cylinder could be correlated with the extension of root into deeper soil in the fi
We need to verify this assumption. If this is succesful, a large number of genotyp
could be evaluated at the seedling stage. However, we need to direct m
research efforts on root studies to select genotypes adaptable to adverse clim
and edaphic environments of the semiarid tropics. No studies have yet been m
on the contribution and function of different members of the root system
seminal, adventitious and nodal, in relation to crop growth. We need to expl
if correlations exist between certain anatomical characteristics like intensity
pericycle lignification and silica crystals, and biotic (e.g., *Striga*) or abiotic str
(e.g., drought).

7

ROLE OF CLIMATIC FACTORS ON SORGHUM GROWTH

INTRODUCTION

Climate plays an important role in determining the growth and development of a crop. The expression of phenotypic traits is the result of interactions of genotypes and the environment. The productivity of the crop is the yield of plants expressed as a unit of some factor that limits production (Elston, 1980). At different stages of crop development, several physical and biotic factors may operate simultanously in limiting plant growth, but productivity under diferent enviroment is determined by several plant processes like transpiration, water use efficiency and assimilate partitioning (Fisher & Turner, 1978). These are in turn highly controlled by the environment. The growth of a crop through its various developmental phases is guided by different environmental components. Germination and emergence are highly influenced by temperature and soil humidity and density, while canopy development, very important for the interception of light for efficient photosynthesis, is influenced by the photosensitive nature of the genotype. Photosensive cultivars continue to maintain uninterrupted leaf production without producing any effective panicle unless a particular day length is reached. Panicle initation is highly influenced by the day length.

Of the different environmental factors which affect the sorghum crop, soil and atmospheric environments are the most important. These are further influenced by biotic factors and crop managment. It is therefore necessary to understand the environmental parameters and their influence on crop growth. Large diversity and variability of environments in different sorghum-growing regions affect sorghum production. The environment influences yield by directly interacting with the physiological processes of sorghum production and indirectly through diseases and insects. This chapter dicusses macro- and micro-climates and their role in crop growth.

SORGHUM GROWING REGIONS AND THE ENVIRONMENT

Sorghum is grown in the semiarid tropics (SAT) right from sealevel to elevations of 3000 m, including high, low and variable rainfall areas, as well as different seasons of the year. The sorghum crop is widely adaptable to varying soil and environmental conditions. Miller (1982) proposed that sorghum breeders should

have good knowledge of the climatic environment in which they work, and th they should develop highyielding and more stable varieties for that zone by obtai ing appropriate collections from diverse climates and recombining them into mo widely adapted improved types. He also stated that sorghum has moved fro Ethiopia to USA, Argentina, Venezuela, Central America, Australia, India an several areas of Africa. The crop is grown between the tropics of Capricorn an Cancer (23.5° N and S Latitude). The main area of diversity in both wild an cultivated sorghum is in the northeast quadrant of Africa which is claimed as th origin.

Doggett (1970) concluded that the great diversity in *Sorghum bicolor* existi in the ecological habitats of northeast Africa was due to disruptive selecti isolation and recombination. Although sorghum is grown in some temperate re gions, it is one of the major crops in the semiarid tropical countries of the wor where the crop has to face adverse climatic conditions during its growth peri Based on the data of average production of sorghum during 1974-78 in differe countries, Von Oppen and Ryan (1981) analyzed sorghum production in differe regions in SAT. According to them, India produces 34% to the crop grown i SAT, and is the largest sorghum producing country in the world. The other ma sorghum producing countries in Asia are Pakistan, China and Thailand. In th Americas, México and Argentina together produce 34% of the crop grown in SA The major sorghum growing countries in west Africa are Ghana, Niger, Niger Upper Volta and Mali contributing 15% of the production in the SAT. Ethiop Kenya, Sudan, Tanzania, Malawi, Monzabique, Zimbabwe and Zambia are th major producers in eastern and southern Africa; while Saudi Arabia and Yem contribute only 3% of the crop grown in the SAT. Von Oppen and Ryan (198 defined core sorghum growing regions contributing at least 20% of the share the SAT, and on this basis Nigeria, Ethiopia, Sudan, Malawi and Monzabiq represent the core production areas.

In India, rainy season sorghum areas extend from 9 °N (Madural in Ta Nadu) to 25 °N (Hamirpur, Himachal Pradesh) while the postrainy seas sorghum growing areas lie within the narrow belt of 14 °N (Nellore, Andh Pradesh) to 21 °N (Dhule, Maharashtra). Over 99% of sorghum in India produced in the SAT areas (Tables 7.1 and 7.2).

With its versatile adaptability and its use as a food and feed, sorghum is grow in the seasonality dry tropical climates spread over 4 continents and 48 countri They are characterized by having mean annual temperatures greater than 18 and rainfall exceeding evapotranspiration for only 2 to 4.5 months in the dry SA and for 4.5 to 7 month ion the wet/dry SAT. The coefficient of variability rainfall in SAT is 20 to 30% (Higgins, 1978).

The several constraints to sorghum productivity in the SAT include intens rainfall interspersed with drought, a short but variable rainy season, high rates evapotranspiration in the growing season and low infiltration capacity of the so These diverse environmental conditions have a direct impact on the growth a development of sorghum. Miller (1982) identified vast areas in southern Russ northern China, South America and some areas in South Africa and Austra where sorghum has potential for expansion.

Table 7.1 Highest and lowest air temperature recorded in the rainy season sorghum growing season at selected locations in semiarid India (Sivakumar & Virmani, 1980).

Location	Jun	July	Aug	Sep	Oct	Nov
Akola	42.2	36.2	31.4	35.0	35.6	33.6
	22.5	21.8	21.7	21.1	14.7	10.6
Hyderabad	39.9	34.0	33.0	32.8	33.3	31.5
	21.2	21.0	20.9	20.3	15.8	11.8
Indore	40.0	34.1	31.5	32.6	33.2	31.2
	21.4	21.0	20.4	18.9	13.0	8.2
Jhansi	44.9	39.6	35.5	35.6	36.0	33.4
	23.8	23.1	22.7	21.6	14.7	8.8

Table 7.2 Highest and lowest air temperature recorded during the post rainy sorghum growing season at selected locations in semiarid India (Sivakumar & Virmani 1980).

Location	Oct	Nov	Dec	Jan	Feb	Mar
Bijapur	33.6	31.8	31.4	32.7	35.8	38.5
	17.0	12.9	11.1	12.0	14.1	17.3
Gulbarga	34.4	32.8	31.5	32.7	36.1	39.4
	16.8	12.9	10.5	11.7	14.3	17.4
Sholapur	34.7	32.2	31.9	33.3	36.4	39.7
	16.6	12.9	10.7	11.3	13.1	16.7
Ahmednagar	33.5	32.2	31.1	32.0	34.4	38.5
	14.5	10.5	8.0	8.0	9.6	13.0

Sivakumar and Virmani (1982) briefly describe the salient features of the environment in sorghum growing areas of Africa and India:

Radiation

Solar radiation guides photosynthesis in the production of biomass. The amount of dry matter produced by plants depends, to large extent, on the interception of the incoming solar radiation by the crop canopy. The total solar radiation in SAT Africa ranges from 400-500 cal/cm²/day with the highest solar radiation in the northern and southern boundries of semiarid Africa. The average global solar radiation during the rainy season varies from 400 to 450 cal/cm²/day while in the postrainy season it is reduced by 10-40 cal/cm²/day.

Temperature

The average maximum temperature varies from 35°C in northern Upper Volta, Niger and Sudan to 22°C in the Ethiopia highlands. The average maximum

temperature in Kenya and Tanzania ranges from 25-30°C while the minimum ranges from 10-23°C.

In India, sorghum is grown in the rainy and postrainy seasons. The average temperature in the rainy season varies from 31°C (in the early growing season) to 28°C (in November). In the postrainy season, the average mean temperature ranges from 22 to 29°C. Therefore, the maximum temperature variation during rainy season is not significant, but the minimum temperature decreases from 25°C to 20°C, by the time the crop reaches physiological maturity (August-September). In the postrainy season, the maximum temperature rises from 30°C in October to 35°C by March and 42°C by April. The small change in diurnal temperature range in the rainy season promotes good vegetative growth and grainfilling. In the postrainy season, the large diurnal range in temperature has a direct impact on growth of sorghum (Peacock, 1982). Among sorghum-growing areas in India, the maximum temperature can reach as high as 45°C at Jhansi, while the temperature could go down as low as 8°C in November as in Indore. In the postrainy season the maximum temperature could reach as high as 40°C, while a minimum temperature of 8°C is not uncommon. The highest and lowest temperature in SAT India are given in (Tables 7.1, 7.2 and 7.3).

Table 7.3 Seasonal average weather data and photoperiod at Hyderabad (17.5 °N) during different phases of crop growth: 30 genotypes including hybrids and parents.

Elements	GS1				GS2				GS3		
	K	DR	R	JR	K	DR	R	JR	K	DR	JR
Max.Temp.°C	31.1	28.3	31.4	27.4	30.0	29.7	32.2	32.4	29.1	28.8	36.1
Min.Temp.°C	22.6	15.3	21.6	12.2	22.2	13.5	19.6	14.6	22.1	14.7	19.2
Avg.Temp.°C	26.9	21.8	26.5	19.8	26.1	21.6	25.9	23.5	25.6	21.6	27.7
Sunshine hr/day	2.8	9.4	9.6	10.0	4.1	10.3	10.4	10.7	4.3	10.4	10.1
Phootper.hr/day	13.1	11.1	12.0	11.3	12.9	11.2	11.5	11.7	12.5	11.5	12.3
Avg.Rel.Hum. %	71	66	64	57	80	49	57	45	79	51	35

K = 14th June 1976 planting; DR = 1st December 1976 planting;
R = 11th September 1976 planting; JR = 19th January 1976 planting.

Rainfall

As for any other crop, the amount and variability of rainfall has a pronounced effect on yield. The west African region of Ghana, Upper Volta, Niger and Nigeria receive an annual rainfall between 800 and 1600 mm, while the region receiving between 1000 and 1600 mm rainfall is classified as the Sudano-Guinean zone. The early season in this region lasts 4 to 5 months. The eastern Ethiopian highlands receive a rainfall of 1200-1300 mm on the western side of the high plateau, while the eastern valley receives less. Rainfall in the Kenyan highlands is 1200-1500 mm while the western side is more dry rainfall in north and central Tanzania is low south-western Tanzania receives more rainfall. Rainfall in southern Africa is fairly great. Mozambique, Malawi, Zimbabwe and Zambia in southern Africa receive rainfall ranging from 400 to 1600 mm.

The rainfall isohyets in sorghum-growing regions in India ranges from 700 to 1400 mm. Most of the core sorghum growing areas in the rainy season are located between 800 and 1000 mm rainfall isohyets, while the core postrainy season sorghum growing regions fall in the belt with low and uncertain rainfall up to 800 mm.

TEMPERATURE

Temperature influences sorghum yield by directly affecting the physiological processes involved in grain production and indirectly through diseases and insects.

The effect of temperature on growth and development and physiological processes is fairly known. The response of temperature varies with the crop and also among varieties. The physiological processes in cultivated crop plants are controlled by a wide range of temperatures. Leopold and Kriedmann (1975) indicated that the temperature extremes within a biological range exert selective pressure for survival or elimination of individuals within a species. Thus, in order that the tropically-adapted types have a selective advantage with low base temperature, they must have come from an area which does not experience freezing temperatures. Base temperature is the temperature at which 50% of the seeds fail to germinate in 18 days (Miller, 1982). The plants developed in these regions would not be subjected to frost early in the growth period and would not be eliminated from selection as they would be able to germinate with the onset of rain. This early establishment could force selection for pest resistance. On the other hand, the genotypes which were developed at high elevations or in areas where frost was prevalent early in the season, survived only if they did not germinate too early when frost occurence was high.

The plants with high base temperatures become adapted to highland areas of Ethiopia and the great plains in the U.S. while plants with lower base temperatures are more adaptable to warmer nighttime environments of south Texas, Venezuela, the lowlands of Mexico, Australia, India and the lowlands of Ethiopia and Africa (Miller, 1982).

Arnold (1959) indicated that the base temperature for sorghum germination is 10.5°C. Thomas and Miller (1979) using the procedure of Gbur *et al.* (1979) have shown that the base temperature is not constant within the species, but may vary from 4.6°C to 16.5°C. Thomas (1980) established that lines and hybrids which were 'tropically adapted' had a lower base temperature than the lines designated as 'temperately adapted'. Hybrids exhibited lower base temperature than their inbred parents. Miller (1982) stated that sorghum has the major adaptation factors of height, duration of growth, response to photoperiod and sensitivity to temperature when exposed to genetic manipulation. In his opinion temperature, photoperiod, rainfall and the interactions of these climatic driving forces interact within the biological range and exert selective pressure among sorghum species to affect adaptation in a particular area. Miller (1982) has also suggested that

major variations exist within *Sorghum bicolor* for base temperature. These differences in response among plants indicate that by measuring temperature characteristics, there may be more effective ways of predetermining areas of geographic adaptation. This may allow the breeder to predict ranges of adaptation for a particular cultivar in an environment. Rao and Rana (1982) state that temperate-tropical crosses have become an integral part of all sorghum breeding programs in the world. The conversion approaches have received emphasis in the USA and in India. In most temperate-tropical crosses, when plants are grown under tropical conditions, the early stages are dominant. The following are some examples of the effect of temperature on sorghum growth.

Air temperature

Temperature indicates the capacity to transfer heat by conduction. Clear skies promote maximum radiation during daytime and rapid loss of heat at night. This in turn brings about wide diurnal changes in the aerial environment.

Mean temperature is generally calculated in the following way

$$\text{Mean Temp. °C} = \frac{\text{Max. Temp.°C + Min. Temp.°C}}{2}$$

The temperature quotient, Q_{10} used to assess the effect of temperature on the rates of growth and differentiation (Yoshida, 1981) can be worked out as follows

$$Q_{10} = \frac{\text{Rate at (T+10)°C}}{\text{Rate at T °C}}$$

where Q_{10} is the increase in the rate for every 10°C rise in temperature.

Aerial temperature has a significant effect on sorghum growth, i.e., on photosynthesis, respiration, leaf temperature, phenology and other yield components. The critical temperature for growth varies from one growth stage to another and depends on crop variety. The effect of temperature on sorghum growth has been demonstrated by different researchers (Eastin, 1972a and 1976; Sullivan *et al.*, 1977; Angus *et al.*, 1980).

Effects on photosynthesis and respiration

Photosynthesis shows a decline with an increase in temperature and is inactivated at excessively high temperatures, but respiration may not be affected similarly (Moss *et al.*, 1961). Metabolic efficiency appeared to diminish between 25°C and 40°C in sorghum (Eastin and Sullivan, 1974).

Effect on phenology

Chowdhury and Wardlaw (1978) observed a reduction in the grainfilling period from 42 to 18 days by increasing temperatures from 21/16 to 33/28°C. They intepreted that metabolic efficiency expressed in terms of grains (GS3) was appreciably reduced by higher temperatures. Castleberry (1973) reported that the most sensitive period to temperature is when floret differentiation occured.

When planted on the same date at different locations at same latitude, crops of the same cultivar may differ considerably in rates of growth and development. Differences caused by location often are greater than differences among cultivars grown at one location. This suggests that with a narrow range of latitude, variations in temperature may be largely responsible for differences in maturity among sorghum cultivars planted on the same date (Fryer *et al.*, 1966).

Gibson *et al.* (1977) reported that the greatest temperature response occurs

in GS1. This growth stage is largely dependent upon production and expansion of 6 to 8 upper leaves (Schaffer *et al.*,1979) which support grain filling. The most important yield-seed number is determined during this phase. Hence planting date has to be decided ensuring that temperature during GS2 is most favorable.

A probabilistic model to predict the duration of different growth stages has been put forward by Reddy (1984). Temperature is found to have a significant effect on phenology and duration of different phases is curvilinear. This study indicates that even a slight change in temperature (1.9°C) causes contrasting variations in the duration of growth stages of sorghum cultivars belonging to different taxonomic groups (Tables 7.4 and 7.5).

Table 7.4 Phenology of CSH1, in days and Heat Units (HU) with 10°C as base temperature (Reddy *et al.*, 1984).

	Days			Heat Units (HU)		
Phenophase	Mean	Max-Min	(range)	Mean	Max- Min	(range)
1-GS1	23.6	29-20	(9)	665.9	1065- 506	(559.6)
2-GS2	34.0	41-25	(16)	944.8	1224- 787	(436.6)
3-GS3	33.4	40-25	(15)	956.7	1265- 766	(499.8)
4-1+2	58.3	69-50	(19)	1595.8	2290-1344	(946.2)
5-1+2+3	91.8	102-79	(23)	2552.5	3425-2233	(1192.2)

The classical heat unit of degree day requirement varies for different growth stages of sorghum (Table 7.4). Growing degree days which determine the summation of heat units over the growing period is estimated in the following way :

$$\text{Growing degree days (GDD)} = \frac{\text{Min T°C + Max. T°C}}{2} - \text{Base T°C}$$

Temperature is substituted for the maximum temperature if the maximum is higher than the cutoff temperature. When the daily minimum temperature is lower than the base temperature, a sine curve is used to aproximate diurnal change in temperature between maximum and minimum. The relationship between GDD and different growth stages was found to be highest with 38°C cut off temperature and base temperature of 7°C (Huda, 1982). The classical heat unit concept is accurate enough to predict phenological events (Quinby *et al.*, 1973; Reddy, 1984).

Effect of temperature on yield components

Higher temperature (day/night 33/28°C) from germination to panicle initiation reduced grain yields of sorghum, as did high temperature during the last part of panicle development on floret abortion (Downes, 1972). Eastin (1976) exposed sorghum cultivars to day/night temperatures of 29/17°C, 29/22°C, 29/27°C and 34/22°C from panicle initiation to bloom and showed that night temperature 2-3°C above the optimum reduced yield by 25-33%. In sorghum, the rate of kernel development at higher temperature (30/25°C) was greater than other cereals. In wheat, the rate of development of individual kernels was higher at

lower temperatures (21/16°C) than in other species (Chowdhury and Wardlaw, 1978). Grain number per panicle was not affected by temperature as high as 35/25°C, but yield was due to reduction in grain weight. Excesive high temperatures lead to head-blasting or abortion of grains (Jordan *et al.*, 1983).

Table 7.6 Regression coefficients of predictive equations: cv. CSH1.

Phenophase	Eq.No.[1]	Regression parameters a	b	c	r
GS1	2	29.5	- 3.6*		0.51
	3	34.0	- 3.6*	-0.07	0.55
GS2	2	49.6	-10.1**		0.71
	3	58.7	- 6.8**	-0.23**	0.87
GS3	2	44.2	- 5.8**		0.60
	3	43.9	- 5.7**	-0.02	0.62
Days to anthesis	2	79.3	-13.7**		0.75
(GS1 + GS2)	3	92.9	-11.2**	-0.27**	0.86
Days to physio-	2	120.5	-18.2**		0.70
logical maturity	3	133.2	-12.6**	-0.35**	0.83
(GS1 + GS2 + GS3)					

1- **a** is the regression constant and **b** and **c** are regression coefficients; **R**= Correlation coefficient; probability= * at 5% level, ** at 1% level

Predictive equations:

2 Y = **a** +/- **b** (19.6-**T**)^1/3 (with average temperature)

3 Y = **a** +/- **b** (19.6-**T**)^1/3 + H (with average temperature and humidity)

T = average temperature,°C; H = average relative humidity, %

Leaf temperature

Plant leaf temperature is influenced by an energy exchange process between atmosphere and leaf tissue which is controlled by radiation, convection and transpiration. Leaf water deficits develop when there is increase in stomatal closure, causing decrease in transpiration and subsequently, a rise in leaf temperature. Transpiration reduces leaf temperature considerably (Gates, 1968; Van Bavel and Ehrler, 1966). Miller *et al.* (1971) showed that leaf temperature and relative water content were highly correlated indicating that difference in leaf temperature is an indication of the plant water status. Carrison *et al.* (1972) reported that there was an increase in leaf air temperature differential whenever there was a decrease in relative water content. This is a direct consequence of stomatal closure and reduced rate of evaporative cooling. The leaf-air temperature differential considered a stress-day factor.

Soil temperature

The soil derives its heat from 2 main sources: direct radiation from the sun and by conduction from the interior of the earth. The pattern of soil temperature

different places depends on longitude, altitude, seasons and soil types. The soil surface temperature is coldest in the early morning and warmest in the early afternoon. The amplitude of the daily soil temperature wave decreases with depth in the soil. At midday heat is directed downward through the upper layer of the soil and the exit of heat from the middle of the layer begins after sunset but sometimes continues downward throughout the night (Rosenburg, 1974).

High soil-surface temperature affects the seedling emergence of sorghum (Wilson and Eastin, 1982; ICRISAT, 1982). The coleoptile bends downwards after reaching the high soil surface temperature regime. Cultivars showed significant variability in seedling emergence to soil surface temperature.

A study on 30 sorghum cultivars showed that 85% of them showed good emergence when the temperature reached a maximum of 38°C at seed depth, while only 36% emerged when temperature reached 48°C, a common occurrence in tropical soils (Andrews *et al.*, 1981).

The soil surface temperature has been found to influence seedling growth of sorghum (unpublished).

Sorghum grown at high altitudes is exposed to low temperature for germination. The minimum temperature for sorghum germination is about 10°C and slightly higher for emergence (Pinthus and Rosenblum, 1961). A down soil temperature of about 17-18°C at seed depth is reported to be satisfactory for emergence (Adams, 1965). Therefore, there is a necessity to select cultivars that can germinate at low temperature.

SOLAR RADIATION

Sun is the source of all the energy received on earth. It is the main source of energy which directs photosynthesis in plants and all other energy-consuming processes on earth. Solar radiation heats the soil, air, causes evaporation of water and this in turn affects the weather. Most of the solar energy falls in the wave length 300 to 3000 nm and is called short wave radiation. Sun emits long wave radiation ranging from 3,000 to 50,000 nm. All the solar energy emitted does not reach the earth's surface. Much of the ultraviolet radiations which are harmful to life are absorbed by water, ozone and carbon dioxide in the extraterrestrial atmosphere. Methane is an effective absorber of radiation. Water vapor has a major influence in retaining terrestrial radiation and in reducing its escape to space, thus, it helps in maintaining the energy balance on earth (Rosenburg, 1974). Some of the incoming solar radiation is reflected, absorbed and scattered by clouds and gases and causes sky radiation (Rosenburg, 1974; Yoshida, 1981). In the longrun, the amount of solar energy reaching the earth's surface to direct different energy--consuming processes is termed net radiation. In other words, net radiation is the sum of radiation received minus the short wave radiation reflected and long wave radiation emitted. This constitutes the radiation energy available on earth.

Green plants use a part of net solar radiation called photosynthetically active radiation (PAR) with wavelengths from 400 to 700 nm for photosynthesis. The ratio of PAR to total solar radiation is close to 500 nm in both tropical and temperate regions (Monteith, 1972).