 L/h per emitter. All thin-wall drip tubing was buried approximately 30 cm deep using a modified ripper shank.

Irrigation water was applied daily based on replacement of estimated crop water use for peanut (Table 2). Air temperature (maximum, minimum and average), relative humidity, total solar radiation, and precipitation were recorded daily. From 1998 to 2003, meteorological data were collected using programmable logic control (PLC) modules. This system worked, but was vulnerable to lightning. In spring 2004 this PLC system was replaced with more reliable datalogger system (Campbell Sci., Inc, Logan, UT; CR23X). Daily potential evapotranspiration (ET_o) was estimated using the modified Jensen-Haise equation adjusted for local conditions (Jensen and Haise, 1963). Daily crop coefficients, K_c, were determined by dividing the estimated daily mean peanut (Stansell *et al.*, 1976), cotton (Harrison and Tyson, 1993), and corn (Lambert *et al.*, 1988) water use values by the daily estimated archived ET_o data for the same time period. Daily ET_o was then multiplied by the daily K_c to estimate the daily water replacement for each crop (estimated ET_a) which is identified as the 100% irrigation level. The other two irrigation levels were determined by multiplying the 100% irrigation level by 75 and 50%, respectively. Length of irrigation time for each irrigation treatment was calculated on estimated daily ET_a to apply the desired depth of water. An irrigation event was not applied if precipitation exceeded the estimated crop water use for that day. A maximum of 10 mm precipitation would be used as a "carry over" to stop irrigation for a short time span following a precipitation event. Daily ET_a values were subtracted from the "carry over" until its value was zeroed, then irrigation events would resume. The 10-mm "carry" is about 25% soil moisture depletion for this soil type.

Lime was applied on all plots and in all years as determined by soil test to maintain soil pH to approximately 6.5. Seed-bed preparation for all crops consisted of one to two passes (once in the fall and once in the spring) with experimental tillage equipment (USDA-ARS-National Peanut Research Laboratory) that would essentially till the top 10 to 15 cm of soil. This equipment would reshape the soil into one single planting bed that was about 1.4 m wide. This equipment also provided the opportunity for controlled-traffic such that no wheeled equipment ran over the buried lateral positions. A small field cultivator was used to break any soil crust, incorporate herbicides, and for weed control prior to planting any crop. After harvest, the crop residue would be mowed (cotton and corn), lightly tilled with a disc harrow, and then re-bedded as described previously.

The only peanut cultivar used, "Georgia Green" (Branch, 1996), was planted between May 1st to 12th (depending on weather conditions) with a vacuum type planter (Monosem, ATI., Inc., Lenexa, KS) at about 20 seeds m^{-1} on a 0.91-m row spacing (Table 2). Treatments in each respective year received the same weed, insect, and disease control management applications following general recommendations outlined by individual product labels or University of Georgia Agricultural Extension Service recommendations (Prostko, 2004). Harvest dates were based on the optimum crop maturity determined by the hull scrape method (Williams and Drexler, 1981). Yield rows were dug with a 2-row inverter and harvested with a 2-row combine. Sample weights were recorded and subsequently divided such that a 4 to 7-kg sub-sample was collected from each plot sample. Each sub-sample was graded and shelled to determine farmer stock grade and kernel size distribution, respectively. Pod yield was based on total sample weight adjusted to 7% moisture. Farmer stock grade and kernel size distribution were determined using procedures specified by the USDA (USDA, 1998). Gross revenue was determined using the average market price for 2008 of \$0.45 kg^{-1} of farmer stock grade peanut (Georgia Dept. of Ag, 2009).

Due to restricted amount of land area, not every crop rotation was planted every year. Consequently, not every combination of peanut rotation could be analyzed by rotation every year. A factorial design of general analysis of variance procedure was used to analyze peanut yield and grade data (Statistix9, 2008) with respect to irrigation rate (tiers), crop rotation, and lateral spacing. Crop yield and grade data were analyzed by individual years, irrigation treatment, crop rotation, and lateral spacing within and across years if applicable. Differences between crop yield and quality means were determined using Tukey's HSD multiple comparison when ANOVA F-test showed significance ($P \leq 0.05$).

Results and Discussion

Plant and Harvest Date. Peanut were planted May 1st to 15th and harvested Sept 8th to 24th (Table 2) for all years of the project. The average planting date was May 7th which is always within the time period recommended for reduced risk of tomato spotted wilt tospovirus (Brown *et al.*, 2004). Harvest dates were Sept 8th to 25th for an average harvest date of Sept 14th. The range of harvest dates were more variable compared with planting date due to seasonal growing conditions and harvest time weather conditions.

Rainfall and Irrigation. Rainfall was lowest in 2002 with just under 300 mm for the growing season (Day of Year, DOY 121 to 258) of May 1st to middle of Sept. The highest rainfall occurred during the 2005 season. The average rainfall for all ten growing seasons was 477 mm. Table 2 also shows the irrigation amounts applied during the growing season for the various years and irrigation levels. Over the 10-year period, the 100% irrigation treatment averaged 295 mm irrigation per growing season. The 75 and 50% irrigation treatments averaged 213 and 154 mm irrigation per growing season for an actual 72 and 52% irrigation treatment, respectively. These percentages were very similar to the designed treatments implying the irrigation system worked well over this 10-year period. Figure 1 shows cumulative

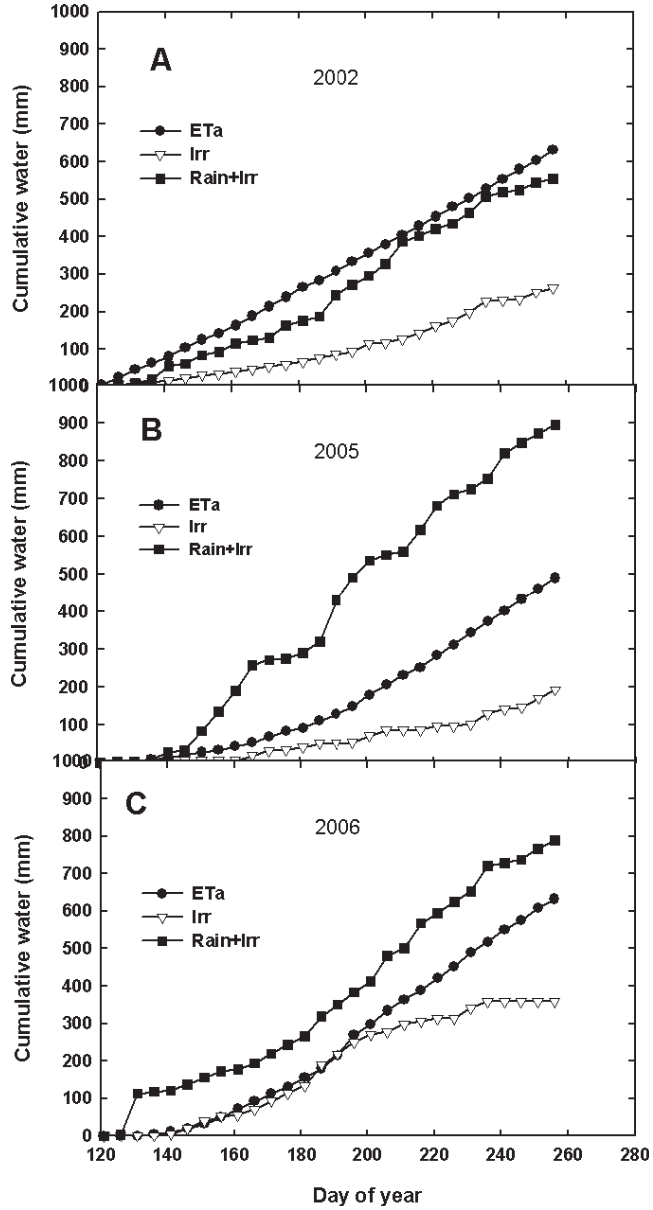

Fig. 1. Estimated cumulative ET$_a$ and measured cumulative irrigation and irrigation plus rainfall during years 2002 (A), 2005 (B), and 2006 (C) for low, high, and average rainfall between day of year 121 to 257.

rainfall, irrigation, and estimated evapotranspiration (ETa) for a low (2002), high (2005), and average (2006) rainfall year. In 2002, it was anticipated that higher irrigation amounts would be required compared to other years due to the low rainfall amounts. In Figure 1A, irrigation was much less than the estimated water use however, the cumulative irrigation plus rainfall was a close match to the estimated ET$_a$ of the crop. Figure 1B shows cumulative ET$_a$, irrigation, and rainfall plus irrigation for the highest rainfall year of 2005 while Figure 1C shows these same parameters for 2006 a somewhat average rainfall year. In Figures 1B and 1C, irrigation plus rainfall were both much greater that the estimated ET_a of the crop. Rainfall amounts can be quite large with long periods of drought between rainfall events. Thus, irrigation timing and amount is greatly affected by rainfall event, intensity, and amount.

Irrigation Treatment. Table 3 shows the ANOVA probability values for yield, grade, and kernel size distribution. There were only two years where irrigation treatment indicated significant yield difference, 2003 and 2006. These two years were not considered low rainfall years; in fact 2003 had the second highest rainfall measured while 2006 was near the average (see Figure 1C). It would seem that irrigation treatment effects would occur in the dryer rainfall years of 2000 and 2002. As previously discussed, cumulative irrigation in 2002 was much less than ET_a with irrigation plus rainfall nearly equal to the estimated ET_a of the crop. However, there was no yield reduction between irrigation levels for 2002 indicating that rainfall plus irrigation seemed to be adequate even for the 50% irrigation level. Yield data indicate that in 2003 and 2006, lower yields were measured at the 50% irrigation treatment compared with the 75 and 100% irrigation treatment (Table 4). With only two out of ten years showing lower yields at the 50% irrigation treatment and no significant yield difference between the 75 and 100% irrigation treatment, it would seem reasonable to conclude that irrigating a 75% of estimated ETa would be an effective irrigation level. Irrigating at 75% of estimated ET_a would imply a 25% saving of water without compromising crop yield. Also, depending on rainfall patterns, it may even be possible to reduce irrigation by as much as 50% of estimated ETa without reducing yield for a 50% water conservation effort; however the risk of reduced yields would increase as drought length increased. Rainfall patterns could explain the reason for yield response to irrigation in some years (2003 and 2006) and not others. Monthly rainfall data show that in 2006 both June and July were very dry months with over 70 consecutive days with only one rainfall event greater than 5 mm. In 2003, monthly totals were over 130 mm/month for the growing season, however, there were multiple periods of up to 17 consecutive days without rainfall followed by intense rainstorms. In 2002, rainfall was least in May and June, but July was wet. These examples indicate that cumulative rainfall for either a year or a month does not necessarily correlate to yield. Therefore, individual rainfall events (timing), intensity, and total amount can be a challenge to irrigation scheduling and to determine final crop yield.

Over the 10-year period of this research, the 50, 75, and 100% irrigation treatments averaged 3263, 3468, and 3497 kg/ha, respectively, over all lateral spacings and crop rotations. Averaging across all years and rotations may not be statistically valid, however, these yield averages indicate 75 and 100% irrigation level has similar yield values and are both numerically higher than the 50% irrigation level. Table 3 also shows significant yield interaction did occur once each between irrigation by rotation (2002) and irrigation by lateral (2001). There was no yield interaction between irrigation, rotation and lateral spacing.

Lateral Spacing. In Table 3, the probability values show that drip laterals spaced at 1.83-m had the same yield as laterals spaced at 0.91-m in nine out of ten years. There was significant yield difference between the two lateral spacings in 2000. During the 2000 growing season, the 0.91-m lateral spacing average 4028 kg ha^{-1} while the 1.83-m lateral spacing averaged 2894 kg/ha (Table 4). When averaged across years, the 0.91-m lateral spacing averaged 3484 kg/ha while the 1.83-m lateral spacing averaged 3334 kg/ha. The higher yield advantage of 150 kg/ha for the narrow lateral spacing versus the wide lateral spacing would only add about $68/ha to the gross revenue. The wide lateral spacing costs about $377/ha just for the tubing and twice this amount for the narrow lateral spacing ($754/ha at $0.0672/m of tubing). At this level of increased yield and revenue (150 kg/ha and $68/ha, respectively) it would take over 5.5 years to pay for the cost of only the tubing provided peanut was grown each year and peanut yield was static. Other expenses would be incurred that would include installation costs of extra fitting adaptors, fuel, labor, maintenance and possible other design criteria such as added zones, mainline, valves, etc. There were significant yield differences with lateral by rotation interaction in 3 out of 9 years (2000, 2002, and 2006). These crop years are also associated with strong responses to yield for either lateral (2000) or rotation (2002 and 2006) which may dominate these interaction responses. Therefore, there is not consistency with "lateral by rotation" interaction with which to draw any long term conclusions.

Overall, there was little yield increase when using narrow lateral spacing, therefore, it is recommended that on these soils and in this environmental location, that laterals be spaced in alternate row middles for maximum yield and possible economic return.

Crop Rotation. The probability values indicate that crop rotation significantly affected peanut yield seven out of eight years (Table 3). In all cases where yield was significantly affected by crop rotation, continuous peanut had the lowest yield (Table 4). Conversely, higher yields were measured when time periods between peanut crops was

Table 3. Probability values for yield, grade (TSMK, oil stock) and kernel size distribution (jumbo, medium, and ones) with respect to irrigation, crop rotation, and lateral spacing for peanut 1999 to 2007 at Sasser, Georgia.

source	1999	2000	2001	2002	2003	2004	2005	2006	2007
Yield									
irr[a]	0.54	0.40	0.09	0.84	0.03	0.47	0.17	0.02	0.54
rotate	0.00	0.66	0.00	0.00	0.00	0.00		0.00	0.00
irr × rotate	0.29	0.21	0.29	0.00	0.27	0.76		0.48	0.99
lateral	0.53	0.00	0.37	0.55	0.10	0.20	0.79	0.93	0.30
irr × lateral	0.78	0.16	0.05	0.78	0.70	0.46	0.38	0.08	0.68
rotate × lateral	0.77	0.02	0.14	0.04	0.16	0.35		0.03	0.52
irr × rotate × lateral	0.81	0.96	0.79	0.08	0.84	0.62		0.49	0.97
TSMK									
irr	0.73	0.57	0.20	0.11	0.18	0.97	0.19	0.37	0.76
rotate	0.00	0.52	0.00	0.00	0.00	0.03		0.00	0.00
irr × rotate	0.62	0.71	0.08	1.00	0.78	0.70		0.95	0.82
lateral	0.47	0.00	0.82	0.79	0.01	0.57	0.83	0.89	0.90
irr × lateral	0.52	0.99	0.73	0.20	0.00	0.76	0.82	0.01	0.44
rotate × lateral	0.63	0.14	0.89	0.42	0.15	0.10		0.21	0.20
irr × rotate × lateral	0.52	0.84	0.38	0.89	0.03	0.41		0.01	0.43
Oil stock									
irr	0.18	0.50	0.12	0.04	0.02	0.19	0.18	0.47	0.50
rotate	0.00	0.34	0.06	0.00	0.00	0.07		0.02	0.00
irr × rotate	0.47	0.73	0.11	0.97	0.85	0.31		0.61	0.63
lateral	0.16	0.00	0.94	0.78	0.62	0.29	0.08	0.19	0.85
irr × lateral	0.36	0.81	0.90	0.13	0.60	0.39	0.47	0.00	0.17
rotate × lateral	0.24	0.18	0.74	0.55	0.24	0.12		0.01	0.59
irr × rotate × lateral	0.64	0.81	0.69	0.85	0.05	0.85		0.01	0.18
Jumbo									
irr	0.67	0.79	nd[b]	0.85	0.25	0.33	0.17	0.06	0.48
rotate	0.01	0.25	nd	0.00	0.00	0.00		0.03	0.00
irr × rotate	0.64	0.61	nd	0.07	0.58	0.94		0.71	0.82
lateral	0.49	0.00	nd	0.10	0.70	0.61	0.01	0.13	0.71
irr × lateral	0.71	0.80	nd	0.05	0.16	0.27	0.28	0.02	0.38
rotate × lateral	0.80	0.77	nd	0.18	0.30	0.46		0.00	0.53
irr × rotate × lateral	0.52	0.53	nd	0.97	0.99	0.67		0.52	0.62
Medium									
irr	0.48	0.66	nd	0.44	0.40	1.00	0.11	0.67	0.39
rotate	0.00	0.65	nd	0.00	0.31	0.04		0.01	0.89
irr × rotate	0.17	0.86	nd	0.49	0.70	0.82		0.03	0.18
lateral	0.72	0.04	nd	0.32	0.92	0.49	0.54	0.19	1.00
irr × lateral	0.87	0.69	nd	0.24	0.08	0.48	0.81	0.13	0.93
rotate × lateral	0.16	0.09	nd	0.06	0.54	0.09		0.93	0.34
irr × rotate × lateral	0.71	0.20	nd	0.98	0.29	0.16		0.24	0.60
Ones									
irr	0.77	0.25	nd	0.15	0.43	0.90	0.24	0.08	0.34
rotate	0.00	0.46	nd	0.00	0.00	0.01		0.02	0.03
irr × rotate	0.62	0.36	nd	0.86	0.60	0.97		0.78	0.77
lateral	0.11	0.00	nd	0.71	0.16	0.54	0.03	0.58	0.10
irr × lateral	0.50	0.82	nd	0.12	0.02	0.71	0.05	0.02	0.49
rotate × lateral	0.20	0.45	nd	0.90	0.07	0.63		0.13	0.52
irr × rotate × lateral	0.80	0.35	nd	0.59	0.80	0.88		0.59	0.75

[a]Abbreviations: TSMK, total sound mature kernels; irr, Irrigation; rotate, crop rotation; lateral, lateral spacing.
[b]no data recorded.

Table 4. Yearly peanut yield and project yield average for irrigation level, lateral spacing, and crop rotation by year for 1999 to 2007 for Sasser, Georgia.

Treat[b]	1999	2000	2001	2002	2003	2004	2005	2006	2007	Avg
	kg/ha									
Irr										
50%	3813a[a]	3213a	4322a	4038a	3425b	2760a	2765a	2423b	2611a	3263
75%	4062a	3610a	4903a	4032a	3656ab	2913a	2728a	2945a	2355a	3467
100%	4000a	3560a	4562a	4144a	3818a	2820a	3048a	2864a	2657a	3497
Lateral										
0.9 m	4024a	4028a	4645a	4103a	3550a	2781a	2857a	2748a	2621a	3484
1.83 m	3893a	2894b	4546a	4040a	3716a	2881a	2837a	2740a	2461a	3334
Rotate										
pp	2877b	3603a	3612b	2336c	2827b	2330b	–	2414b	1691c	2711
cp	–	3406a	–	4382b	–	2509bc	–	3016a	–	3328
mp	–	3374a	–	5496a	–	2924b	–	2803a	–	3651
cmp	–	–	5579a	–	–	3562a	–	–	2596b	3912
cmmp	5040a	–	–	–	4439a	–	–	–	3337a	4272

[a]Values in the same year and treatment with the same lowercase letter are not significantly different using Tukey's HSD at P=0.05.

[b]Abbreviations: Treat, treatment; Avg, yield average; irr, irrigation level; Lateral, lateral spacing; Rotation, crop rotation; p, peanut; c, cotton; m, corn.

longer. Though not statistically valid, average yield by rotation across the project time period indicated that continuous peanut had an average yield of 2711 kg/ha while alternate year cotton-peanut and corn-peanut rotation averaged 3328 and 3651 kg/ha, respectively. The two year and three year rotations between peanut crops averaged 3912 and 4272 kg/ha, respectively (See Table 4).

Over the life of this project, the alternate year rotation of corn-peanut tended to have higher peanut yield compared with the alternate year rotation of cotton-peanut. The corn-peanut rotation had on average 323 kg/ha greater yield compared with the cotton-peanut rotation. However, the corn-peanut rotation only had higher yields 50% of the time compared with the cotton-peanut rotation. When a situation occurs to shorten the time period between peanut to an alternate year rotation, the grower should choose the crop (corn or cotton) with the best economic return and not for the possible increase in peanut yield.

The importance of crop rotation has been known for many years in peanut. Lower peanut yield in continuous peanut production is probably due to increased disease pressure (Henning *et al.*, 1982). Hence, the recommended crop rotation for highest peanut yield would be to have the longest time frame between peanut crops as possible with major emphasis on holistic farm planning for economic returns. In general, the lowest TSMK occurred consistently with the continuous peanut rotation and increased as time between peanut crops increased.

Peanut Grade and Kernel Distribution. Irrigation treatment had no effect on total sound mature kernel (TSMK) percentages within year (Table 3). Lateral spacing affected TSMK two out of ten years or 20% of the time. Crop rotation affected TSMK 7 out of 8 years or about 87% of the time. The continuous peanut rotation tended to have the lowest TSMK with higher percentages occurring as time between peanut rotations increased. There were significant treatment interactions for grade and kernel distribution for irrigation by rotation, irrigation by lateral, rotation by lateral, and water by rotation by lateral. However, there does not seem to be any year to year consistency or relationship consistency to draw any long term conclusions with the significant interactions.

In general, as TSMK increases, the percent oil stock tends to decrease. Irrigation treatments affected the percent oil stock 20% of the time (Table 5). Lateral spacing affected the percent oil stock only 10% of the time, with crop rotation affecting oil stock 62% of the time. Over the 10-year period there was little difference in the overall percentages of oil stock kernels with irrigation treatment or lateral spacing. However, crop rotation had great effect on oil stock percentages. Continuous peanut rotations tended to have higher percentages (over 7%) of oil stock compared with other rotations. Alternate year peanut rotations had the same oil stock percentage (6.4%) when averaged over the 10-year period. The lowest percentage of oil stock occurred with the longer rotations of 3 (5.6%) and 4 (5.5%) years between peanut crops (Table 5).

Table 5. Yearly peanut grade values and project average consisting of Total Sound Mature Kernels (TSMK) and oil stock for irrigation level, lateral spacing, and crop rotation by year for 1999 to 2007 at Sasser, Georgia.

Treat[b]	1999	2000	2001	2002	2003	2004	2005	2006	2007	Avg
	TSMK %									
Irr										
50%	67.2a[a]	69.9a	73.2a	72.6a	66.1a	61.4a	67.4a	68.1a	70.8a	68.5
75%	66.2a	71.0a	72.7a	72.4a	66.8a	61.2a	60.7a	68.1a	69.9a	67.7
100%	67.5a	70.7a	71.3a	71.8a	67.5a	61.1a	67.0a	69.1a	70.5a	68.5
Lateral										
0.9 m	66.7a	72.4a	72.5a	72.3a	66.3b	61.0a	64.7a	68.4a	70.4a	68.3
1.83 m	67.2a	68.7b	72.4a	72.2a	67.3a	61.5a	65.4a	68.5a	70.3a	68.2
Rotate										
pp	62.5b	71.4a	70.9b	69.2b	65.0b	61.5ab	–	67.9a	68.2b	67.1
cp	–	69.6a	–	73.2a	–	58.5b	–	69.8a	–	67.8
mp	–	70.6a	–	74.4a	–	61.4ab	–	67.6b	–	68.5
cmp	–	–	74.0a	–	–	63.5a	–	–	70.7a	69.4
cmmp	71.4a	–	–	–	68.6a		–	–	72.3a	70.8
	Oil stock %									
Irr										
50%	6.2a	6.7a	4.6a	4.9b	7.3a	6.2a	7.8a	7.9a	5.3a	6.3
75%	7.4a	5.9a	5.3a	5.3ab	7.2a	6.8a	9.4a	8.4a	6.0a	6.9
100%	7.1a	6.3a	6.0a	5.7a	6.7b	7.6a	8.1a	7.6a	5.6a	6.7
Lateral										
0.9 m	7.2a	5.3b	5.3a	5.3a	7.2a	7.0a	7.9a	8.1a	5.7a	6.5
1.83 m	6.6a	7.3a	5.3a	5.3a	7.0a	6.7a	9.0a	7.8a	5.6a	6.7
Rotate										
pp	8.0a	5.5a	5.8a	6.9a	8.1a	7.6a	–	8.4a	6.8a	7.1
cp	–	6.7a	–	4.7b	–	6.9a	–	7.4b	–	6.4
mp	–	6.7a	–	4.2b	–	6.4a	–	8.2a	–	6.4
cmp	–	–	4.8a	–	–	6.5a	–	–	5.6b	5.6
cmmp	5.7b	–	–	–	6.1b	–	–	–	4.6b	5.5

[a]Values in the same year, treatment, and grade factor with the same lowercase letter are not significantly different using Tukey's HSD at P=0.05.

[b]Treatment = treat; yield average = Avg; irrigation level = Irr; lateral spacing = Lateral; crop rotation = Rotate; p=peanut, c=cotton, m=corn.

Kernel size distribution of jumbos, mediums, and ones, was not affected by irrigation treatment. Lateral spacing affected jumbo sized kernels 22% of the time, medium sized kernels 11% of the time and number one sized kernels 22% of the time. Crop rotation affected jumbos, mediums and ones 86%, 57%, and 86% of the time, respectively. Typically, as percentages of jumbos decrease, percentages of mediums and ones increase. As both jumbos and mediums decreased then percentages of ones increased. There was no clear evidence of any one crop rotation affecting kernel distribution compared to another except for continues peanut treatment. In this continuous peanut treatment jumbo- and medium- sized kernels tended to decrease and number one sized kernels tended to increase. This implies that shorter time periods between peanut crops in a rotation would negatively affect kernel size but not necessarily the peanut grade or TSMK.

Conclusions

The use of deep subsurface drip irrigation is feasible for peanut and the associated crop rotations. Average peanut yields across the life of the project indicate 75 and 100% irrigation level had similar yield values and both were numerically higher than the 50% irrigation level. In addition, there was no yield reduction when 75% of the recommended water was applied compared with full (100%) recommended amount, implying a possible 25% water savings for the same yield.

There was a numerical yield benefit of 150 kg/ha with laterals installed underneath each crop row compared with alternate row middles. However, the gross revenue returned from the area where the tubing was placed under each row may not offset the cost of the extra tubing compared with the alternate row middles. It would take over 5 years of constant yield increase to pay for the extra tubing. Therefore, it is recommended that on this soil series and environmental conditions, laterals may be spaced in alternate row middles for highest economic yield and possible economic return.

There was no clear evidence supporting either corn or cotton prior to peanut in an alternate year rotation. Peanut yield did increase as time between peanut crops increased. There was a 27, 43, and 56% increase in peanut yield with 1, 2, and 3 year between peanut crops compared with continuous peanut crops, respectively. It is recommended to have the longest time frame between peanut crops as possible for highest peanut yield with major emphasis on holistic farm planning for maximum economic returns.

Kernel size distribution was most effected by crop rotation and not by irrigation rate or lateral spacing. Typically, as percentages of jumbos decreased, percentages of mediums and ones increased. Also, as both jumbos and mediums decreased then percentages of ones increased. There was no clear evidence of any one crop rotation negatively affecting kernel distribution compared to another except for continues peanut treatment where jumbo- and medium- sized kernels tended to decrease and number one sized kernels tended to increase. This implies that shorter time periods between peanut crops in a rotation would negatively affect kernel size but not necessarily the peanut grade or TSMK.

Literature Cited

Bosch, D.J., N.L. Powell, and F.S. Wright. 1998. Investment returns from three sub-surface micro-irrigation tubing spacing. J. Prod. Agric. 11:371-376.

Branch, W.D. 1996. Registration of 'Georgia Green' peanut. Crop Sci. 36:806.

Brown, S., J. Todd, A. Culbreath, J. Baldwin, J. Beasley, B. Kemerait, E. Prostko, and N. Smith. 2004. Minimizing spotted wilt of peanut. Extension-Bulletin 1165. Ga. Agric. Exp. Stn. Athens, GA.

Bucks, D.A. and S. Davis. 1986. Trickle irrigation for crop production, Chapter1, eds. F.S. Nakauyama and D. A. Bucks. Netherlands: Elesevier Publications.

Bucks, D.A., S.G. Allen, R.L. Roth, and B.R. Gardner. 1988. Short staple cotton under micro and level-basin irrigation methods. Irrig. Sci. 9:161-176.

Camp, C.R., E.J. Sadler, and W.J. Busscher. 1989. Subsurface and alternate-middle microirrigation for the southeastern coastal plain. Trans. ASAE 31(2):451-456.

Camp, C.R., W.M. Thomas, and C.C. Green. 1993. Microirrigation scheduling and tube placement for cotton in the southeastern coastal plain. Trans. ASAE 36(4):1073-1078.

Camp, C.R., P.J. Bauer, and P.G. Hunt. 1997. Subsurface drip irrigation lateral spacing and management for cotton in the southeast coastal plain. Trans. ASAE 40(4):993-999.

Dougherty, M., A.H. AbdelGadir, J.P. Fulton, E. van Santen, L.M. Curtis, C.H. Burmester, H.D. Harkins, and B.E. Norris. 2009. Subsurface drip irrigation and fertigation for north Alabama cotton production. J. Cotton Sci. 13:227-237.

Enciso, J.M., P.D. Colaizzi, and W.I. Multer. 2005. Economic analysis of subsurface drip irrigation lateral spacing and installation depth for cotton. Trans. ASAE 48(1):197-204.

French, O.F., D.A. Bucks, R.L. Roth, and B.R. Gardner. 1985. Micro and level-basin irrigation management for cotton production. pp. 555-561. *In* Anon (ed.). Drip/trickle irrigation in action. Proc. 3rd Int. Drip/Trickle Irrigation Congress, Fresno, CA. 18–21 Nov. 1985. ASAE, St. Joseph, MI.

Georgia Dept. of Agric. 2009. Georgia Agricultural Facts: 2009 Edition. USDA, NASS, Georgia Field Office, Stephens Federal Building, Suite 320, 355 East Hancock Avenue, Athens, Georgia 30601, www.nass.usda.gov/Statistics_by_State/Georgia/ Publications/ Annual_Statistical_Bulletin/index.asp. Accessed 7 November 2012.

Harrison, K.A. and A.W. Tyson. 1993. Irrigation scheduling methods. Coop. Ext. Bull. B-974. 12 pp. Cooperative Extension Service, The Univ. of GA College of Agric. and Environ. Sci., Athens, GA.

Henggeler, J.C. 1988. Drip irrigation: Lowering installation costs, increasing yields and improving water-use efficiency. pp. 31-32. *In* J.M. Brown and D. Richter (eds.). Proc. 1988 Highlights of cotton production Res. Conf., Special Sessions: New Developments from Industry. 3–8 Jan. 1988, New Orleans. Natl. Cotton Council of America., Memphis, TN.

Henning, R.J., A.H. Allison, and L.D. Tripp. 1982. Cultural practices. pp. 123-138. *In* H.E. Pattee and C.T. Young (eds.). Peanut Science and Technology, Am. Peanut Res and Ed Soc, Yoakum, TX.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. J. Irrig Drain. Div. ASCE 889:15-41.

Lambert, J.R., I. Israel, I. Meirson. 1988. Computer program for scheduling irrigation by water budget. pp. 7-22. *In* C.R. Camp, and R.B. Campbell (Coordinators). Scheduling irrigation for corn in the southeast. USDA, ARS-65.

Lamm, F.R., L.R. Stone, A.H. Khan, and D.H. Rogers. 1992. Optimum lateral spacing for drip–irrigated corn. ASAE Paper No. 92–2575. St. Joseph, Mich.: ASAE.

Mitchell, W.H. 1981. Subsurface irrigation and fertilization of field corn. Agron. Journ. 73(6):913-916.

Mitchell, W.H. and D.L. Sparks. 1982. Influence of subsurface irrigation and organic additions on top and root growth of field corn. Agron Journ. 74(6):1084-1088.

Nuti, R.C., S.N. Casteel, R.P. Viator, J.E. Lanier, K.L. Edmisten, D.L. Jordan, G.L. Grabow, J.S. Barnes, J.W. Mathews, and R. Wells. 2006. Management of cotton grown under overhead sprinkle and sub-surface drip irrigation. J. Cotton Sci. 10:76-88.

O'Brien, D.M., D.H. Rogers, and F.R. Lamm. 1998. An economic comparison of subsurface drip and center pivot sprinkler irrigation systems. Appl. Eng. Agric. 14(4):391-398.

Phene, C.J., K.R. Davis, R.B. Hutmacher, and R.L. McCormick. 1987. Advantages of subsurface irrigation for processing tomatoes. Acata Hortic 200:101-113.

Powell, N.L. and F.S. Wright. 1993. Grain yield of subsurface microirrigated corn as affected by irrigation line spacing. Agron. Journ. 85(6):1164-1170.

Prostko, E. (ed.) 2004. Peanut Update-2004. Extension publication No. CSS-04-0109. Ga. Agric. Exp. Stn. Athens, GA.

Sorensen, R.B., F.S. Wright, and C.L. Butts. 2001. Subsurface drip irrigation system design for research in row crop rotations. Appl. Eng. In Agric. 17(2):171-176.

Sorensen, R.B. and M.C. Lamb. 2008. Corn and cotton yield with two surface drip lateral spacings. Online. Crop Management doi:10.1094/CM-2008-0118-01-RS.

Stansell, J.R., J.L. Shepherd, J.E. Pallas, R.R. Bruce, N.A. Minton, D.K. Bell, and L.W. Morgan. 1976. Peanut responses to water variables in the southeast. Peanut Sci. 3(1):44-48.

Statistix9. 2008. Statistix9: User's Manual. Analytical Software, Tallahassee, FL 32317.

Tollefson, S. 1985. The Arizona System: Drip irrigation design for cotton. In Drip/Micro Irrigation in Action, 3rd Int. Drip/Micro Irrigation Congress, 401–405. St. Joseph, Mich.: ASAE.

USDA. 1998. Farmers' Stock Peanuts Inspection Instructions. Washington, D.C.: U.S. Department of Agriculture, Agric. Marketing Serv., Fruit and Vegetable Div.

USDA- National Agricultural Statistics Service. 2009. 2007-CENSUS OF AGRICULTURE. United States Summary and State Data, Volume 1. Geographic Area Series Part 51.

Williams, E.J. and J.S. Drexler. 1981. A non-destructive method for determining peanut pod maturity. Peanut Sci. 8:134-141.