

The efficiency of photosynthesis of a crop depends partially on the interception of solar radiation by the crop canopy. Interception of solar light is maximum in the early morning and late afternoon when the sun's rays fall on the crop canopy at an angle. Interception is minimum when the sun is overhead. But there is a sharp increase in radiation intensity from 7:00 a.m. reaching the peak at 12:00 p.m. and then there was gradual and sharp decline from 13:00 pm onwards in the month of January at ICRISAT, Patancheru, in India (17.5°N) when the sky was comparatively clear (Sivakumar and Virmani, 1980). There is a positive correlation between the interception and conversion of solar radiation into dry matter of the photosynthetic photoflux density (PPFD) by the sorghum crop (ICRISAT, 1981). Growth efficiency was calculated from the slope of the regression between cumulative intercepted PPFD, dry matter and the caloric value of the crop.

Research at Botswana (ICRISAT, 1982) has shown that net radiation measured above the sorghum crop was slightly higher for high plant population, perhaps because less radiation was reflected. Net radiation measured below the crop canopy showed considerable differences between high and low plant populations. The net radiation intercepted by the crop, calculated simply as the difference between measurements above and below the canopy was considerably larger for the higher populations. These trends were maintained throughout the growth, but were somewhat reduced towards the end of the season. These trends indicate that the pattern of net radiation distribution has important implications for water use by different populations densities. It seems probable that much more water moves via the crop pathway under high population while evaporation directly from the soil is greater under low population. Some of the energy below the canopy will be redistributed back to the crop layer by both radiant heat flux and sensible heat flux from the soil, so that differences in the volume of water moving via the crop pathways will not exactly match distribution of net radiation. Energy passing from the soil, i.e. soil heat flux, was maximum under low population. This energy raises soil temperature and is not used directly for evapotranspiration. Thus, in the absence of sensible heat from surrounding areas, net radiation above the canopy minus heat flux represents the total energy available from the crop and soil for evapotranspiration.

RELATIVE HUMIDITY

Humidity is expressed as a percentage of water vapor in the atmosphere at an existing temperature. Even with sufficient water supply to the crop, low humidity causes a daily water deficit. This may have a direct effect on the structure of leaf surface which in turn may influence the internal factors affecting transpiration (Slavik, 1973). The increase in transpiration from morning to mid-afternoon is the result of the increase in leaf air vapor pressure deficit.

O'Leary (1975) and Tromp (1977) concluded that although relative humidity played a significant role in plant growth and development, the literature on the effect of humidity is scanty. In recent years the effect of humidity on crop growth and yield has been reported in wheat (Hoffman and Jobes, 1978) and cotton (Bartsch, 1977), but there is little effect on phenology of the crop. In sorghum

Appathural (1957) observed that under high humidity (80%) the duration of the total lifecycle was shortened while under low humidity (50%), it tended to lengthen. Reddy (1979) and Reddy *et al.* (1984) observed that decrease in humidity caused delay in anthesis and the duration to physiological maturity. A probabilistic model has been derived by Reddy *et al.* (1984) in which the addition of humidity has improved the crop condition in GS2 (correlation coefficient increases from 0.71 to 0.87) than in GS1 and GS3. However, the effect of humidity is significant in the duration to anthesis and to physiological maturity (correlation coefficients increased from 0.75 to 0.86 and 0.70 to 0.83, respectively; Table 7.5).

WIND SPEED

Wind is defined as air in motion and its speed is measured with an anemometer and expressed in km/hr. An increase in wind speed may either increase or decrease transpiration or have no effect, depending on the temperature and vapor pressure deficit between leaf and air, concomitant changes in the resistance of leaf-boundary-layer and variation in internal leaf resistance (Monteith, 1965; Gates, 1968). If the saturation deficit of the air exceeds that at the surface of the leaf, the transpiration rate will increase with wind speed. But when the deficit is the same, transpiration will decrease with increase in wind speed if the deficit at the leaf surface is greater than in the air (Monteith, 1965).

DAYLENGTH

Daylength is the time interval between sunrise and sunset. The natural day length or photoperiod indicates the day length and, the duration of the twilight. Twilight is the time interval before sunrise or sunset, when the position of the sun is 6°C below horizon. House (1980) has made a concise review about the effect of daylength on floral initiation in sorghum.

As sorghum is generally a shortday plant sensitive to photoperiod, the vegetative bud does not flower until the daylength is short enough for the initiation of floral bud which is called the critical photoperiod. Tropical varieties will not flower in temperate zones, because the daylength during summer in the temperate zone never becomes short enough to reach the critical photoperiod stage. Therefore, before the advent of short days, the cultivars become very tall and plants are damaged by frost (House, 1980). Temperate varieties will flower when daylength is less than 12 hours. As plants are moved into the temperate zone, day length may exceed 13 hours. As this is a longer day than in the tropics exceeding the critical photoperiod of the tropical type, it remains vegetative. The temperate zone cultivar may need a critical photoperiod of 13.5 hours in which case a 13-hour day length is still shorter than the critical period at which the temperate cultivar will flower. Therefore, when days are shorter than the critical period, floral initiation occurs.

Daylength not only changes as one moves North or South from the equator, but also with the time of year. This change in daylength has a direct effect on floral initiation as does latitude. Therefore, cultivars having a critical photoperiod

of 12 hours or less cannot be used in the temperate zone unless and until the daylength is artificially reduced. A knowledge of the photoperiodic response of sorghum is of great value to breeders in planning their hybridization program.

RAINFALL AND SOIL WATER

Water is essential to maintain all the vital activities of the plant. Scarcity of water under rainfed agriculture retards the growth of the crop to a large extent. Therefore, in rainfed cultivars, water supply needs to be maintained either by rainfall or by irrigation. The plant absorbs water from the soil through roots, stems and finally to leaves, through which the plant loses water through its stomata.

Soil moisture

After application of water to the soil, some water known as gravitational water runs through due to gravity and drains below the root zone. The remaining water in the soil is known as capillary water and is held by capillary force. To extract capillary water, roots must exert a tension greater than that with which the water is held by soil particles. The moisture in the soil moves in response to water potential gradients, and also as a result of temperature gradient (Rosenburg, 1974). The root zone should have sufficient moisture for proper growth of the plant. Several forces operate in the aerial system, and the root region to maintain this dynamic flow of water from the root to leaves.

Movement of water in soil-plant systems

Perrier (1973) described the pathway of water transfer from the soil to the plant. Water moves in response to a potential gradient both in the soil and the plant. The rate of water movement from the soil is largely controlled by the efficiency of the root system, soil temperature, concentration of soil solution and the free energy status of soil moisture. Changes in soil environment or aerial factors may alter water relations of the plants. For example, drying of soil or an increase in solar irradiation may increase the water deficit in the plant. Besides this, various plant responses counteract these changes in order to preserve water, reduce damage and maintain growth. The closure of stomata under dry conditions is a widely recognized response. Various other internal adjustment mechanisms also exist, for instance, accumulation of solutes in the cells may alter water relations.

Slatyer (1967) and Soman (1980) reviewed the role of solutes in water relations, discussing thermodynamic concepts in terms of soil-plant-water relations. They found that changes in solute content cause fluctuations in free energy of water in the cells. The solute component of the total potential is a function of the solute concentration and of any ionizations. Changes in the mineral supply may affect plant-water relations, but very little is known about this relationship. Mineral salts are necessary to maintain the osmotic pressure of the cell sap. Variations in water relations have been attributed to changes in the solute potential. Stout and Simpson (1978) found that changes in solute potential were associated with parallel changes in solute content.

The energy state of water expressed as water potential (Ψ) is the difference between the chemical potential, i.e., free energy of water in the system, and the

of pure water. Slatyer (1967) put forward the concept of free energy and water movement through the plant. The water in a tissue is held by 2 main forces, the solute potential (ψ_s) due to dissolved mineral potential and (ψ_p) due to the aqueous solution itself, which form the component potential of Ψ ($\psi_s + \psi_p$). A third force, the matric potential (ψ_m) due to the surface forces of the tissue also signifies the energy state of water. Therefore $\Psi = (\psi_s + \psi_p + \psi_m)$ where ψ_s and ψ_m are always negative, and ψ_p may be positive or zero).

The water potential system treats water in soil, plant and the atmosphere as parts of one continuous system. As water changes from the liquid to vapour at a given temperature, the chemical potential remains the same at equilibrium.

At field capacity of soil moisture, plant roots remain in equilibrium with soil water. However, under lower or near zero evaporative situations as happens during the night, losses of water are minimal, and leaf water status attains the level of equilibrium with soil water. To maintain the crop growth rate, it is essential to maintain an uninterrupted flow of water from the soil to the plant system, and any interruption in this flow of water has a direct effect on crop growth and development. The loss of water from the plant canopy is largely controlled by different microenvironments existing within leaves and around the canopy (Perrier, 1973).

Evapotranspiration

Penman (1948, 1956) defines potential evapotranspiration as the amount of water transpired per unit time by a short green crop of uniform height which completely covers the ground and soil, and which is never water deficient. When soil is maintained in a saturated state, evapotranspiration is primarily a function of energy responsible for transpiration and soil surface evaporation. Evapotranspiration is measured by different means in millimetres of water depth over the area considered.

Transpiration is the process by which plant releases water to the atmosphere through stomates in the leaves in response to the atmospheric demand. There are several plant characteristics that affect transpiration. Of these, location and distribution of stomata, reduction of transpiration surface (leaf rolling) and plant age are important.

Evaporation is the moisture lost in vapor from the soil surface. The amount of water available to the roots depends on the balance between rainfall and evaporation, and the relationship between soil moisture content, water potential and conductivity, effective rooting depth and water (Yoshida, 1981).

Evapotranspiration (ET) is affected by the following factors:

SOLAR ENERGY = ET increases with higher solar energies

TEMPERATURE = higher temperatures increase evaporation of water

WIND OR AIR MOVEMENT : a dry wind continuously sweeps away moisture vapor from a wet surface

RELATIVE HUMIDITY = ET is higher when relative humidity is lower and the capacity of air to retain water increases rapidly with temperature

PLANT CHARACTERISTICS = ET is influenced by leaf morphology, depth of rooting and duration of growth

SOIL WATER REGIME = ET is at maximum in saturated soils, but decreases with decrease in soil moisture content.

The knowledge of actual or potential evapotranspiration as given by Penman (1948) has wide utility, as well as other methods listed:

1. **HYDROLOGICAL OR WATER BALANCE APPROACH** - this includes methods such as catchment hydrology, soil moisture sampling and lysimetry.
2. **MICROMETEROLOGICAL APPROACH** : This includes diverse methods such as aerodynamic or mass transport (perfile method: Eddy correlation method), energy balance (Bower ratio method) and combination of aerodynamic and energy balance method (Rosenburg, 1974).

Water balance

Water shortage causes a deficit of water balance in the soil and the plant, disturbing the proper course of all life processes in the plant, and results in failure of crop. The term 'soil-water balance' refers to the balance between moisture loss through evapotranspiration, runoff or drainage resulting in a change of soil moisture in the profile.

To adopt suitable crop management practices, it is necessary to quantify water available at the root zone of sorghum at different stages of crop growth. It is a difficult and timeconsuming process to quantify soil moisture at the root zone. Therefore, a suitable water balance model for predicting water balance will make the job easier for crop management specialists by means of accounting for surplus or deficit soil water. Water balance models provide useful means of evaluating land, and water management systems for better crop growth and crop production. Different water balance models have been developed by several researchers (Ritchie, 1972; Reddy, 1983). Soil water balance models can help solve several agricultural problems; development of agroclimatic models in establishing the length of growing period, adjusting crops to climates, assessment of fallow crop strategies, in the interpretation of considerable variability in crop yields between seasons and regions, and monitoring of supplementary irrigation (Reddy, 1984). In determining the soil water balance, evaporation is estimated. There are several approaches to estimate evapotranspiration. A realistic model takes into account differences among soil types, evaporative demand factors and crop factors such as type of crop cover, and the stage of crop growth.

Water use efficiency

Water shortage is the main factor limiting sorghum production in dryland areas. The growth and development of the crop in drylands depends on the efficiency with which the cultivars maintain growth with minimum water use. Jones *et al.* (1979) interpreted that the potential methods for increasing grain production in dryland agriculture are to modify land surface for better utilization of runoff water and minimizing soil water evaporation. Water use efficiency (WUE) can be expressed as the weight of dry matter produced per unit of water usage (Sullivan *et al.* 1980):

$$WUE = \frac{\text{Total biomass}}{\text{water use}} \quad \text{or} \quad \frac{\text{grain yield}}{\text{water use}}$$

They showed that WUE decreased as seasonal ET declined. Hybrid sorghum showed an increase in WUE under different irrigation treatments.

Response of sorghum to soil moisture deficit

Soil moisture deficit has a direct effect on crop growth. The first symptoms of

deficit of soil moisture in sorghum are wilting, rolling and twisting of plant leaves (Musick *et al.*, 1976). According to them, early in the crop season, grain sorghum has the remarkable ability to recover from the effects of deficient soil moisture, but irrigation after severe soil moisture deficit before heading of sorghum stimulates growth.

Leaf water potential

Soil moisture deficit has effects on leaf water content and stomatal conductance. Johnson *et al.* (1974) reported that the rates of net photosynthesis and transpiration of leaves and ears decreased linearly with decreasing leaf water potential.

According to Slatyer (1969) the level of plant water potential, and hence of internal water deficit, is influenced by 2 main factors: level of soil water potential and diurnal lag of absorption behind transpiration. Research on sorghum at Botswana showed that leaf water potentials of upper leaves were slightly higher in the narrower row spacings in both high and low populations throughout the growing season than in wider row spacings.

Stomatal conductance

Under decreasing tissue water, stomates close and the conductance of transpiration water decreases. Stomatal conductance was determined by measuring the rate of water flux (cm/sec) from the leaves with the help of the porometer. Sivakumar *et al.* (1981) showed that there was a gradual decrease in leaf water potential with age of sorghum crop and also with increase in moisture stress levels, because of the relative distance from the line source sprinkler system.

Stomatal conductance was influenced by the time of day and also by canopy depth. Under conditions of adequate water supply, stomates remained open from early in the morning until about 16:00 p.m. With decreasing irradiance, the stomatal conductance showed a rapid drop.

Using line source sprinkler, with a decrease in soil moisture with gradient inline source, there was a decrease in stomatal conductance and leaf water potential, and a rise in leaf temperature in sorghum (Sivakumar *et al.*, 1981).

Leaf-air temperature differential (stress degree day)

Drought induced stomatal closure caused by a decrease in leaf water potential, increases leaf temperature above the air temperature differential and was defined by Reddy *et al.* (1984) as stress degree day (SDD). The environmental stress imposed on leaves can be explained by considering the difference between leaf temperature and air temperature, the leaf-air temperature differential. This is strongly related to soil-water availability (Van Bavel and Ehler, 1966). High temperature causes leaf dessication and leaf firing in sorghum (ICRISAT, 1981).

There are several sophisticated techniques like porometer used to measure the water status of the plant but they are timeconsuming, and sometimes not reliable due to the extreme precautions required. These techniques can be used only on a small number of cultivars to avoid variation of plant water status.

Selection of genotypes for drought resistance

Plants have profound differential abilities to cope with drought. Crop cultivars are often exposed to depleting soil moisture conditions as a result of drought at different stages of plant development.

Drought at the seedling stage affects the establishment of seedlings and impairs

the development of roots, leaf expansion and initiation of reproductive meristem. Similarly, drought occurring at GS2 stage (panicle initiation to flowering) affects the normal development of the panicle thereby affecting the development of the florets and size of the vegetative shoot (source). Drought at the grainfilling stage affects the normal process of fertilization, seed setting and the size of grains. The effect of water stress on growth and development of sorghum was reported by Wilson and Whiteman (1965) and Bonnett (1979).

Effect of water stress on plant functions

Water stress is one of the wellknown causes of reduction in the growth rate of the plant, mainly due to either inhibition of cell division and/or enlargement (Kramer, 1969; Slatyer, 1973; Stocker, 1960). Water stress causes a decrease of pressure on the cell walls with the consequent separation of cellulose microfibrils. The emphasis is on inhibition of cell enlargement by water stress (Acevedo, *et al.*, 1971; Boyer, 1970). If water stress causes a decrease in leaf area, the number of stomata per unit area should increase provided stomatal differentiation is not affected. The rates of cell division and enlargement in stressed and unstressed leaves give an idea about the response of cultivars to water stress.

Bidinger (1978) reviewed the effect of water stress on plant development. Water for transpiration in plants comes mainly from the cellwalls lining the inner stomatal cavity; water loss in turn leads to a decrease in the chemical and water potential remaining in these cell walls. As water in the plant cells forms a continuous system throughout the plant, the negative potential is transmitted along with water in the xylem system from leaf to root. This creates a gradient between root and soil and causes water to move from the soil into the root. This potential gradient between leaf and soil is maintained by continued transpiration from the leaves.

Transpiration from leaves starts at sunrise and decreases in the evening. Atmospheric conditions favoring high rates of transpiration do not themselves induce large water deficits in the plant (Macklon and Weatherley, 1965). It is only when rapid water flux is coupled with the low water conductivity of the soil that high water stresses occur. The change in leaf ψ is transmitted to the absorbing surface (Weatherley 1970, Hsiao, *et al.* 1970) and absorption starts. But the entire water loss from leaves will not be compensated by absorption. Thus, a deficit for water develops in transpiring tissue. The magnitude of this deficit increases until the rate of absorption equals the rate of transpiration. This rhythm is repeated every 24 hours.

As diurnal rhythm of high and low ψ continues, the soil will no longer contain enough water to meet the daily evaporative demand and plant ψ declines progressively. Consequently, ψ in plants at dawn is also expected to become more negative. When this happens, the decreasing ψ plant at the root surface (root) fails to maintain the water flow to roots because of the drastic decline in the soil hydraulic conductivity with soil water content (Slatyer, 1967).

As ψ declines, the leaf turgor also declines for increasingly longer periods as the soil dries out. Finally, permanent wilting occurs when plant ψ at dawn equals to the solute potential at zero turgor (Slatyer, 1957 a,b).

The subcellular changes in sorghum leaves during water stress and subsequent rewetting are described by Giles *et al.* (1976). At -14 bars leaf water potential

stomata are closed, abscisic acid levels are elevated and the amounts of starch in the bundle sheath chloroplasts are much lower. The outer chloroplast membranes swell and the tonoplasts reorganize to form small vessels from the large central vacuole at a higher leaf water potential (ψ) of -37 bars. On rewetting, large amounts of starch reappear. The maintenance of tonoplast integrity is an important factor in the ability of plants to withstand drought. Reduction in cell division and cell expansion have a direct effect on leaf area index. As radiation interception is directly related to leaf area index, the photosynthetic efficiency of the crop is reduced.

Hsiao and Acevedo (1974) have summarized the mechanisms underlying the effect of water stress. Loss of tissue water may be due to the following physical and chemical changes: 1- the chemical potential or activity of cellular water is reduced, 2- turgor pressure decreases in cell, 3- small molecules and macromolecules become more concentrated in the plasmalemma and tonoplast, and membranes of organelles are altered as cell volume is reduced, 4- the effect on macromolecules might be through the removal of water of hydration or through modifications of the structure of adjacent water.

Hsiao (1973) stated that cell wall synthesis under water stress continued for a period even when there was no growth due to lack of turgor in the stressed plants. Cell division appeared to be as sensitive as cell expansion to prolonged water stress (Gardner and Nieman, 1964), while in other cases cell division appeared to be less sensitive. The sensitivity of mitosis to prolonged mild stress may be an indirect result of reduced cell expansion. Under severe water stress, turgor pressure may come down to zero and under such a situation, plants can maintain some growth through osmoregulation, a mechanism of solutes build up in the cells so that turgor pressure can be developed inspite of low water potential. Hsiao and Acevedo (1974) suggested that one of the earliest tests for a breeder in selecting drought resistant plants (or even plants with higher wateruse efficiency) would be to determine the ability of the plant to maintain expansive growth at reduced water potential.

Effect of water stress on leaf growth

Growth can be defined as an increase in dry weight or leaf area. The rate of growth is, therefore, the change in weight or area per unit time. These differences result from physiological and biochemical processes. Environmental factors such as water stress affect at least some of the mechanisms causing changes in the rates of the processes (Soman, 1980).

Leaf growth of many crops is inhibited by water stress; such is the case with wheat (Ford and Thorne, 1974; Connor, 1975; Sands and Correl, 1976; Quarrie and Jones, 1977; Rawson *et al.*, 1977); Maize (Lawton, 1969; Boyer, 1970; Hsiao, *et al.*, 1970; Kleinendorst, 1975); sorghum (McCree and Davies, 1974; Kaigama *et al.*, 1977; Stout *et al.*, 1978); and barley (Nicholas and May, 1963; Hussain and Aspinall, 1970; Biscoe *et al.*, 1975).

It is generally believed that water stress affects leaf growth but observations vary and opinions differ as to what stress affects and how stress operates. Reduction in leaf area may result from small leaf size and/or decreased leaf number. Leaf size is the outcome of the leaf expansion rate and the duration of growth;

leaf number depends upon leaf initiation and senescence. Water stress has been found to affect all these processes. Leaf expansion depends upon cell division and cell enlargement. Attempts have been made to relate variation in leaf area due to water stress to either cell division or enlargement. Earlier cessation in cell division along with smaller cells has been observed in sorghum (McCree and Davies, 1974), wheat (Quarrie and Jones, 1977), and maize (Kleinendorst, 1975).

Effect of water stress on inflorescence development
Flowering in cereals is thought to be sensitive to water stress. The rate of appearance of floral primordia appears to be reduced by mild water stress.

The effect of water stress on inflorescence development in sorghum appears to be somewhat different from those on other cereals (Wilson and Whiteman, 1965). When severe stress was applied for about a week at the time of inflorescence growth, it ceased. Yet upon rewatering, panicle development apparently proceeded unaffected, and the number of grains was not significantly different from control plants.

Mechanisms of drought resistance

Different mechanisms exist in crop plants to resist soil moisture stress (Levitt, 1972). Jordan and Monk (1980) have reviewed sorghum literature related to various mechanisms for avoidance or tolerance of drought and indicated that avoidance mechanisms provided the greatest opportunities for yield maintenance. Reactions and resistance of grain sorghum to heat and drought have been discussed by Jordan and Sullivan (1982):

Drought escape

Escape mechanisms to resist drought operate in sorghum in 3 ways - early maturity, developmental plasticity, and remobilization of stem reserves (stored before anthesis) to grain,

Early maturity

In much of the Indian peninsula, early maturing hybrids and varieties of 100-110 days duration are known to escape the effect of a late drought and have replaced the traditional sorghum types with a duration of 130-180 days. This has resulted in a remarkable increase in sorghum production in spite of intermittent drought on early maturing genotypes in proportion to their lower leaf area index and lower root density. Blum (1970b) has demonstrated the yield advantage associated with early maturity for dryland sorghum grown in the mediterranean climate. Early maturity has greater potential in cultivars where growth is achieved on stored moisture.

Drought avoidance

For the same level of soil moisture stress, some sorghum genotypes consistently maintain higher leaf water potentials (Blum, 1974 a,b and 1975a). This phenomenon is independent of leaf rolling which serves to reduce the effective leaf area per plant (Begg and Turner, 1976). Drought avoidance is achieved by increased root growth or by maturity before the onset of drought. Genotypic differences in sorghum roots have been found to exist (Blum *et al.*, 1977 a,b; Jordan *et al.*, 1979). Screening methods using nutrient culture (Jordan *et al.* 1979) or brick chambers have been found satisfactory for seedling drought studies.

Drought tolerance

The response and tolerance of plant tissue to reduction in leaf water potential may involve a number of physiological and metabolic processes. Maintenance of growth and interpretation of results are difficult to assess due to complex interactions in size among the organs (Blum, 1973; Begg and Turner, 1976).

Heat and desiccation tolerance and ability to recover from stress

The usefulness and practicality of testing for heat and desiccation tolerance were reviewed by different authors (Arnon, 1975; Sullivan and Ross, 1979).

Osmotic adjustment

Diurnal and seasonal osmotic adjustment in response to water stress has been reported in sorghum by Jones and Turner (1978) and genotypic differences for this trait were studied by Stout *et al.* (1978). Under conditions of high atmospheric demands for water, a decrease in osmotic potential was shown to contribute to leaf expansion in sorghum (Acevedo *et al.*, 1971). Thus, we find that different mechanisms exist in sorghum to withstand drought, and genotypes show a wide range of variability to drought response.

Jordan and Sullivan (1982) stated that maturity, root system diversity, epicuticular wax loads, osmoregulation, heat and desiccation tolerance play an important role in determining the avoidance mechanism in sorghum. Genetic variability has been demonstrated by several authors (Jordan and Monk, 1980). High root to shoot ratios of young plants have been correlated with superior drought resistance (Nour and Weibel, 1978; Bhan *et al.*, 1973). Increased rooting depth will increase total water availability for the plant (Jordan and Miller, 1980). The aerial surfaces of most sorghum cultivars are covered with a thick, amorphous layer of epicuticular wax. In addition, normal or bloom types show the presence of wax filaments on peduncle, leaf sheath and basal portions of the abaxial leaf surface giving a fluffy, white appearance. Epicuticular wax is said to enhance drought resistance. The presence of the waxy bloom is controlled by a single, dominant gene. Several bloomless and sparse bloom variants are reported (Ayyangar and Ponnaiya, 1942; Ayyangar *et al.*, 1937). Consistent yield advantage of waxy bloom is observed in water deficient environments (Ross, 1972; Webster, 1977; Webster and Schmalzel, 1979). Chatterton *et al.* (1975) reported that transpiration is lower in waxy bloom isolines. Genotype response across environments over the years was variable in some cultivars that maintained high epicuticular wax loads (Ebercon *et al.*, 1977; Powell *et al.*, 1977; Jordan and Miller, 1980).

The role of high epicuticular wax loads is considered to be important to leaf survival rather than to maintenance of high productivity since its principal function is to retard water loss via the cuticular pathway (Jordan and Miller, 1980). Osmoregulation is defined as osmotic adjustment by cells through synthesis and accumulation of solutes in response to water deficits. The solutes are a complex mixture of organic acids, amino acids and sugars. This mechanism of osmoregulation serves as a means to maintain turgor as tissue water potentials fall and growth is retarded (Hsiao, 1973).

Two cultivars, RS 610 and Shalu, differ in drought resistance, but did not show differences in their osmoregulatory capacity (Jones and Turner, 1978; Turner and Jones, 1980). Blum *et al.* (1977 a,b) demonstrated cultivar differences in the

capacity to accumulate proline in response to water stress. Blum (1979 a,b) suggested that proline may be an important energy source during recovery from water stress. Hensell *et al.* (1975) reported cultivar differences in stomatal sensitivity to water deficit but large-scale screening was not attempted. Ackerson *et al.* (1980) reported osmotic adjustment of lines and hybrids subjected to drought in the field.

Sullivan (1972) described a simple method to evaluate heat and desiccation tolerance based on loss of membrane integrity of leaf tissue following stress under controlled conditions. Heat tolerance has been positively correlated with yield when crops are exposed to heat and drought stress (Sullivan and Ross, 1979). Genotypic variability exists in sorghum for both heat and desiccation tolerance (Sullivan 1972; Blum and Ebercon, 1976; Sullivan *et al.*, 1977; Sullivan and Ross, 1979), but parallel ranking between the 2 tests were not obtained (Sullivan and Ross, 1979).

SCREENING

Several approaches for drought resistance screening have been advocated (Seetharama *et al.*, 1984). These may be either direct or indirect selection for resistance and explain either selection for absolute performance of crops under actual stress conditions or selection for a small reduction in growth and components under stress compared to unstressed plants. Indirect selection implies screening for morphological or physiological characteristics which appear to be related to drought resistance (Maiti, 1981). Evans (1980) stated that empirical selection is likely to remain the most effective procedure. Direct selection from field screening often fails due to sudden and unexpected rains. Field screening could be done at sites or in seasons where there is little or no rainfall or where moisture supply can be controlled. Warmer parts of the dry season are preferred as the temperature and radiation levels tend to be high and vapor pressure low, all favouring high transpiration rates when soil moisture supplies are inadequate to meet the demand.

Selection for desiccation and heat tolerance was adopted by Sullivan and Ross (1979) and for stomatal sensitivity to stress by Hensell *et al.* (1975). Use of these techniques to evaluate germplasm is difficult to achieve. Therefore, to evaluate a large number of germplasms and breeder lines, priority should be given to field screening. The selected lines can then be subjected to various tests for investigating the underlying drought resistance mechanisms.

Breeding strategies

Strategies for breeding for drought resistance have been discussed by various authors (Blum, 1979 a,b; Hurd, 1976; Sharma and Saxena, 1979; Townley-Smith and Hurd, 1979). According to Nederski and Jeffers (1973), a superior yielding variety under optimum conditions will also give good yields under suboptimal conditions. Stability of yields over various environments would lead to accumulation of stable yield genes which perform under stress situations (Blum, 1973).

Blum (1973) outlined some approaches for improving drought resistance in sorghum: 1- the improvement of yield performance under conditions of drought stress should be associated with an improvement of yield at potential levels. 2- selection of superior varieties under drought conditions may be less adaptable to the relevant environments even as breeders attempt to manipulate yield genes.

Varieties developed in such a program are grouped for high genotypes X environment interactions. At subpotential levels, heritabilities for yield and yield components are relatively low and selection for yields is not efficient (Johnson *et al.*, 1974); 3- a combined research approach supported by background research in plant breeding and plant physiology may provide genetic improvement for drought resistance.

At ICRISAT, many simple techniques have been developed to screen sorghum germplasms and breeder lines for drought resistance at seedling stage under semicontrolled conditions in brick flats, PVC cylinders and also in the fields. Significant genotypic differences in response to drought at seedling stage have been found both in the germplasms and breeder's elite lines, as measured by scores for wilting, recovery and survival after the release of stress. Many of the lines resistant to drought at the seedling stage have been observed to have light green leaves with a glossy surface, while the susceptible lines, generally have dark green leaves. About 21,000 germplasm accessions have been screened for the "glossy" trait and about 520 glossy lines have been identified. These lines are being tested for drought resistance.

Field screening at ICRISAT, attempts have been made by physiologists to evolve simple, direct empirical drought screening methods to evaluate germplasms and breeder's lines. The experiments were conducted under soil moisture stress in the post-rainy and summer seasons. Initially this was confined to 1- drought during the panicle development stage, and 2- conditions of receding soil moisture in vertisols. The former represents the midseason drought pattern of the rainy season in many parts of SAT and the later shows similarity with the crop grown under receding soil moisture conditions in Israel as well as in parts of West Africa.

The line-source-sprinkler irrigation (LS) proposed by Hanks *et al.* (1976) is useful to maintain a stress gradient with minimum land and cost. A single row of overhead sprinklers produces a gradient of water application pattern. A series of test rows of different genotypes at right angles to the line source can be planted. Each row is thus being exposed to a uniform gradient of water from zero to any desired maximum. Genotypic differences in response to declining water supply can be detected when yield is plotted against water applied through LS. The intercepts and slopes of regression equations indicate yield potential and plant susceptibility to gradual decline in water supply, respectively. Genotypes with higher intercepts and lower degree of slopes are selected. This technique is being used at ICRISAT; experiments were conducted to evaluate 1- relationships between soil water and crop growth, 2- development and yield, and 3- usefulness of the technique to screen sorghum genotypes for drought resistance.

GENERAL COMMENTS

An account of crop environment clearly shows that growth and development of a crop is largely dependent on interaction of microclimates with crop canopy. A knowledge of these microclimates is an essential prerequisite to adopting suitable crop management practices. This chapter emphasizes that the sun is the