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TEMPERATURE AND ALDICARB EFFECTS ON COTTON ROOT GROWTH AND DEVELOPMENT

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REDDY V. R., REDDY K. R. and WANG Z. *Temperature and aldicarb effects on cotton root growth and development.* BIOTRONICS **26**, 1–11. 1997. The effects of temperature on cotton (*Gossypium hirsutum* L.) canopy growth is well documented, but there have been few studies on root growth and root distribution patterns. The purpose of this study was to determine how cotton root growth at different soil depths responded to temperature during the early growing stages, so that these responses could be incorporated into plant growth models used to manage cotton production. In addition, the effect of aldicarb, a systemic insecticide widely used in the cotton growing regions, on root growth was also evaluated. Cotton plants (cv. DES-119) were grown in outdoor sunlit soil-plant-atmosphere-research units at four day/night temperatures (20/12, 30/22, 35/27, 40/32℃). Aldicarb was applied to soil at sowing at 0.84 kg ha^{-1} and at initial flower bud formation at 2.24 kg ha^{-1}. Root number, length, and distribution in various soil depths were determined weekly during a 56 day experimental period. Plants grown at 30/22℃ produced more growing roots than those grown at either 20/12℃ or 40/32℃ at the end of the experiment. Root length at 30/22 and 35/27℃ was also 20% greater than that at 40/32℃. Total root dry weight at 30/22℃ was 1.5 and 5 times as much as those at 40/32 and 20/12℃, respectively. Increases in day/night temperatures resulted in increases in rooting depth and the percentages of root distribution in the deeper soil depths. Aldicarb not only increased total root dry weight for all four temperatures, but also altered root distribution in favor of the 20–40 and >40 cm soil depths over the top 20 cm layer. Our results showed that the optimum range of temperature for cotton root growth is 30/22 to 35/27℃, and that both high temperatures and aldicarb altered the distribution of roots, favoring deeper root systems under optimum water and nutrient conditions.

Key words: aldicarb; cotton; root morphology; soil depth; temperature.

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INTRODUCTION

Field-grown cotton (*Gossypium hirsutum* L.) can experience stress conditions caused by both high (*3*) and low (*4, 5, 23*) temperatures. Temperature effects on cotton growth have been studied extensively, with major emphasis on shoot growth. Many authors reported a temperature around 30℃ as optimal for cotton growth (*7, 18*). Night temperatures are of a particular importance for a number of physiological processes in cotton (*18, 19*). Photosynthesis of plants grown at a night temperature of 20℃ was only 77% of those grown at a night temperature of 28℃ (*26*).

There are more studies on the effect of cool temperatures on cotton growth and development than of super-optimal temperatures. This is because that in the U. S. A. cool temperatures frequently occur in the early stages of cotton growth (*5, 13*). Super-optimal temperature research has focused mainly on heat shock proteins and membrane thermostability (*3*) at early stages of the cotton development.

Information on cotton root growth, particularly on root distribution in the soil profile in relation to the temperature regime, is very limited (*4, 19, 21*). Previous studies on root growth and distribution were related to cotton mineral nutrition (*8, 14*). Crop simulation models used widely for cotton yield predictions require more information, both qualitative and quantitative, on root growth and development.

Aldicarb, 2-methyl-2(methylthio) propionaldehyde O-(methylcarbamoyl) oxime, is a systemic insecticide widely used in the U. S. to control early season insects in cotton (*10, 25*). Aldicarb, when applied at planting, controls several pests such as thrips (*22*), fleahoppers (*22*), and aphids (*9*). In addition to the well-documented pest control properties, we found that aldicarb also has a direct regulatory effect on cotton growth in the absence of pests (*20*). However, it is not known how aldicarb affects cotton root growth and distribution under various day/night temperature regimes. The objectives of this study were 1) to characterize the growth and development of cotton roots in various day/night canopy air temperature regimes, and 2) to evaluate the effects of canopy air temperatures on root distribution patterns at various soil depths, and 3) to determine the effect of aldicarb on root growth and distribution at a range of air temperatures.

MATERIALS AND METHODS

Soil-Plant-Atmosphere-Research (SPAR) Units

The SPAR units used in these studies have been described previously (*1, 16*). Briefly, each SPAR unit consisted of a soil bin (100 cm high, 200 cm long, and 50 cm wide) containing a rooting medium and an acrylic plastic chamber (200 cm high, 200 cm long, and 150 cm wide) to accommodate aerial parts of the plants. The soil bin was completely surrounded by a wooden box with one removable side to facilitate mapping of the roots on glass face. The 200×100 cm viewing glass surface of the soil bin was divided into seven vertical compartments (panels) of 2400 cm^2 (24×100 cm). Air temperature, carbon dioxide concentration, and irrigation in the chambers were controlled by a computer (Digital, Pro 380, Digital Equipment Corp., Maynard, MA, USA*).

Plant Culture

The soil bins of SPAR units were filled with a mixture of Leeper clay loam soil and sand (3:1 by volume). The soil was sterilized with methyl bromide to avoid nematode infestation. Cotton (cv. DES-119) seed was sown in 10 SPAR units. A total of 15 plants in three rows of five plants per row were grown in each SPAR unit. Plants were grown in the SPAR units until 56 days after emergence (DAE) when plants were harvested.

CO_2 concentration was maintained at 350 $\mu L\ L^{-1}$ in the chambers during the daylight hours. The air temperatures in all chambers were initially maintained at 28/23℃ day/night for 11 DAE during seed germination and emergence to obtain healthy and uniform seedlings. During the remainder of the growing season, five day/night temperature treatments, 20/12, 25/17, 30/22, 35/27, and 40/32℃, were applied to the 10 SPAR units (two units for each temperature treatment). During the growing season, one of two SPAR units from the same temperature treatment was treated with aldicarb. The other chamber was not treated to serve as a control. The first aldicarb application, 0.84 kg ha^{-1}, was made as a soil-dressing at sowing. The second application, 2.24 kg ha^{-1}, was made as a side-dressing at 28 DAE for 30/22, 35/27, and 40/32℃ 33, DAE for 25/17℃, and 42 DAE for 20/12℃ treatments. The second aldicarb application coincided with initial formation of flower buds in each temperature treatment. During the course of the experiment, the SPAR unit set at 25/17℃ for the control plants failed and the treatment was dropped from the study.

The plants were irrigated with drip tubes three times daily to keep the whole soil profile moist. Full strength Hoagland solution (*12*) was applied regularly to meet the optimal nutritional requirement throughout the growing season. The SPAR units were closed, kept free of insects during the entire experimental period, and opened only to make management changes.

Root Growth Measurements

During the growing season, lengths of new roots appearing on the glass face of the soil bin, from every 10 cm soil depth of each panel (total seven panels per soil bin), were marked with a wax pencil and measured weekly. Simultaneously, the number of growing roots at each 10 cm depth of seven panels and the deepest root on the glass surface of the soil bin were recorded at various growth stages. The quantity of the root material appearing at any particular depth on the glass viewing surface was assumed to be representative of roots at that

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depth (*24*). At harvesting (56 DAE), the rooting medium in the soil bins was washed of the roots using a metal screen. This destructive harvesting of the roots was accomplished separately for each 10 cm layer of the root system in the soil bins. After they were washed, the roots were dried and weighed.

Statistical Analysis

Statistical analysis was conducted using SAS procedures (SAS Institute Inc., Cary, NC, USA, 1989). Means for root length and number over the seven panels of each soil bin were calculated from each soil depth. The level of significant difference in root length and number among the treatments was determined by LSD at $p<0.05$. The standard error of the mean ($n=7$) and LSD at 0.05 were calculated and are presented wherever applicable. For root dry weight determination, a pooled root dry weight from each 10 cm soil depth across the seven panels was used.

RESULTS

Temperature Effects on Root Growth

Plants grown at 30/22℃ produced significantly more ($p<0.05$) growing roots than those grown at either lower temperature of 20/12℃ during the experimental period or higher temperature of 40/32℃ at most stages (Fig. 1). During the course of the experiment, root number in the 20/12℃ treatment was 60–70% of that in the 30/22℃ treatment. The root number in the 35/27℃ treatment was

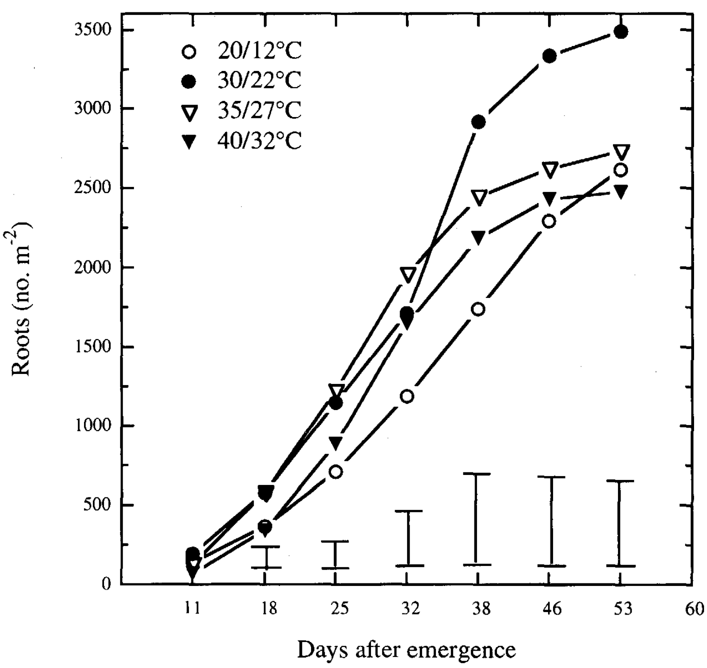

Fig. 1. Temporal trends in cotton root numbers as influenced by temperature. Vertical bars represent LSD at 0.05 and each value is a mean of seven observations.

not different from the 30/22℃ treatment prior to 32 DAE, but was significantly lower than the 30/22℃ treatment from 46 to 53 DAE.

Plants grown at 35/27℃ had a significantly greater ($p<0.05$) root length than those grown at 20/12 and 40/32℃ during the early growth period from 11 to 32 DAE, but the difference diminished as growth stages progressed (Fig. 2). There was no significant difference in root length between the 35/27 and 30/22℃ treatments during the growing season except that the 35/27℃ treatment had greater root lengths than the 30/22℃ treatment at 25 and 32 DAE.

At 53 DAE, greater number of growing roots were observed in plants grown at 30/22℃ compared to plants grown at 20/12, 35/27, and 40/32℃ (Table 1). Plants grown at 30/22℃ produced 66 roots per square meter per day, whereas plants grown in the other temperatures produced only $\approx$50. There was no significant difference in the number of roots among plants grown at 20/12, 35/27, and 40/32℃. Root lengths were not different among plants grown at 20/12, 30/22, and 35/27℃, but plants grown at 40/32℃ had less root length than plants grown at 30/22 and 35/27℃. Root dry weight at 56 DAE was numerically higher in the 30/22 and 35/27℃ treatments than in the 40/32 and 20/12℃ treatments.

Temperature Effects on Root Distribution

At the early growth stages from 11 to 38 DAE, the depth of root development with time was not different among the four temperature treatments (Fig. 3). However, at the later growth stages after 38 DAE, plants grown in the two higher temperatures (35/27 and 40/32℃) developed deeper ($p<0.05$) root

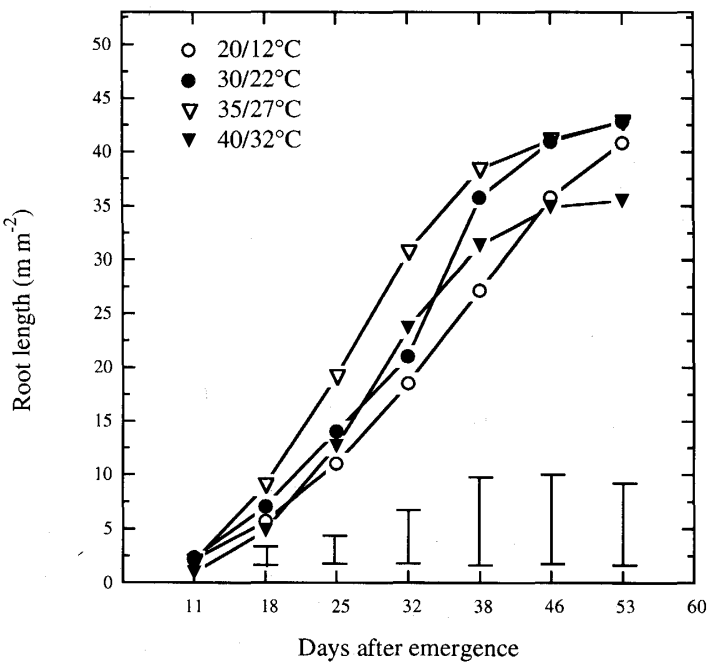

Fig. 2. Temporal trends in cotton root length as influenced by temperature. Vertical bars represent LSD at 0.05 and each value is a mean of seven observations.

Table 1. Cotton root dry weight, number, and length as affected by temperature.

Day/night temperature (℃)	Root number (no. m^{-2})	Root development rate (no. m^{-2} d^{-1})	Root length (m m^{-2})	Root elongation rate (m m^{-2} d^{-1})	Root dry weight (g m^{-3})
20/12	2616b	49b	40.9ab	0.77ab	24.6
30/22	3488a	66a	42.9a	0.81a	121.5
35/27	2729b	52b	42.9a	0.81a	116.4
40/32	2474b	47b	35.5b	0.67b	84.5

Root dry weight was taken at 56 days after emergence.
Root number and length measurements were taken at 53 days after emergence.
Means within the columns followed the same letter are not significantly different ($LSD_{0.05}$).
Each value for root number and length is the mean of seven observations.

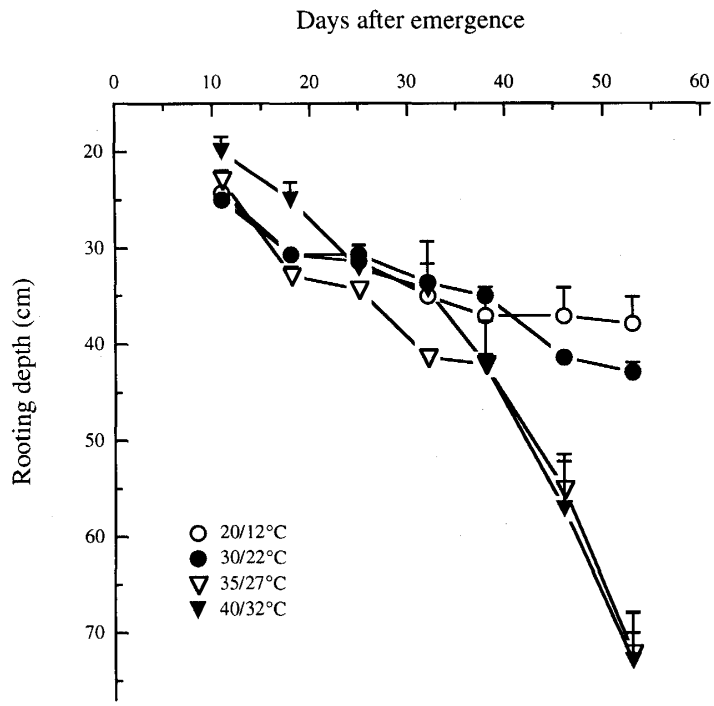

Fig. 3. Change in rooting depth with time for cotton grown at different temperature regimes. Vertical bars represent SE (n=7).

systems than those grown in the two lower temperatures (20/12 and 30/22℃). The deepest roots in the 20/12 and 30/22℃ treatments were observed at 37 and 35 cm at 38 DAE, and grew slightly to 38 and 43 cm at 53 DAE, respectively. However, the rooting depth at 35/27 and 40/32℃ was ≈42 cm at 38 DAE and grew more than 20 cm to the 75 cm depth from 38 to 53 DAE.

Approximately, >90% of total root dry weight was found at the top 20 cm soil layer for all four temperature treatments (Table 2). The percentages of root dry weight in the 40/32℃ treatment were less in the top 20 cm soil depth than those in the three low temperature treatments, but greater in the 20–40 and >40 cm soil depths.

The percentage of total root number in the top 20 cm soil layer varied from 58–71%, depending on growth temperature (Table 2). The 20–40 soil depth also contained ≈30–40% of total growing roots, whereas the >40 cm soil depth only accounted for <2% of total growing roots. The effect of day/night temperature on the distribution of root number at different soil depths was similar to the effect on root dry weight. The two higher temperature treatments had greater percentages of growing roots presented in the >40 cm soil depth than the two lower temperature treatments, whereas the 20/12℃ treatment had a greater percentage of roots growing in the top 20 soil layer.

Aldicarb Effects on Root Growth and Distribution

Aldicarb increased root dry weight at each soil depth and increased total root dry weights by ≈20, 30, 10, and 25% for the 20/12, 30/22, 35/27, and 40/32℃ treatments, respectively (Table 3).

Aldicarb treatment increased total root lengths by 17 and 60% in the 35/27 and 40/32℃ treatments, respectively, but did not affect root length in the 20/12 and 30/22℃ treatments (Table 4). Aldicarb also altered the percentages of root length in favor of deeper soil depths for all four temperature treatments. The aldicarb-treated plants grown at 20/12, 30/22, and 40/32℃ had higher percentages of root length at 20–40 and >40 cm, and consequently lower percentages in the uppermost 20 cm layer than the control plants. Though aldicarb in the 35/27℃ treatment decreased the percentage of root length at 20–40 cm, it doubled the percentage of root length in >40 cm depth when compared to control.

Table 2. Influence of temperature on the distribution of cotton root biomass and root number at different soil depths. Each value of the percentage of root number is the mean±S. E. (n=7).

Day/night temperature (℃)	Soil depth (cm)		
	<20	20−40	>40
	% total root dry weight		
20/12	96.2	3.3	0.5
30/22	93.3	4.4	2.3
35/27	94.8	2.8	2.4
40/32	88.7	7.4	4.0
	% total growing roots		
20/12	71±3	29±2	0.1±0.0
30/22	64±7	36±4	0.1±0.0
35/27	58±3	40±3	2.0±0.3
40/32	63±5	35±2	2.0±0.3

Table 3. Effect of aldicarb on root dry weights at different soil depths for cotton grown at various day/night temperatures for 56 days. Aldicarb was applied as a soil-dressing (0.84 kg ha^{-1}) at sowing and as a side-dressing (2.24 kg ha^{-1}) at initial squaring.

Treatment	Root dry weight at various soil depths (g m^{-3})			Total*
	<20 cm	20–40 cm	>40 cm	
		20/12℃		
Control	94.2	3.2	0.5	97.9
Aldicarb	113.6	4.2	0.6	118.4
		30/22℃		
Control	443.4	20.9	11.0	475.3
Aldicarb	508.1	92.1	21.0	621.2
		35/27℃		
Control	431.6	12.8	10.8	455.2
Aldicarb	458.1	25.8	20.9	504.8
		40/32℃		
Control	288.3	24.0	12.9	325.2
Aldicarb	343.2	36.3	27.8	407.3

*Total is the sum of root dry weights at the <20, 20–40, and >40 cm soil depths.

Table 4. Effect of aldicarb on root length at different soil depths for cotton grown at various day/night temperatures for 56 days. Aldicarb was applied as a soil-dressing (0.84 kg ha^{-1}) at sowing and as a side-dressing (2.24 kg ha^{-1}) at initial squaring.

Treatment	Root length at various soil depths (m m^{-2})			Total**
	<20 cm	20–40 cm	>40 cm	
		20/12℃		
Control	158±6*	63±4	0.2±0	221
	(71%)	(29%)	(0%)	(100)
Aldicarb	139±6	71±7	0.1±0	210
	(66%)	(34%)	(0%)	(100)
		30/22℃		
Control	142±16	79±8	0.1±0	221
	(64%)	(36%)	(0%)	(100)
Aldicarb	121±17	85±4	3.2±0.4	209
	(58%)	(40%)	(2%)	(100)
		35/27℃		
Control	118±6	82±7	4.8±0.9	205
	(58%)	(40%)	(2%)	(100)
Aldicarb	150±9	78±6	11.4±1.8	239
	(63%)	(32%)	(5%)	(100)
		40/32℃		
Control	110±10	61±3	4.3±1.4	175
	(63%)	(35%)	(2%)	(100)
Aldicarb	132±12	139±7	8.8±1.8	280
	(47%)	(50%)	(3%)	(100)

*Each value is a mean ± SE of seven observations.
**Total is the sum of root length at the <20, 20–40, and >40 cm soil depths.

DISCUSSION

Our results showed that the optimum temperature for cotton root growth is between 30/22 to 35/27℃ day/night regimes (Fig. 1, 2, Table 1), the same optimum range of temperatures for cotton shoot growth (*18*). A similar result was obtained in cotton by Pearson et al. (*15*). The optimal root growth may be related to the optimal uptake of water and nutrient (*21*) and maximal carbohydrate supply from canopy at these temperatures.

Plants grown in the two higher temperatures (35/27 and 40/32℃) developed deeper root systems than those grown in the two lower temperatures (20/12 and 30/22℃) (Fig. 3). The difference in rooting depth is probably associated with changes in soil temperature (Table 5) and root temperature response. Bland (*4*) found that the rate at which rooting depth increased was positively related to the rate of soil warming. Deeper soil temperatures in our two higher air temperature treatments (Table 5) may be more adequate to cotton root growth than in the two lower air temperature treatments. Consequently, high air temperatures increased the rooting depth (Fig. 3) and the percentage of root number in deeper soil depths (Table 2). It is also possible that plants grown at higher air temperatures require more water to maintain higher rates of transpiration which may lead to the development of deeper root systems.

Aldicarb increased root dry weight (Table 3) and the percentages of roots in deeper soil (Table 4). The increased root growth in deeper soil depths occurred even in the presence of adequate supply of water and nutrients, showing a direct effect of aldicarb on root growth. The mechanism by which aldicarb promoted cotton root growth is unknown. However, it is known that aldicarb in soil rapidly converts to its sulfoxide and sulfone which quickly moved down to the deeper soil depths (*6*). The quick downward movement of the sulfoxide metabolite is consistent with the increased deeper root growth caused by aldicarb application. The altered root development may also be related to the changes in canopy development. Aldicarb can quickly convert to its sulfoxide and sulfone in cotton leaves (*2, 11*) that may directly affect cotton canopy growth and development.

Our data suggest aldicarb effectiveness varied with growth temperature. It

Table 5. Mean daily soil temperatures at four different soil depths from days 12 to 56 after emergence for various air temperature treatments. Air temperature treatments in the SPAR units were imposed at 11 days after emergence and plants were harvested at 56 days after emergence.

Soil depth (cm)	Soil temperatures at various air temperature treatments (℃)			
	20/12℃	30/22℃	35/27℃	40/32℃
5	23.5±0.3	26.3±0.2	27.7±0.1	29.9±0.1
25	27.2±0.2	29.1±0.2	30.3±0.2	31.3±0.2
50	27.1±0.2	28.8±0.2	29.7±0.2	30.5±0.2

Each value is mean ± SE of 44 observations.

appears that the aldicarb was less effective when plants were exposed to a temperature of 20/12℃ than to the three higher temperatures (Tables 3, 4). Temperature may influence the effectiveness of aldicarb by a) altering the canopy (*18*) and root growth (Table 1) of cotton, b) changing the rates of uptake of aldicarb and its metabolites, and c) affecting the rates of breakdown and metabolism of aldicarb in both soil and plants.

Under favorable water, nutrient, and temperature conditions cotton roots mostly concentrated in the top 20 cm soil. This layer contained >60% of total growing roots and >90% of total root dry weight for all four temperature treatments (Table 2). The 20–40 cm soil depth contained 30–40% of growing roots (Table 2). Roots at these soil depths are important for plants to explore more water and nutrients deep in soil. Therefore, adequate water and fertilizer application at these depths is essential for cotton root and shoot growth. Deeper root systems observed in aldicarb treated plants may have added advantage in water and nutrient deficit conditions since roots can explore more soil volume and depth.

In summary, we have observed differences in cotton root growth in response to air temperature. It appears that the optimal temperature for the growth of cotton root systems is 30/22 to 35/27℃ day/night. Both higher temperatures and aldicarb promote the development of deeper root systems. Under the temperature range tested in this study, root growth and development was found to be more sensitive to aldicarb with increase in day/night temperatures.

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