Pod Yield and Mineral Concentration of Four Peanut Cultivars Following Gypsum Application with Subsurface Drip Irrigation

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ABSTRACT

A 2-year study (2004 and 2005) was conducted where gypsum was applied to four peanut (*Arachis hypogaea* L.) cultivars and irrigated with subsurface drip to determine pod yield and mineral concentration of peanut plants and kernels. Gypsum rates were none, 560 and 1120 kg/ha. Peanut cultivars were C99R, Georgia Green (GG), NCV-11 (NCV), and GA-O2C (O2C). Irrigation was applied daily with subsurface drip irrigation except when precipitation exceeded the estimated daily water requirement. Average soil Ca and S concentrations increased as gypsum was applied, 5% and 20%, respectively, compared with the non-treated control. The average soil calcium to potassium (Ca:K) ratio increased to 9.8:1 compared with 7.6:1 prior to applying calcium. When averaged across calcium rates, peanut leaves had 3 and 14 times higher calcium and 1.4 times higher S concentrations compared with pegs and pods, respectively. The cultivars GG and NCV had the same pod yield. Cultivars C99R and O2C had the same yield as NCV but were less than GG. Germination rates were higher when gypsum was added compared to the non-treated control and with cultivars C99R and O2C. There was no difference in vigor by gypsum application rate. Kernel Ca concentration was higher with the addition of gypsum compared to the non-treated control. Cold test germination seed vigor increased with C99R and O2C compared with GG and NCV.

Key Words: *Arachis hypogaea*, gypsum, farmer stock grade, germination, pod yield, seed vigor.

Calcium is a highly required mineral for increased peanut yield and grade (Cox *et al*, 1982). Lower concentrations of calcium in the peanut pegging zone can result in low pod yield, grade, and germination. There is little or no transport of calcium from the roots to the leaves and back to the pod via the phloem through the peg, thus calcium uptake must be through the developing pod (Wiersum, 1951; Sumner *et al.*, 1988). This implies that two conditions must occur for calcium uptake to the plant or to the pod; 1) there must be enough soil moisture in the pod zone for water uptake by roots and pods, and 2) calcium must be present in sufficient concentrations to dissolve into the soil water for uptake into the roots and pods. If one or both of these conditions does not occur, then yield and grade may be reduced. Additions of calcium sulfate (gypsum) and irrigation by overhead sprinkler systems assure that neither water nor calcium is deficient. Various researchers have shown the importance of calcium rate and timing with relationship to yield of both runner and Virginia type peanut (Adams and Hartzog, 1991; Adams *et al.*, 1993; Jordan *et al.*, 2000; Wiatrak *et al.*, 2006; Grichar *et al.*, 2004). Most research was accomplished using overhead irrigation or non-irrigated conditions. Currently, there is no research information available describing pod yield and calcium fertilization when irrigated with subsurface drip irrigation (SDI).

Irrigation systems using SDI have the capability of frequently supplying water to the root zone while reducing the risk of cyclic water stress that is typical of other irrigation systems or nonirrigated production (Phene *et al.*, 1987). Subsurface drip systems are adaptable to variations of field shape making them an important consideration in the Southeast. In recent years, drip irrigation has been expanded with good success on field crops such as corn (*Zea mays* L.) (Lamm *et al.*, 1997, 2001; Mitchell, 1981; Mitchell and Sparks, 1982; Powell and Wright, 1993), cotton (*Gossypium hirsutum* L.) (Camp *et al.* 1997; Sorensen *et al.*, 2004), and peanut (Jordan *et al.*, 2002; Sorensen *et al.*, 2001a, b; Zhu *et al.*, 2004). Irrigation SDI laterals have been installed at 0.2 and 0.3 m soil depths (Bucks *et al.*, 1981; Camp *et al.*, 1989; Phene *et al.*, 1987; Tollefson, 1985) on cotton, corn, fruits, and vegetables. Drip laterals have been spaced at 1, 2 and 3 m apart with various crops with yields decreasing as lateral spacing increases greater than 2 m (Camp *et al.*, 1997; French *et al.*, 1985; Lamm *et al.*, 1992; Powell and Wright, 1993). Bosch *et al.* (1998) showed that 1.83 m lateral spacing in corn-

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peanut rotations had the highest returns on sandy soils in Virginia-North Carolina region.

SDI systems may be efficient in supplying water and nutrients to the root zone, but may not be efficient in supplying water to the peanut peg zone where water is needed to move calcium into the developing fruit. The objective of this research was to determine the efficacy of current calcium recommendations when using SDI systems by documenting yield response and mineral concentration of peanut plants to three calcium application rates when irrigated with SDI.

Materials and Methods

A SDI system was installed in the spring of 2000 near Sasser, GA on Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 2 to 5% slope. The SDI system had drip laterals buried at 0.3 m deep and spaced at 0.91 m with emitters spaced at 0.3 m. Water flow rate was 5.6 L/min per 100 m or 1.0 L/hr per emitter. Peanut was planted following cotton in adjacent sites during the 2004 and 2005 growing seasons.

The experiment was a factorial design with three calcium (gypsum) rates and four peanut cultivars replicated four times. Calcium rates were none, 560 and 1120 kg/ha. Peanut cultivars selected were C99R, Georgia Green (GG), NCV-11 (NCV), and GA-O2C (O2C). Individual plots were 1.83 m wide by 12 m long for a total of 48 plots.

Land preparation was the same both years with disk harrowing two times followed by an experimental bedder (USDA-ARS-National Peanut Research Laboratory, Dawson, GA) used to make 1.83 m beds. Peanut was planted in a twin-row orientation using a commercial vacuum type planter (Monosem planter, ATI Inc, Lenexa, KS). Twin-row orientation was planted at 1.17 m outside rows by 0.7 m inside rows with 0.22 m between the twin-rows with four rows on a bed. Seeds were planted at rates recommended for reducing the risk of Tomato Spotted Wilt Virus (Brown *et al.*, 2004). Pest management practices, i.e., disease, insect, and weed control, followed University of Georgia Agricultural Extension Service recommendations for peanut production (Prostko, 2004). Decisions to apply pest management practices were determined by field scouting. Irrigation water was applied daily based on replacement of crop water use for peanut described by Stansell *et al.* (1976) except when precipitation amounts exceeded estimated water use.

A composite soil sample (0 to 30 cm) was taken in early spring for fertility recommendations. Initial pH for 2004 and 2005 was 6.3 and 6.2, respectively. The initial Ca concentration was 405 (2004) and 397 mg/kg (2005). Gypsum was applied by hand over individual rows at first flower or 40 days after planting (DAP), whichever came first. Soil and plant samples were taken 80 DAP and analyzed for mineral nutrition (Waters Agricultural Laboratories, Inc. Camilla, GA). A composite of 6 subsamples in each plot were taken at the 0 to 5 cm soil depth. Three plants were randomly selected in each plot for chemical analysis. Plants were partitioned into leaves, pegs, and pods. At the 80 DAP sampling period, the pods were immature such that peanut kernels were not separated from the hulls before analysis.

Cultivars were dug individually at maturity determined by the hull scrape method (Williams and Drexler, 1981). Yield rows were dug with a 2-row inverter and combined with a stationary plot combine (Kingaroy Engineering Works, Ltd., Kingaroy, Australia). Pod yield was determined after being mechanically dried, weighed, and adjusted to 7% moisture (wet basis). Since Virginia type peanuts require different screen openings compared with runner type peanuts for market grade, farmer stock grade and kernel size distribution for all peanut cultivars were determined using screens specified in USDA grading procedures (USDA, 1993) for a runner type peanut. It is understood that Virginia type peanut will not have a valid market grade with this procedure while runner type peanuts will have a valid market grade. Mineral analysis was performed on kernels that rode an 8.3×19 mm slotted screen. Germination, vigor (cold test germination), and calcium concentrations were determined from a 250 g kernel subsample (riding a 6.4×19 mm slotted screen) by the Georgia Department of Agriculture (Tifton, GA).

Plant, kernel, and soil analysis along with pod yield and farmer stock grade were analyzed using a general analysis of variance procedure (Statistix8, 2003). Tukey's HSD least significant difference range test was used to show differences among means ($P \leq 0.05$) when *ANOVA F*-test showed significance.

Results and Discussion

Precipitation during the peanut growing season was less in 2004 (494 mm) compared with 2005 (695 mm) (Fig. 1). Cumulative irrigation amount shows less water applied through the drip system in 2005 (136 mm) compared with that applied in 2004 (181 mm). The disparity between irrigation totals

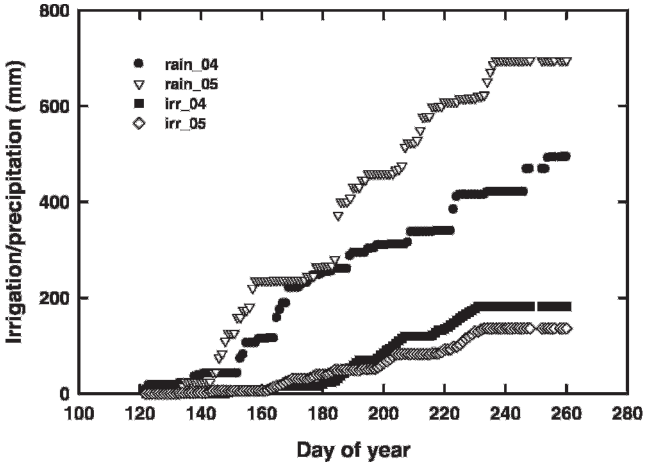

Fig. 1. Irrigation and precipitation applied/received during the 2004 and 2005 growing season.

for 2004 and 2005 was not as great as the difference between precipitation amounts for those same years. Cumulative precipitation patterns in 2005 shows about a 30 day period with little precipitation followed by a large precipitation event (day 152 to 182). This pattern of drought followed by precipitation events occurred both years and is typical of the southeast. In 2005, one large storm pattern accumulated over 180 mm in a ten day period (day 184 to 194) which was more than 25% of the total precipitation for the growing season.

Soil analysis. There was a year, Ca level, and year by Ca level interaction depending on chemical element (Table 1). Both years, before gypsum was applied there were differences across the various plots with K, Mg, and S. A change in year was also a change in location of the plots. Both plots (2004 and 2005) had the same soil series and were

Table 1. Analysis of variance probability values for soil P, Mg, Ca, S, and Fe before and 40 days after application of 560 and 1120 kg/ha of gypsum for 2004 and 2005.[a]

		Soil mineral				
Treatment	df	K	Mg	Ca	S	Fe
				Before Application		
				P-values from ANOVA		
Year (Y)	1	**0.001**	**0.007**	0.379	**0.000**	0.584
Gypsum (Ca)	2	0.053	0.057	**0.040**	0.461	0.313
YxCa	2	0.097	0.096	0.067	0.962	0.561
				After Application		
Year (Y)	1	**0.008**	**0.000**	0.104	**0.000**	0.430
Gypsum (Ca)	2	0.111	**0.002**	**0.001**	0.836	0.454
YxCa	2	0.145	**0.005**	**0.019**	0.773	0.682

[a]Significant values are in bold case, $P<0.05$.

Table 2. Analysis of variance probability values for P, Mg, Ca, S, and Fe at 80 days after application of 560 and 1120 kg/ha of gypsum for four peanut cultivars and three plant parts.[a]

		Plant mineral				
Treatment	df	K	Mg	Ca	S	Fe
				P-values from ANOVA		
Year (Y)	1	**0.001**	0.799	0.085	**0.000**	**0.039**
Plant part (Pp)	2	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Gypsum (Ca)	2	**0.038**	0.230	0.406	0.274	0.888
Cultivar (C)	3	**0.000**	0.109	0.111	**0.004**	0.906
Y*Pp	2	**0.010**	0.127	0.667	0.138	0.061
Y*Ca	2	**0.000**	**0.010**	**0.010**	**0.023**	0.678
Y*C	3	**0.000**	**0.030**	0.052	0.361	0.332
Pp*Ca	4	0.328	0.927	0.833	0.830	0.396
Pp*C	6	0.196	0.144	0.366	**0.038**	0.920
Ca*C	6	**0.000**	**0.029**	**0.012**	0.073	0.538
Y*Pp*Ca	4	0.061	**0.039**	0.214	0.063	0.364
Pp*Ca*C	12	**0.033**	**0.042**	0.243	0.154	0.834

[a]Significant values are in bold case.

Table 3. Mineral analyses of leaves, pegs, and pods for K, Mg, Ca, S, and Fe at 80 days after application of 560 and 1120 kg/ha of gypsum averaged across four peanut cultivars.[a]

	Plant part		
Gypsum rate	Leaf	Peg	Pod
kg/ha	%		
		K	
0	1.9c	2.5abc	1.1d
560	2.2bc	2.8a	1.3d
1120	2.2bc	2.7ab	1.3d
		Mg	
0	0.74c	0.25cd	0.22d
560	0.56ab	0.27bcd	0.22d
1120	0.54abc	0.26bcd	0.22d
		Ca	
0	1.7a	0.63b	0.13c
560	1.9a	0.54b	0.12c
1120	1.9a	0.53b	0.13c
		S	
0	0.26a	0.18b	0.18b
560	0.27a	0.21b	0.18b
1120	0.26a	0.20b	0.18b
		Fe	
	mg/kg		
0	148b	992a	187b
560	162b	846a	205b
1120	160b	936a	200b

[a]Means followed with the same letter within each element are not different at the $P \leq 0.05$.

adjacent to each other. Differences in fertility by year can be attributed to change in location as well as mineral nutrition history from previous years when managing each site independently for maximum yield for the previous crops. There was no difference in the year by calcium level interaction before gypsum was applied, but there were differences in calcium concentration after application. It was expected that the calcium rate should show differences due to the amount of gypsum applied at the various rates. As expected, both Ca and S increased as gypsum was applied, 5% and 20%, respectively (data not shown). With a change of site (year) there were differences in K, Mg, and S concentration both before and after gypsum application while soil Ca did not change with year (data not shown). The Ca:K ratio should be 3:1 for best yield and reduce the risk of interference of Ca uptake by K (Hallock and Garren, 1968). Soil Ca:K ratio before gypsum addition was 7.6:1 and after application was 9.8:1. The lowest ratio was 5.5:1 in 2004 when gypsum was applied during the growing season (data not shown).

Plant Analysis. Mineral analyses of peanut plants show that year, plant partitions (leaves, pegs, and kernels), cultivar, and associated interactions have differing mineral concentrations (Table 2) depending on specific mineral and treatment. Ca concentration was different for specific plant parts but not by year, calcium level or cultivar (Table 2). Sulfur on the other hand was not different for calcium level but was different for year, plant part, and cultivar. It was expected that peanut would have different mineral analysis by year, plant part, and cultivar due to different growing conditions, site location, and soil amendments applied.

Calcium concentrations were 3 and 14 times higher in leaves compared with pegs and pods, respectively (Table 3). These data coincide with results from Grichar *et al.*, (2004) that showed Ca concentrations were higher in leaves compared with pods (hulls or kernels). Sulfur concentrations were 1.4 times higher in leaves compared to pegs and pods. Both pegs and pods had the same S concentration. Potassium and Mg had mixed concentrations between all three plant parts with pods tending to have lower concentrations compared with leaves or pegs. Iron concentrations were excessively high in the peg compared with those in leaves or pods (Table 3) and irrespective of gypsum level.

Table 4. Analysis of variance probability values determined for yield, TSMK, LSK, kernel calcium, germination, and vigor by treatment of year, calcium level (gypsum), and cultivar.[a]

	Yield and quality parameters						
Treatment	df	Yield	TSMK	LSK	Ca	Germ	Vigor
	P-values from ANOVA						
Year (Y)	1	0.981	**0.000**	**0.002**	**0.005**	0.317	0.889
Gypsum (Ca)	2	0.526	0.961	0.873	**0.000**	**0.002**	**0.040**
Cultivar (C)	3	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Y*Ca	2	0.344	0.776	0.710	0.342	**0.003**	**0.027**
Y*C	3	**0.000**	**0.003**	**0.003**	0.117	**0.000**	**0.000**
Ca*C	6	0.372	0.843	0.279	0.136	0.199	0.070
Y*Ca*C	6	0.183	0.977	0.936	**0.011**	**0.001**	**0.013**

[a]TSMK = total sound mature kernels; LSK = loose shelled kernels. Significant values are in bold case.

Table 5. Pod yield, TSMK, LSK, germination, vigor, and kernel calcium by treatment of year, gypsum applied, and cultivar.[a,b]

Treatment	Yield and quality parameters					
	Yield	TSMK	LSK	Germ	Vigor	Ca
	(kg/ha)	%				mg/kg
			Year			
2004	3120a	62b	1.7a	84a	84a	513b
2005	3117a	70a	1.2b	83a	84a	540a
			Gypsum			
0 (kg/ha)	3177a	66a	1.5a	79b	82a	497b
560	3047a	66a	1.4a	86a	87a	537a
1120	3130a	66a	1.4a	86a	84a	542a
			Cultivar			
C99R	2943b	69ab	2.6a	89a	90a	501c
GG	3440a	64bc	1.1bc	80b	76b	539b
O2C	2909b	71a	1.4b	87a	89a	601a
NCV	3180ab	60c	0.7c	79b	81b	457d

[a]TSMK = whole kernels riding 6.4×19 mm slotted screen plus sound splits; LSK = loose shelled kernels.
[b]TSMK for NCV should not be interpreted as the official farmer stock grade.

Peanut yield and quality. There was no pod yield by year or calcium level difference (Table 4). The grade parameters of Total Sound Mature Kernels (TSMK) and Loose Shelled Kernels (LSK) showed differences by year and cultivar but not with calcium rate. Kernel calcium concentration was different by year, calcium level, and cultivar. Both germination and vigor percentage were different for calcium level and cultivar but not by year (Table 4).

The cultivars GG and NCV had the same pod yield (Table 5). Cultivars C99R and O2C had the same yield as NCV but were less than GG. Previous research shows that pod yield is not necessarily increased as levels of calcium increase (Adams and Hartzog, 1991; Adams *et al.*, 1993; Jordan *et al.*, 2000; Wiatrak *et al.*, 2006). It would seem that the addition of calcium may not always affect yield but may influence disease reduction (Grichar *et al.*, 2004), pod development, and germination (Cox *et al.*, 1976).

The cultivar O2C had the highest TSMK (71%) followed by C99R and GG (64 and 69%, respectively) while NCV had the lowest TSMK (60%). These data are different than those presented by Main *et al.* (2002) and Wiatrak *et al.* (2006) which showed that GG had higher TSMK than C99R.

Calcium concentration in the peanut kernel was higher when gypsum was applied compared with no gypsum (Table 5). The addition of gypsum had no effect on yield, TSMK, LSK, or peanut vigor while the addition of gypsum did influence germination. The cultivar, O2C had the highest calcium concentration in the kernels followed by GG, C99R, and finally, NCV. Germination and vigor were highest in O2C and C99R (88%) followed by GG and NCV (80%) (Table 5).

Conclusions

Pod yield for peanut cultivars in this research are comparable with those reported by Wiatrak *et al.* (2006) and Jordan *et al.* (2000). Kernel calcium levels were higher than calcium levels described by Grichar *et al.* (2004). Germination and vigor percentages were within acceptable limits. Fields that are irrigated with SDI have similar pod yield, farmer stock grade, and quality as reported fields with overhead irrigation; however, there was no yield response to increasing Ca rates in this study. Based on this study, there is no evidence indicating a change in calcium recommendations for subsurface drip irrigation on peanut is needed.

Literature Cited

Adams, J.F. and D.L. Hartzog. 1991. Seed quality of runner peanuts as affected by gypsum and soil calcium. J. Plant. Nutr. 14:841-851.

Adams, J.F., D.L. Hartzog, and D.B. Nelson. 1993. Supplemental calcium on yield, grade, and seed quality of runner peanut. Agron. J. 85:86-93.

Bosch, D.J., N.L. Powell, and F.S. Wright. 1998. Investment returns from three sub-surface microirrigation tubing spacings. J. Prod. Agric. 11(3):371-376.

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

Bucks, D.A., L.J. Erie, O.F. French, F.S. Nakayama, and W.D. Pew. 1981. Subsurface microirrigation management with multiple cropping. Trans. ASAE 24(6):1482-1489.

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

Cox, F.R., G.A. Sullivan, and C.K. Martin. 1976. Effect of calcium and irrigation treatments on peanut yield, grade, and seed quality. Peanut Sci. 3:81-85.

Cox, F.R., F. Adams, and B.B. Tucker. 1982. Liming, fertilization, and mineral nutrition. pp. 139-163. *In* H.E. Pattee and C.T. Young (eds.). Peanut Science and Technology. APRES, Inc, Yoakum, TX.

French, O.F., D.A. Bucks, R.L. Roth, and B.R. Gardner. 1985. Micro and level-basin irrigation management for cotton production. *In* Drip/Micro irrigation in action, 3rd Int. Drip/Micro Irrigation Congress, 555–561. St. Joseph, Mich.: ASAE.

Grichar, W.J., B.A. Besler, and H.A. Melouk. 2004. Peanut (*Arachis hypogaea*) response to agricultural and power plant by product calcium. Peanut Sci. 31(2):95-101.

Hallock, D.L. and K.H. Garren. 1968. Pod breakdown, yield, and grade of viginia type peanuts as affected by Ca, Mg, and K sulfates. Agron. J. 60:253-257.

Jordan, D.L., C.W. Swann, J.F. Spears, R.L. Brandenburg, J.E. Bailey, and M.R. Tucker. 2000. Comparison of Virginia and runner market-type peanut (*Arachis hypogaea*) grown in the Virginia-Carolina production area. Peanut Sci. 27:71-77.

Jordan, D.L., J.E. Bailey, J.S. Barnes, C.R. Bogle, S.G. Bullen, A.B. Brown, K.L. Edmisten, E.J. Dunphy, and P.D. Johnson. 2002. Yield and economic return of ten peanut-based cropping systems. Agron. J. 94(6):1289-1294.

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. ASAE, St. Joseph, MI.

Lamm, F.R., L.R. Stone, H.L. Manges, and D.M. O'Brien. 1997. Optimum lateral spacing for subsurface drip-irrigated corn. Trans. ASAE 40(4):1021-1027.

Lamm, F.R., T.P. Trooien, H.L. Manges, and H.D. Sunderman. 2001. Nitrogen fertilization for subsurface drip-irrigated corn. Trans. ASAE 44(3):533-542.

Main, C.L., J.T. Ducar, and G.E. McDonald. 2002. Response of three runner-market type peanut cultivars to diclosulam. Weed Tech. 16:593-569.

Mitchell, W.H. 1981. Subsurface irrigation and fertilization of field corn. Agron. J. 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. J. 74(6):1084-1088.

Phene, C.J., K.R. Davis, R.B. Hutmacher, and R.L. McCormick. 1987. Advantages of subsurface irrigation for processing tomatoes. Acta Hortica 200:101-114.

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

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. 2001a. Pod yield and kernel size distribution of peanut produced using subsurface drip irrigation. Appl. Eng. in Agric. 17(2):165-169.

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

Sorensen, R.B., M.J. Bader, and E.H. Wilson. 2004. Cotton yield and grade response to nitrogen applied daily through a subsurface drip irrigation system. Appl. Eng. in Agric. 20(1):13-16.

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

Statistix8. 2003, Statistix8 User's Manual. Analytical Software, Tallahassee, FL 32317 (www.statistix.com).

Sumner, M.E., C.S. Kvien, H. Smal, and A.S. Csinos. 1988. On the calcium nutrition of peanut (*Arachis hypogaea* L.). I. Operational model. J. Fert. 5:97-102.

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, MI: ASAE.

United States Department of Agriculture (USDA). 1993. Milled Peanuts: Inspection Instructions. U. S. Department of Agriculture, Agricultural Marketing Service, Fruit and Vegetable Division, Washington, D. C.

Wiatrak, P.J., D.L. Wright, J.J. Marois, and D. Wilson. 2006. Influence of gypsum application on peanut yield and quality. Online. Crop Management doi:10.1094/CM-2006-0223-01-RS.

Wiersum, L.K. 1951. Water transport in the xylem as related to calcium uptake by groundnuts (*Arachis hypogaea*). Plant Soil 3:160-169.

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

Zhu, H., M.C. Lamb, C.L. Butts, and P.D. Blankenship. 2004. Improving peanut yield and grade with surface drip irrigation in undulating fields. Trans. ASAE 47(1):99-106.