J. Agronomy & Crop Science **192**, 168—177 (2006)
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ISSN 0931-2250

Crop/ Forage/ Soil Management/ Grassland Utilisation

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Influence of Soil Temperature on Seedling Emergence and Early Growth of Peanut Cultivars in Field Conditions

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With 4 figures and 4 tables

Received January 10, 2005; accepted August 29, 2005

Abstract

Peanut or groundnut (*Arachis hypogaea* L.) sown in early spring often has poor seed germination and seedling development. The influence of soil temperature on seedling emergence and early growth of six peanut cultivars (Florida MDR98, Southern Runner, Georgia Green, SunOleic 97R, Florunner and C-99R) was studied in natural field soil profiles in temperature-gradient greenhouses. We evaluated the influence of a range of soil temperatures by sowing at eight dates between January 2001 and May 2002 in Gainesville, Florida. On each sowing date, two additional temperature treatments (ambient and ambient +4.5 °C air temperature) were evaluated by sowing on either end of each greenhouse and applying differential heating. In total, 16 different soil temperature treatments were evaluated. Each treatment was replicated four times in four different greenhouses. Mean soil temperature from sowing to final emergence in different treatments ranged from 15 to 32 °C. Sowing date, temperature treatment and cultivar had significant effect on seedling emergence and development (V_2 stage). For all cultivars, the lowest germination was observed at the earliest sowing date (coolest soil temperature). Among cultivars, Florida MDR98 was the most sensitive to reduced (cool) temperature with the lowest germination and smallest seedling size at 21 days after sowing, followed by Southern Runner. Georgia Green was the most cold-tolerant with the highest germination, followed by SunOleic 97R. There were no significant differences among cultivars for base temperature, which averaged 11.7 and 9.8 °C for rate of emergence and rate of development to V_2 stage respectively. These results imply that cultivar choice and/or genetic improvement of peanut for cold tolerance during emergence and seedling development in regions where cooler soil temperatures persist and/or regions where early sowing is desirable.

Key words: cultivars — early vegetative growth — seedling emergence — soil temperature

Introduction

Seedling emergence and early seedling vigour are important characteristics for obtaining a good plant stand and subsequent high yields, particularly in regions where low soil temperatures prevail at the time of sowing. Under optimum soil and irrigation conditions, soil temperature is one of the major environmental factors that influence not only the proportion of seeds that germinate, but also the rate of emergence and subsequent establishment. In addition, factors such as seed dormancy, production and harvest conditions, and subsequent storage of seed are known to influence seedling emergence and vigour (Ketring 1979; Roberts 1988). Seedling emergence may also be influenced by cultivar and genetic differences in relationship to temperature (Wynne and Sullivan 1978, Mohamed et al. 1988a).

The rate of germination or seedling emergence can be calculated as the reciprocal of time to complete germination or emergence; this commonly has a linear response to temperature (Roberts 1988), as do other developmental events such as flowering (Roberts and Summerfield 1987). At suboptimal constant temperatures, there is a positive linear relationship between seed germination rate from the base temperature (T_b), at which the rate is zero, to the optimal temperature (T_o) at which seeds germinate most rapidly. At superoptimal temperatures there is a negative linear relation between the optimal temperature and the ceiling temperature (T_c), when the germination rate is again zero (Roberts 1988). Similarly, at constant soil moisture conditions, per cent seed germination increases with increasing temperature above T_b, reaching maximum at T_o and decreasing at superoptimal temperatures. The rate of development towards emergence and flowering of 16 peanut cultivars was reported to be positively associated with air temperature (Bell et al. 1991). Mohamed et al. (1988a) studied the effects of temperature on the rate of seed germination of 15 peanut cultivars in incubators and reported that T_b ranges from 8 to 11 °C, T_o from 29 to 36.5 °C, and T_c from 41 to 47 °C (Mohamed et al. 1988a). Similarly, T_b for the peanut cultivar Chibahandachi for start of emergence, 50 % emergence and complete emergence were 10.5, 9.9 and 10.7 °C, respectively, under field conditions (Awal and Ikeda 2002). Angus et al. (1981) reported a higher T_b of 13.3 °C for seedling emergence of peanut. These different ranges in cardinal temperatures may be attributed to cultivar differences. The base temperature for other developmental events such as leaf appearance, branching, flowering, pegging, and podding was identified as 10 °C (Leong and Ong 1983).

Peanut crops in several regions of the southwestern United States (e.g. early spring crop sown in Florida, Georgia, Virginia, North Carolina and West Texas), and in moist/humid subtropical regions of Asia (e.g. in northern India, Pakistan and Indonesia) suffer from poor seedling emergence. Reduced soil temperature during the seedling emergence and establishment phase may be responsible for poor emergence. In addition, reduced soil temperatures also restrict its production in regions where reduced temperatures exist. The influence of soil temperature on seedling emergence under natural soil profiles is not well understood. Although some studies have investigated the effects of temperature on seed germination in artificial conditions using standard germination tests on paper towels or Petri dishes, these tests often do not correlate well with soil conditions in the field. Furthermore, little is known about the extent of variability in seedling emergence and seedling vigour of peanut cultivars in response to soil temperature in general, and in particular, reduced soil temperatures at the time of seed germination and seedling establishment. Response of cultivars to temperatures will improve the understanding of effects of reduced temperature and possible scope for genetic improvement for tolerance. Thus, the objectives of our study were: (i) to investigate the effects of soil temperature on seedling emergence, seedling vigour and plant establishment of peanut under field conditions in natural soil profiles; and (ii) to determine if there were cultivar differences in response to soil temperatures.

Materials and Methods

This experiment was conducted in four large temperature-gradient greenhouses on natural field (soil was millhopper fine sand, a loamy, siliceous, hyperthermic grossarenic paleudult) for 2 years from January 2001 to May 2002. Each temperature-gradient greenhouse covers a total soil surface area 4.3 m wide and 27.4 m long with a semicircular arch framework covered with polyethylene telephtalate film (Sixlight; Taiyo Kogyo Co., Tokyo, Japan) (Sinclair et al. 1995). A white porous polypropylene screen was mounted on the inlet end of each greenhouse and the outlet end was closed with plywood surrounding five built-in fans used to control linear, one-directional air movement through the greenhouse. Each greenhouse was divided into four plots along the 27-m length providing four temperature zones (+0, +1.5, +3.0 and +4.5) across length. In our experiment, we used only two cells (ambient and ambient + 4.5 °C). In each cell, air temperature was measured at 10-s intervals using aspirated copper constantan thermocouples at 50 cm above the soil surface and means were stored at hourly intervals. Similarly, soil temperature at sowing depth (4.5 cm) was measured at hourly intervals using HOBO StowAway temperature loggers (Onset Computer Corporation, Bourne, MA, USA). Details of the temperature-gradient greenhouse structure, design and quality of temperature control are described by Sinclair et al. (1995) and Fritischi et al. (1999).

Soil in the greenhouses was tilled using hand-operated rota-tiller, levelled and irrigated before sowing. All seed lots were treated with ethylene (257 μmol mol^{-1} of air) in a closed container at 23 °C to ensure that dormancy was broken. Seed of six peanut cultivars (Florida MDR98, Southern Runner, Georgia Green, SunOleic 97R, Florunner and C-99R) were randomly selected from each seed-lot and were treated with Vitavax (a.i. captan, N-trichlormethylthio-4-cyclohexene-1,2-dicarboximide; Gustafson, Plano, TX, USA). Details of these cultivars are published elsewhere (Gorbet and Shokes 2002a,b, Whitty et al. 2003). Seed were sown at a depth of 4.5 cm in two rows of 1.8 m length and 20 cm apart, with a plant-to-plant spacing of 9 cm (20 seed were sown per row, i.e. 40 seed per replicate treatment). Each cultivar was sown in two temperature regimes (ambient and ambient + 4.5 °C) on eight different sowing dates (29 January 2001, 22 February 2001, 23 March 2001, 1 May 2001, 26 December 2001, 5 February 2002, 21 March 2002 and 18 April 2002). For each sowing date, there were four replications provided by four temperature-gradient greenhouses. These eight sowing dates and two temperature treatments provided a total of 16 different soil temperatures, ranging from 15 to 32 °C from sowing to final emergence.

After sowing, the plots were irrigated on alternate days by using automatic micro-sprinkler to maintain adequate moisture for germination and growth. Plots were checked every 2 days to determine the number of seed emerging (cracking), number of seedlings emerged (emergence of any green part of the plant) and number of plants reaching the V_2 stage (Boote 1982; formation of first two fully expanded green tetrafoliolate leaves). Final emergence was estimated as the ratio of the number of seeds emerged to the number of seeds sown, and expressed as percentage. Time from sowing to emergence and the V_2 stage (50 % of plants emerged or reached V_2 stage, respectively) was calculated from observed data. The rate of seedling emergence was estimated as the inverse of the number of days from sowing to 50 % emergence. Similarly, rate of development to V_2 stage was estimated as the inverse of the number of days from sowing to V_2 stage. Thermal times to emergence and V_2 stage were calculated as degree-days (°Cd) above base temperature (T_b) of 11.6 °C and 9.8 °C, respectively, using hourly soil temperatures for emergence and V_2 stage. These two base temperatures were estimated from data on rate of emergence and rate of development to V_2 stage from the current experiment. Data on early growth was obtained by harvests at 21 days after sowing (DAS) all treatments and planting dates. At harvest, plants were separated into component parts (leaves, stems and roots) and the respective dry weights were recorded after oven-drying at 65 °C.

Parallel to the field experiments, a standard paper towel seed germination test was conducted to: (a) determine the per cent germination of each seed-lot; and (b) to determine if dormancy inhibited germination. Sub-samples of seeds from each cultivar were randomly obtained from original seed lots during both years and treated with fungicide (Vitavax; a.i. captan) to avoid seed-borne diseases. Half of the seed were treated with ethylene and half were not. Ethylene treatment was provided as indicated earlier, and control seed were stored in an incubator without ethylene at the same temperature (23 °C). There were four replications of 40 seed for each treatment. Seed were rolled in three wet seed germination paper towels and placed in incubators held at 27 °C. After 6 days, the numbers of germinated and non-germinated seed were counted. Paper towels were frequently checked to ensure sufficient moisture content. A seed was considered germinated if the radicle was > 10 mm long. Germination was expressed as the ratio of germinated seed to the total number of seed, and then expressed as percentage.

Data analyses for all the measured and calculated variables were conducted using ANOVA procedures in SAS (SAS Institute, Cary, NC, USA). The data from field experiments were analysed as split–split–plot design. Sowing dates (eight dates) were considered as the main plots, temperature treatments (ambient and ambient + 4.5 °C) as sub-plots and cultivars (six) as sub-sub-plots. There were four replications of each treatment provided by four greenhouses. Similarly, germination experiments in controlled environments were analysed using a split–plot design with four replications. Ethylene treatments (with and without ethylene) were considered as main plots and cultivars (six) as the sub-plots.

Results and Discussion

Significant ($P < 0.001$) effect of sowing dates was found for all the traits (Tables 1–3). The earliest sowing dates, when the coolest soil temperatures were present from sowing to final emergence, resulted in a significantly lower percentage of seedling emergence, when compared with later sowing dates, when soil temperatures were higher (Table 1). The time (duration) in days from sowing to 50 % emergence and to V_2 stage was the longest in the earliest sowing dates, when compared with later sowings. For example, time from sowing to 50 % emergence in the earliest sowing date (26 December, soil temperature, 16.4 °C) was 29 days, while on later sowing dates (21 March to 1 May) when soil temperature was above 26 °C, it was only 6–7 days (Table 1). Similarly, time from sowing to V_2 stage in the earliest sowing date (26 December) was 31.3 days, while on later sowing dates (21 March to 1 May) with soil temperatures above 26 °C, it was 8–9 days (Table 2). The rate of emergence and to V_2 stage, as calculated by the reciprocal of time, was slowest at earlier sowing dates compared with later sowing dates. These differences were mainly due to soil temperature. In controlled environments and field conditions, studies have shown that the rate of germination or emergence linearly increases with temperature in several crop species including legumes, such as cowpea, soya bean, chickpea (Covell et al. 1986, Ellis et al. 1986, Craufurd et al. 1996) and peanut (Mohamed et al. 1988a, Awal and Ikeda 2002). In addition to poor emergence, reduced soil temperatures also resulted in smaller seedlings at 21 DAS because of decreased shoot and root growth (Table 3). The total dry matter produced was greater at later sowing dates than at earlier sowing dates, because of faster developmental rate and growth. The lower dry matter at cooler soil temperature in early sowing may be related to poor root growth resulting in inadequate nutrient absorption and water uptake or vice versa.

There were significant effects ($P < 0.001$) of temperature treatments (ambient and ambient + 4.5 °C) on emergence percentage, time and rate to emergence and V_2 stages and dry matter

Table 1: Main effects of sowing date, temperature and cultivars on final emergence, time to 50 % emergence, rate of emergence and thermal time to 50 % emergence (based on soil temperature)

Treatment	Final emergence (%)	Time to 50 % emergence (days)	Rate of emergence (day^{-1})	Thermal time to 50 % emergence (°C days)
Sowing dates (S)				
1. 29 Jan 2001	81 (19.4)[1]	11.5 (18.6)[1]	0.095	77.2
2. 22 Feb 2001	88 (21.9)	8.4 (23.3)	0.122	95.9
3. 23 Mar 2001	86 (22.3)	11.0 (21.3)	0.093	104.4
4. 01 May 2001	87 (26.6)	6.5 (26.1)	0.155	93.5
5. 26 Dec 2001	71 (16.8)	29.2 (15.8)	0.035	155.2
6. 05 Feb 2002	80 (19.2)	16.7 (19.2)	0.063	119.2
7. 21 Mar 2002	84 (26.4)	7.8 (26.3)	0.132	112.4
8. 18 Apr 2002	85 (29.5)	5.6 (30.1)	0.180	103.2
SED (7, 21 d.f.)	1.7***	0.43***	0.003***	4.5***
Temperatures (T)				
1. Ambient	79 (21.3)	13.9 (21.4)	0.098	103.2
2. Ambient + 4.5 °C	86 (24.3)	10.3 (23.8)	0.121	102.1
SED (1, 24 d.f.)	0.98***	0.39***	0.003***	NS
Cultivars (C)				
1. C-99R	84 (22.8)	12.1 (22.6)	0.106	104.5
2. Florunner	77 (22.8)	12.7 (22.6)	0.102	109.1
3. Georgia Green	88 (22.8)	11.4 (22.6)	0.116	96.2
4. Florida MDR98	70 (22.8)	12.3 (22.6)	0.111	102.6
5. Southern Runner	80 (22.8)	12.1 (22.6)	0.110	103.4
6. SunOleic 97R	86 (22.8)	11.9 (22.6)	0.111	101.0
SED (5, 240 d.f.)	1.2***	0.15***	0.002***	1.6***
Interactions				
S × T	***	***	***	***
S × C	***	*	***	***
T × C	NS	NS	NS	NS
S × T × C	**	NS	*	*

*,**,***, Significant at the 0.05, 0.01 and 0.001 probability level, respectively; NS, nonsignificant at the 0.05 level.

[1] Numbers in parentheses are the mean soil temperatures (°C) from sowing to final or 50 % emergence.

SED = standard error of difference of means.

production (Tables 1–3). Across all sowing dates and cultivars, higher soil temperature (ambient + 4.5 °C) led to significantly greater emergence, shorter time (days) from sowing to emergence or V_2 stage and increased rate of development and greater dry matter production. However, in terms of accumulation of thermal time above a base temperature, there was no difference from sowing to 50 % emergence or V_2 stage. Awal and Ikeda (2002) reported that thermal times required for emergence were similar at soil temperatures in the range of 18–23 °C.

The interactions between sowing dates and temperature treatments were significant ($P < 0.001$) for all traits (shown in tables 1–3; Fig. 1). Within each sowing date, the elevated temperature treatment (+4.5 °C) had greater emergence, shorter time to emergence and V_2 stage, and faster rate of emergence and earlier V_2 stage and increased dry matter production particularly on earlier sowing dates. At later sowing dates, when ambient soil temperatures were also higher, these differences were smaller and almost disappeared under both ambient and higher soil temperature treatments (Fig. 1).

Cultivars significantly ($P < 0.001$) differed in emergence, when averaged across all sowing dates and temperatures (Table 1). Georgia Green (88 %) and SunOleic 97R (86 %) had significantly higher per cent emergence compared with all other cultivars. The lowest emergence was recorded in Florida MDR98 (70 %), followed by Florunner (77 %) and Southern Runner (80 %). Time to emergence

Table 2: Main effects of sowing date, temperature and cultivars on time to V_2 stage, rate of development to V_2 stage and thermal time to V_2 stage (based on soil temperature)

Treatment	Time to V_2 stage (days)	Rate of development to V_2 stage (day^{-1})	Thermal time to V_2 stage (°C days)
Sowing dates (S)			
1. 29 Jan 2001	15.0 (19.6)[1]	0.069	144.6
2. 22 Feb 2001	12.9 (22.3)	0.079	157.5
3. 23 Mar 2001	17.0 (22.8)	0.060	218.9
4. 01 May 2001	9.4 (26.1)	0.107	152.4
5. 26 Dec 2001	31.6 (16.4)	0.032	205.2
6. 05 Feb 2002	19.1 (19.3)	0.054	177.0
7. 21 Mar 2002	9.3 (26.5)	0.106	158.2
8. 18 Apr 2002	9.5 (30.0)	0.111	181.5
SED (7, 21 d.f.)	0.348***	0.0011***	7.9***
Temperatures (T)			
1. Ambient	17.3 (21.6)	0.071	174.5
2. Ambient +4.5 °C	13.6 (24.2)	0.084	174.3
SED (1, 24 d.f.)	0.452***	0.0014***	NS
Cultivars (C)			
1. C-99R	15.5 (22.9)	0.077	175.4
2. Florunner	15.4 (22.9)	0.078	173.8
3. Georgia Green	15.1 (22.9)	0.079	170.6
4. Florida MDR98	15.9 (22.9)	0.076	178.4
5. Southern Runner	15.6 (22.9)	0.077	170.1
6. SunOleic 97R	15.2 (22.9)	0.078	172.2
SED (5, 240 d.f.)	0.100***	0.0004***	0.97***
Interactions			
S × T	***	***	***
S × C	***	***	***
T × C	**	*	*
S × T × C	***	***	***

*,**,***, Significant at the 0.05, 0.01 and 0.001 probability level, respectively; NS, nonsignificant at the 0.05 level.

[1] Numbers in parentheses are the mean soil temperature (°C) from sowing to V_2 stage.

SED = standard error of difference of mean.

and V_2 stage was shorter for Georgia Green than other cultivars, thus Georgia Green also had a higher rate of seedling emergence. There were differences among cultivars in thermal time to emergence. Cultivar Florunner had significantly greater thermal time compared with other cultivars (Table 1). Similarly, cultivar Georgia Green and SunOleic 97R had significantly less thermal time to V_2 developmental stage than Florida MDR98, or C-99R or Florunner (Table 2). In contrast to our results, Mohamed et al. (1988b) reported that there were no significant cultivar differences in rate of seedling emergence in response to soil temperature in the range of 7–27 °C. However, intraspecific variations in seed germination rate in response to temperature were reported in other legumes, for example, chickpea (Ellis et al. 1986).

The interactions between sowing dates and cultivars ($P < 0.05$ to 0.001) were significant on all traits shown in Tables 1–3. Especially at earlier sowings (26 December, 29 January and 5 February), cultivars Georgia Green and SunOleic 97R had significantly greater emergence, greater shoot and root weights and total dry matter compared with Florida MDR98, Southern Runner or Florunner. There were no significant differences at later sowing dates, and emergence of these three cultivars were similar to those of Georgia Green and SunOleic 97R (data not shown). At earlier sowing dates (26 December, 29 January and

Table 3: Main effects of sowing date, temperature and cultivars on shoot (leaves and stem), root and total dry weight (shoot, root, cotyledons and hypocotyl) at 21 days after sowing (DAS)

Treatment	Shoot dry weight (g plant^{-1})	Root dry weight (g plant^{-1})	Total dry weight (g plant^{-1})
Sowing dates (S)			
1. 29 Jan 2001	0.13 (20.4)[1]	0.060	0.65
2. 22 Feb 2001	0.17 (22.0)	0.067	0.77
3. 23 Mar 2001	0.20 (23.5)	0.066	0.89
4. 01 May 2001	0.27 (27.1)	0.121	1.57
5. 26 Dec 2001	– (13.9)	–	–
6. 05 Feb 2002	– (19.3)	–	–
7. 21 Mar 2002	0.21 (26.4)	0.122	1.19
8. 18 Apr 2002	0.26 (30.4)	0.138	1.33
SED (7, 21 d.f.)	0.021***	0.007***	0.035***
Temperatures (T)			
1. Ambient	0.50 (21.4)	0.068	0.76
2. Ambient +4.5 °C	0.62 (24.4)	0.075	0.84
SED (1, 24 d.f.)	0.023***	0.008	0.043***
Cultivars (C)			
1. C-99R	0.61 (22.8)	0.079	0.90
2. Florunner	0.55 (22.8)	0.064	0.77
3. Georgia Green	0.57 (22.8)	0.077	0.79
4. Florida MDR98	0.54 (22.8)	0.076	0.81
5. Southern Runner	0.52 (22.8)	0.070	0.75
6. SunOleic 97R	0.57 (22.8)	0.081	0.78
SED (5, 240 d.f.)	0.020***	0.001***	0.031***
Interactions			
S × T	***	**	***
S × C	**	*	**
T × C	NS	NS	NS
S × T × C	NS	NS	NS

*,**,***, Significant at the 0.05, 0.01 and 0.001 probability level, respectively.

[1] Numbers in parentheses are the mean soil temperature (°C) from sowing to 21 DAS.

NS, nonsignificant at the 0.05 level; SED = standard error of difference of mean; –, data not collected as there was no emergence.

5 February), time to V_2 stage was significantly longer for cultivars Florida MDR98 and Southern Runner, when compared with Georgia Green, while at later sowing dates all cultivars had similar time to V_2 stage (data not shown).

The three-way interaction between sowing dates, temperature treatments and cultivars was significant for emergence percentage, rate of emergence, time to V_2 stage, rate of development to V_2 stage and thermal time to V_2 stage (Tables 1 and 2). These effects are typically shown for emergence percentage (Fig. 2). The data clearly show that cultivars Florida MDR98 and Southern Runner had the lowest final emergence percentages in early sowings at ambient temperatures; whereas at ambient + 4.5 °C these two cultivars had almost similar emergence percentages to the other cultivars. The cultivars Georgia Green and SunOleic 97R had significantly higher percentage emergence at ambient temperatures in early sowing when soil temperatures were cooler. Similar effects were observed on rate of emergence, time to V_2 stage and rate of development to V_2 stage.

To study the complete response to temperature over all treatments, the data on final emergence, rate of emergence, and rate to V_2 stage were regressed against all 16 temperature values obtained from different treatments (Figs 3 and 4). The results confirm that the cultivar Florida MDR98 had the lowest germination

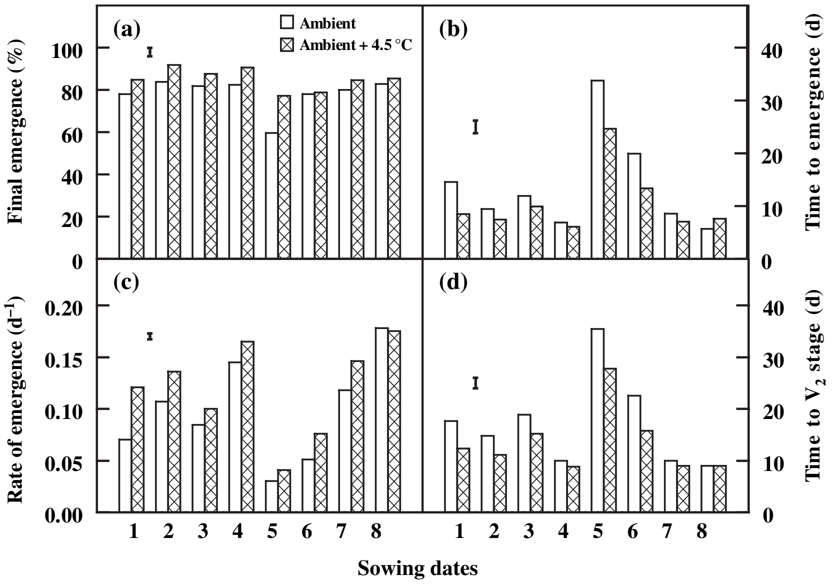

Fig. 1: Influence of sowing dates (for actual dates see Table 1 or Fig. 2) and temperature treatments [ambient (open bars) and ambient +4.5 °C (hatched bars)] on (a) percent final emergence; (b) time from sowing to emergence; (c) rate of emergence; and (d) time from sowing to V_2 stage. Each datum is the mean of six cultivars and four replications. Vertical lines in different panels are the ±SED (standard error of difference of mean) for comparison of treatment means for that trait

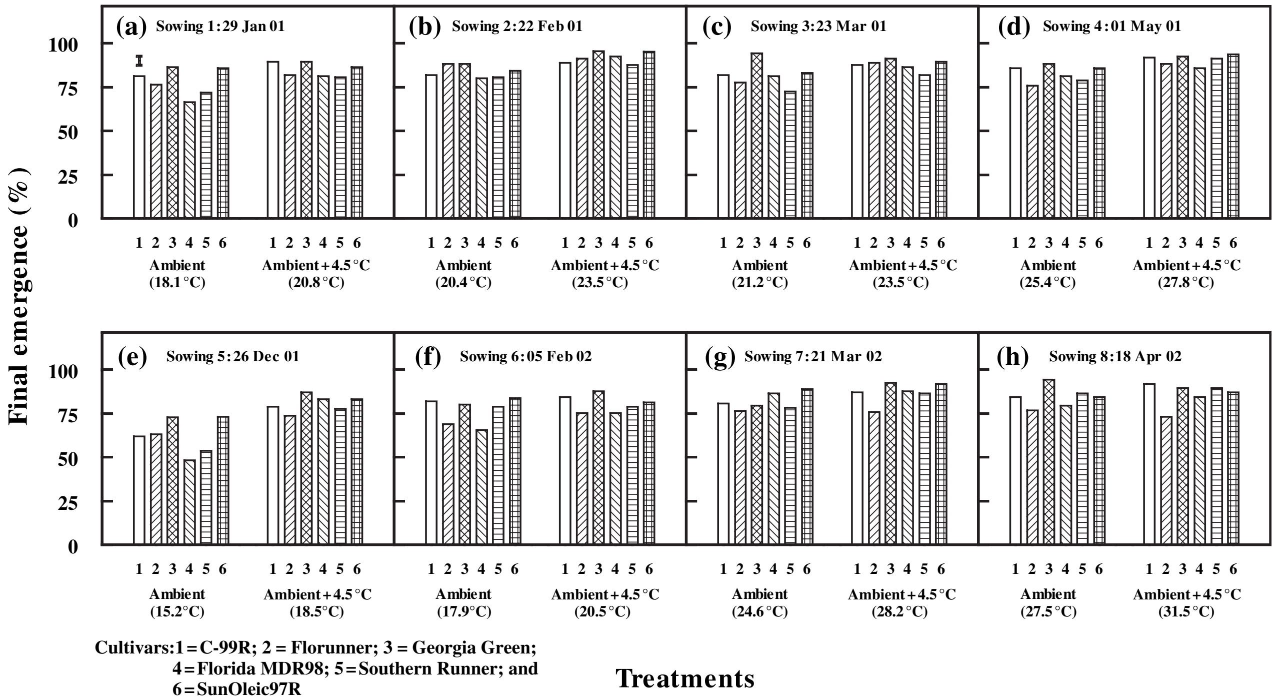

Fig. 2: Influence of sowing dates and temperature treatments (ambient and ambient + 4.5 °C) on percent final emergence of different peanut cultivars. Numbers in the parentheses on the x-axis are the mean soil temperature from sowing to final emergence for that particular treatment. Each datum is the mean of four replications. Vertical line is the ±SED (standard error of difference of mean) for comparison of treatment mean values

percentage, followed by Southern Runner and Florunner at cool soil temperatures, while they performed on par with other cultivars at optimum and above-optimum temperatures. This indicates their greater susceptibility to reduced soil temperatures (Fig. 3).

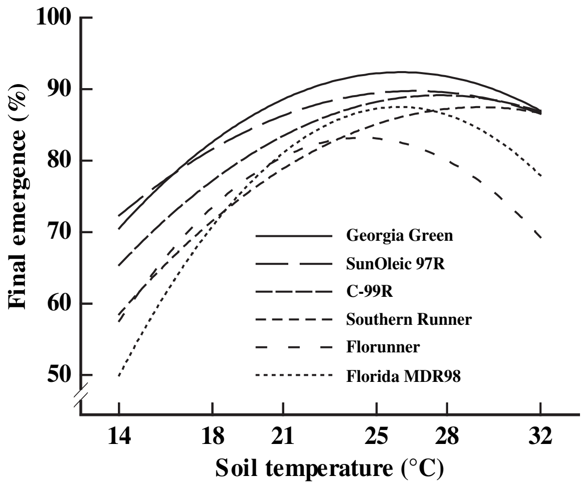

Fig. 3: Final emergence percentage of different peanut cultivars to soil temperature. Regression equations for six cultivars were: (a) Georgia Green: $Y = -9.99 + 7.87X - 0.15X^2$; n = 16; $r^2 = 0.56$; SunOleic 97R: $Y = +12.01 + 5.84X - 0.11X^2$; n = 16; $r^2 = 0.59$; C-99R: $Y = -7.99 + 7.01X - 0.13X^2$; n = 16; $r^2 = 0.65$; Southern Runner: $Y = -18.02 + 7.18X - 0.12X^2$; n = 16; $r^2 = 0.65$; Florunner: $Y = -58.7 + 11.65X - 0.24X^2$; n = 16; $r^2 = 0.51$; Florida MDR98: $Y = -89.52 + 13.64X - 0.26X^2$; n = 16; $r^2 = 0.63$. There were 16 different soil temperatures obtained from eight sowing dates and two temperature treatments within each sowing date

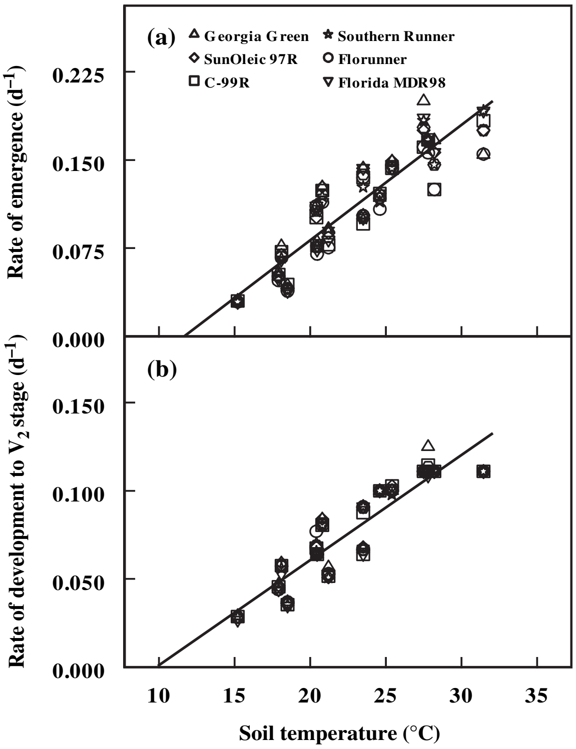

Fig. 4: Relationship between soil temperature and (a) rate of emergence; and (b) rate of development to V_2 stage for different cultivars. The slope and intercept of the regression lines for each of six cultivars were not different, thus a single regression line was drawn across all cultivars. Regression equation for (a) $Y = -0.1145 + 0.00981X$; n = 96; $r^2 = 0.84$; and (b) $Y = -0.0584 + 0.00596X$; n = 96; $r^2 = 0.85$. There were 16 different soil temperatures obtained from eight sowing dates and two temperature treatments within each sowing date

There were no differences in base temperature estimated from rate of emergence and rate of development to V_2 stage (Fig. 4). The calculated base temperatures for cultivars C-99R, Florunner, Georgia Green, Florida MDR98, Southern Runner and SunOleic 97R were 11.36, 10.87, 11.01, 12.57, 12.21 and 11.75 °C for emergence and 9.91, 9.51, 9.65, 10.18, 9.97 and 9.59, respectively, for V_2 stage. A single linear function across all the cultivars best described the relation between soil temperature and rate of emergence and V_2 stage. When averaged across all cultivars, the base temperature was 11.7 °C for emergence and 9.8 for the V_2 stage.

To test if these cultivar differences were due to the presence of inherent dormancy (naturally broken over time), germination was tested using the standard germination test (paper towel technique) on samples from the original seed lots treated with and without ethylene (a chemical used to break dormancy). These results showed that there was no effect of ethylene treatment on germination of these cultivars in either year (Table 4). This confirms that that there was no dormancy in these cultivars, at least as of December–January in the year of harvest. Thus, it is concluded that the differential responses of these cultivars to temperature observed in our field conditions (as in farmers' fields) are mainly due to their susceptibility or tolerance to reduced soil temperatures during emergence and early seedling development and growth. The standard germination test showed significant differences between cultivars in both years. The cultivar Southern Runner had significantly lower germination percentage, while there were no differences among other cultivars (Table 4). Germination percentage under artificial conditions (on heavyweight germination paper in a growth cabinet at fixed 27 °C) was greater than seedling germination under field conditions.

Overall, based on main and interaction effects on emergence and rate of development, our data clearly show that cultivars Georgia Green and SunOleic 97R were more tolerant to cool soil temperatures and had significantly greater emergence percentage with faster development rate and early seedling dry matter accumulation, compared

Table 4: Main effects of cultivar and ethylene treatment on germination of peanut seeds obtained from the two seed lots during 2001 and 2002, germinated in incubators at constant temperature of 27 °C

Treatment	Germination (%) 2001	Germination (%) 2002
Cultivars (C)		
1. C-99R	95.6	92.8
2. Florunner	97.2	90.6
3. Georgia Green	97.8	93.1
4. Florida MDR98	94.4	95.0
5. Southern Runner	90.3	84.4
6. SunOleic 97R	95.6	94.5
SED (5, 36 d.f.)	1.69*	2.00***
Ethylene treatment (E)		
No Ethylene (control)	94.5	92.0
+Ethylene	95.8	91.4
SED (1, 36 d.f.)	NS	NS
Interaction		
C × E	NS	NS

*,**,***, Significant at the 0.05, 0.01 and 0.001 probability level, respectively.

NS, nonsignificant at the 0.05 level; SED = standard error of difference of mean.

with other cultivars. Cool temperature tolerance during sowing and early seedling development phase would prove beneficial, particularly where early sowing of peanut is desirable to avoid delay in maturity due to reduced temperatures and shorter daylength at the time of maturity in October and November. The Florida MDR98 and Southern Runner cultivars are genetically related. Multiple disease resistance to late leafspot [caused by *Phaeoisariopsis personata* (Berk. & M.A. Curtis)], white mold (*Sclerotium rolfsii*), tomato spotted wilt virus (TSWV), and rust in Florida MDR98 is derived partially from Southern Runner, one of its parents. Therefore, germination susceptibility of Florida MDR98 and Southern Runner to cool temperature may be genetically related. Both Florida MDR98 and Southern Runner have PI203396 in their pedigree. Although Georgia Green and SunOleic 97R showed good seedling emergence and seedling vigour at reduced soil temperatures, these two cultivars do not have tolerance to late leafspot diseases and rust. However, Georgia Green has some resistance to TSWV and white mold and Southern Runner is a parent of Georgia Green. Therefore, in regions where cool soil temperatures prevail at the time of sowing, growers should either choose tolerant cultivars or delay the sowing of cold-susceptible cultivars when possible. In regions where multiple disease resistance is needed (for example cultivars Florida MDR98 and Southern Runner in south-east United States), growers should be advised to delay sowing until soil temperatures are adequately warm to obtain a good plant stand. Therefore, sufficient care should be taken while selecting suitable cultivars for specific regions based on the incidence of pests and diseases. An early-maturing peanut cultivar with cold tolerance during germination phase and tolerance to disease such as rust (caused by *Puccinia arachidis* Speg.) and late leafspot has been reported in peanut (Upadhyaya et al. 2002). Cultivars with such genetic background should prove useful in regions where tolerance for both abiotic and biotic stresses in needed. Thus, there is clearly a potential for genetic improvement for cold tolerance and needs attention. In addition, developing peanut cultivars which can germinate at few degrees cooler temperatures can in many cases also increase the region in which this crop can be grown leading to greater production. In addition it is important to understand whether cold tolerance during early stages of crop development results in better yield potential at later stages (Stehli et al. 1999). Research is currently underway to understand the physiological and biochemical reasons for greater cold tolerance of certain cultivars which may include better root growth, acclimation to cool temperature, and differential accumulation of soluble sugars and amino acids in response to cool temperatures.

Conclusions

Cool soil temperatures significantly decreased emergence percentage, decreased rate of emergence, delayed time to emergence and resulted in smaller plant size across all cultivars. There were cultivar differences in percent seedling emergence and early seedling vigour in response to cool temperature under natural field conditions. The cultivars Florida MDR98 and Southern Runner were most sensitive to cool soil temperatures, when compared to other cultivars. The cultivars Georgia Green and SunOleic 97R were most tolerant to cool soil temperatures. There is a scope for genetic improvement for cool temperature tolerance. Future peanut breeding programs should consider cool temperature tolerance, particularly in regions that experience cooler soil temperatures at the time of sowing and early vegetative stage. Cool temperature tolerance might also prove useful in increasing production area of peanut into regions where cool temperatures currently restrict its production.

Acknowledgements

We thank Wayne Wynn and Larry Pitts for engineering support on greenhouses. Partial financial support from Florida Peanut Check-off and United States Agency for International Development, Peanut Collaborative Research Support Program is acknowledged. We thank Dr. Harry Wood of the University of Florida for help in providing the seed. This manuscript is approved for publication as FAES Journal Series No R-10224.

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