Effect of water stress on growth and biomass yield of contrasting genotypes of sugarcane (*Saccharum officinarum*)

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SUMMARY

Effect of water stress on expansive growth measured as leaf extension rate (LER) and plant height of five selected lines of sugarcane (BD 83/019, BD 83/035, IB 85/43, USRI 86/4, and USRI 86/25) was investigated in a screenhouse trial at Unilorin Sugar Research Institute farm. The effect of water stress on biomass yield was also evaluated. Water stress was induced by differential watering intervals of daily, 4, and 10 days corresponding to 100 (no stress), 60 (moderate stress), and 25 per cent (severe stress) soil available water (determined gravimetrically). LER, hence leaf length and plant height, showed significant responses to water stress, decreasing when water is limiting. The results of this study also showed ontogenetic variations in the responses of leaves at different positions to water stress. Similarly, there were genotypic differences in leaf and plant height responses of the investigated lines to water stress, which were found to be related to the effect of water stress on biomass yields of the lines. Consequently, it was concluded that measurement of expansive growth could be very useful for distinguishing between genotypes in their responses to water stress; hence, a promising technique for screening for drought tolerance in sugarcane. The advantages of the techniques are also discussed.

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RÉSUMÉ

ABAYOMI, Y. A. & LAWAL, O. J.: *L'effet de la pression d'eau sur la croissance et le rendement de biomasse des génotypes contrastés de canne à sucre* (Saccharum officinarum). L'effet de la pression d'eau sur la croissance expansive, mésuré comme la proportion de prolongation de feuille (PPF) et la taille de plante de cinq espéces de canne à sucre sélectionnées (BD 83/019, BD 83/035, IB 85/43, USRI 86/4 et USRI 86/25), était enquête dans un bout d' essai d' intérieur au champ d' Institut de Recherche en Sucre à Unilorin. L' effet de la pression d' eau sur le rendement de biomasse était également évalué. La pression d' eau a été déclenchée par l' arrosage à intervalle différentiel quotidien, de 4 et 10 ours correspondant à 100 pour cent (pression nulle), 60 pour cent (pression moyenne) et 25 pour cent (pression sévère) de l'eau disponible dans le sol (déterminé par le système gravimétrique). La proportion de prolongation de feuille (PPF) d' oú la longueur de feuille et la taille de plante, montrait des réactions considérables à la pression d' eau, allait en décroissant lorsque l'eau est contraignante. Les résultats de cette étude montraient aussi les variations ontogénétiques dans les réaction de feuilles à des position différentes à la pression d'eau. De la même façon il y avaient des différence génotypiques dans les réactions des tailles de feuille et de plante des espéces enquêtés à la pression d' eau, qui étaient découvertes d' être liées à l'effet de pression d' eau sur les rendements de biomasse des espèces. Par consequent, la conclusion était tirée que l'évaluation de la croissance expansive pourrait être trés utile pour distinguer entre les génotypes, en ce qui concerne leurs réposes à la pression d' eau, d' oú, une méthode prometteuse pour un test de dépistage de tolérance à la sécheresse dans la canne à sucre. Les avantages de la méthode sont également discutés.

Introduction

Agricultural drought is said to exist when the level and distribution of precipitation is sufficiently low to cause serious shortfall in crop yield (Hulse, 1989). According to Meigs (1953), more than 40 per cent of the world's land surface is within the arid and semi-arid regions, where water limits plant productivity, and the full genetic potential of crop plants are seldom attainable (Innes & Blackwell, 1981). The losses of production in major droughts, especially in developing countries, can be devastating as it occurred in parts of sub-saharan Africa, as well as in most parts of Asia and North America during the last two decades. The development of more drought-tolerant crops and varieties is, therefore, imperative to improve and sustain agricultural production in arid and semi-arid regions of the world.

To develop cultivars that can withstand drought, it is important that one identifies crop genotypes that can survive during stress and/or recover after stress; as the yield of crops under drought is largely determined by these characters (Sairam & Dube, 1984). Thus, method(s) for mass screening of crop varieties must be evolved to speed up breeding programmes involving drought-tolerant and drought-resistant varieties. It is widely recognized that plant response to drought varies with species (Tanguilig *et al.*, 1987), although no particular criterion for drought tolerance has been evolved (Hsiao, 1973). Nevertheless, various attempts have been made to define specific chemical or physical characteristics that indicate drought tolerance. For instance, measurement of expansive growth and photosynthesis are among factors that have been found to be most sensitive to stress (Hsiao, 1973; Boyer, 1976).

A common procedure for evaluating resistance is to relate yield to a standard cultivar over several years at locations where drought may occur (Anderson & Reinberge, 1985). This process depends on year to year changes in weather and is extremely time consuming. Hence, breeders nowadays desire a rapid and inexpensive screening technique for use on early generations of breeding materials to identify drought tolerance.

One of the easiest test for a breeder in selecting for drought resistance/or water use efficiency (WUE) would be to determine the ability of the plant to maintain expansive growth at reduced tissue water potential. Hsiao & Acevedo (1974) noted that such a test should be quick and simple, since young leaves of any species grow rapidly enough so that growth during a fraction of a day can be measured non-destructively, merely with a ruler. This was supported by Wien, Littleton & Ayanaba (1979) who also suggested that the rate of extension growth, e.g. leaf development rate and main stem growth rate, as traits that could be measured to indicate varietal drought resistance. Leaf expansion is also well known to be very sensitive to water stress (Boyer, 1970; Hsiao, Acevedo & Henderson, 1970). The measurement of leaf growth in the field has also shown that leaf growth is a sensitive indicator of water stress (Acevedo, Hsiao & Henderson, 1971; Eastham, Oosterhuts & Walter, 1984).

Sugarcane is an important crop in Nigeria whose productivity is largely threatened by perennial drought; hence, the need to breed and select for drought tolerance in the crop. Consequently, resistant genotype must be identified (to be used as parent materials) from a large germplasm collection of local and exotic genome in the Unilorin Sugar Research Institute farm.

This study therefore aimed to evaluate the effect of water stress on the expansive growth of five selected genotypes, and to determine the suitability or otherwise of such measurement as a screening technique for drought tolerance in the crop.

Materials and methods

The study was conducted in a screenhouse at the Unilorin Sugar Research Institute. Plants were grown in 10-l pots filled with sterilized top soil (loamy sand: 86.4 per cent sand, 10.0 per cent silt, and 3.6 per cent clay:) The study was carried out in a completely randomized design in a factorial experiment with three replications. There were five selected sugarcane genotypes, namely: BD 83/019, BD 83/035, IB 85/43, USRI 86/4, and USRI

86/25. The water stress treatments included a control (no stress) and two stress levels (moderate and severe stress). For the moderate and severe water stress treatments, soil moisture was maintained at 60 per cent (0.5 mpa) and 25 per cent (1.2 mpa) soil available water, respectively. These were found (gravimetric determination) (Kramer, 1983) to correspond to 4 and 10 days watering intervals.

Whole stalk canes were cut into one-budded setts, and two sets were planted per pot, but thinned to one seedling per pot after sprouting. The pots were adequately watered daily after planting until treatment was applied at 6 weeks after planting (WAP). Fertilizer was applied at 2 WAP at rates of 960 mg N/pot, 600 mg P_2O_5/ pot, and 1200 mg K_2O/per pot which were equivalent to 160 kg N/ha, 100 kg P_2O_5 ha, and 200 kg K_2O / ha, respectively. Weed was controlled inside the pot by hand rouging at 2-weekly intervals.

Leaf extension rate in four leaf positions (L8, L10, L12, and L14 from the base) was measured by the method of Tanguilig *et al.* (1987) as modified by Abayomi (1992). A metre ruler was used to measure leaf length every other day, starting as soon as the leaf emerged, and it was continued throughout the whole growth period. Leaf length was measured from the ligule of the last fully expanded leaf below to the tip of the newly emerging leaf. The extension rate per day (ERD) was calculated as follows:

$$ERD = [X_p - X_l]/d$$

where X_l = last measured length.
X_p = present measured length, and
d = measurement interval in days

Height of the main stalk was measured with a metre ruler at weekly intervals starting from when stress was applied until harvest. Plant height was measured from the soil level to the tip of the last-emerging leaf. Each pot was harvested by hand cutting at the soil level. Thereafter, the fresh weight was measured and the plant was oven-dried for 72 h at 80 °C after which the dry weight was measured.

All data were subjected to analysis of variance, and treatment means were separated by the Duncan's New Multiple Range Test, at 5 per cent probability level.

Results

Effect of water stress on extension rate (LER) and length of leaves

The extension growth in four leaf positions was measured during the stress period. Tables 1 and 2 show the individual genotypic responses of the studied genotypes for the maximum LER and final leaf length, respectively.

Table 1 shows the effects of water stress treatments on the maximum LER of the five sugarcane genotypes. The effects of water stress on LER were marked at the four leaf positions of all genotypes except BD 83/019. Consequently, the final lengths of leaves at four positions were reduced to varying degrees, with significant differences in all genotypes except IB 85 /43 (Table 2).

Effect of water stress and genotypes on plant height

Fig. 1 shows the effects of water stress on height of different sugarcane genotypes. The results show that water stress decreased plant height in USRI 86/25, BD 83/035, and USRI 86/4 with increasing magnitude in that order. However, the height of both BD 83/019 and IB 85/43 was appreciably unaffected by water stress treatments.

Effect of water stress and genotypes on biomass yield

Fresh and dry biomass yields were decreased by water stress, even though the differences were not significant (Fig. 2). Although the analysis of variance showed that the water stress × sugarcane genotypes were significant for biomass yields,

TABLE 1

Effect of Water Stress on Leaf Extension Rates (LERs in cm day-1) at Leaf Positions 8, 10, 12, and 14 During Maximum Growth

Water stress	*Sugarcane genotypes*				
	BD 83/019	*BD 83/035*	*IB 85/43*	*USRI*	*USRI 86/4*
			Leaf 8 (L 8)		
No stress	3.8a	5.8a	5.1a	4.7a	5.2a
Moderate stress	3.2a	1.8b	4.5b	3.7a	3.7b
Severe stress	2.7a	1.4b	3.6b	2.5b	2.2c
			Leaf 10 (L 10)		
No stress	4.0a	4.8a	9.7a	8.7a	7.1a
Moderate stress	3.9a	3.3a	5.0b	6.5a	2.8b
Severe stress	3.7a	1.9a	2.3b	1.8b	0.3b
			Leaf 12 (L 12)		
No stress	10.9a	10.3a	7.3a	4.5a	3.9a
Moderate stress	9.5a	4.9b	5.7a	3.5a	1.6a
Severe stress	2.0b	2.3b	2.6a	2.0a	0.3a
			Leaf 14 (L 14)		
No stress	4.4a	5.0a	4.2a	5.0a	3.7a
Moderate stress	3.4a	3.9a	3.1a	3.4a	3.3ab
Severe stress	3.2a	3.6a	2.8a	1.2b	1.8a

Figures followed by the same letters in each column are not significantly different on Duncan's New Multiple Range Test at $P<0.05$.

TABLE 2

Effect of Water Stress on Final Size (Length in cm) of Leaf at Positions 8, 10, 12, and 14 During Maximum Growth

Water stress	*Sugarcane genotypes*				
	BD 83/019	*BD 83/035*	*IB 85/43*	*USRI*	*USRI 86/4*
			Leaf 8 (L 8)		
No stress	126.9a	126.0a	101.3a	112.7a	132.0a
Moderate stress	120.4ab	114.8a	94.2a	107.8a	118.8ab
Severe stress	104.2b	89.3b	92.0a	86.5b	109.3b
			Leaf 10 (L 10)		
No stress	115.3a	122.0a	98.0a	116.7a	145.3a
Moderate stress	110.3a	87.0b	91.5a	78.7b	91.7b
Severe stress	96.2a	76.3b	90.2a	70.3b	88.0b
			Leaf 12 (L 12)		
No stress	108.3a	109.7a	94.0a	106.7a	123.3a
Moderate stress	95.3a	79.3ab	81.0a	70.0b	64.3b
Severe stress	80.2a	53.0b	76.7a	36.7c	61.7b
			Leaf 14 (L 14)		
No stress	127.4a	126.7a	96.7a	120.3a	115.5a
Moderate stress	107.3a	121.1a	84.3a	86.8b	75.3b
Severe stress	73.7b	85.6b	69.8a	32.5c	74.9b

Figures followed by the same letters in each column are not significantly different on Duncan's New Multiple Range Test at $P<0.05$.

Table 3 shows that the responses of the lines to the water stress treatment were not the same. The effects of water stress on fresh and dry biomass were severe on USRI 86/25 and USRI 86/4, moderate on BD 83/035, while BD 83/019 and IB 85/43 were relatively unaffected.

Discussion

The importance of leaf area and its effect on crop yields have long been recognized (Friend, Helson & Fisher, 1962). The final yield of dry matter have been shown to be proportional to the total amount of radiation intercepted by crops during growth (Scott & Jaggard, 1978; Milford *et al.*, 1980), and light interception is largely determined by leaf area index (Milford, Peacork & Riley, 1985). Drought stress has been shown to reduce leaf expansion (Boyer, 1968; Acevedo, Hsiao & Henderson, 1971; Watts, 1974), thereby resulting in smaller leaf area which can adversely affect yield (Fischer & Hagan, 1965; Hsiao *et al.*, 1976).

The results of this study showed that the extension growth and hence, the sizes of the measured leaves were decreased to varying degrees by water stress. Similar decreases in LERs and sizes of leaves due to water stress have been reported by other workers (Lawlor *et al.*, 1981; Milford *et al.*, 1985; Tanguilig *et. al.*, 1987; Abayomi, 1992).

There were ontogenetic variations in leaf growth, and hence in the response to water

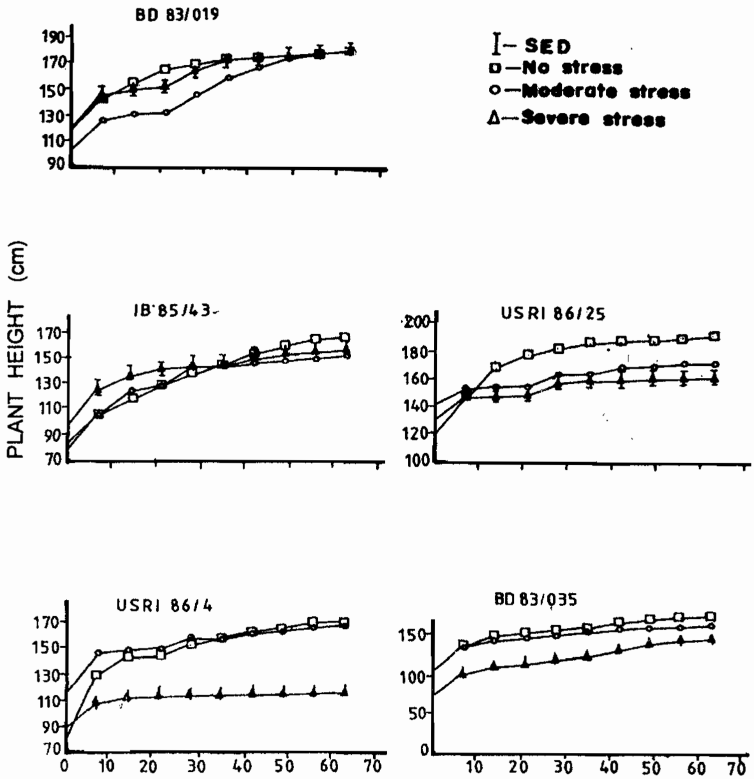

Fig. 1 Genotypic responses of plant height to water stress.

stress. The results of this study showed that the magnitude of the effect of water stress on LERs, and hence on the final leaf lengths, increased with leaf position in sugarcane. Thus, the youngest leaf measured (L 14) showed greater response than the lower leaves in all genotypes. Abayomi (1992) showed similar differences in responses of leaves at different positions to water deficit in wheat. However, lower leaves in sugar beet have been shown to be more sensitive to water stress than the upper leaves (Milford *et al.,* 1992). This suggests that the leaf position becomes an important factor influencing response if a single leaf position is studied, and this will depend on the type of crop.

It has been observed that variation in plant height under stress may be one of the causes of variances in crop yield (Hadjichristoloulou, 1987). Evidence for this observation was found in this study. Both water stress treatments decreased plant height across sugarcane genotypes, although the decrease was more severe with the higher stress. The decrease in plant height in response to drought has been reported for wheat (Day & Italap, 1970; Abayomi, 1992), barley (Day *et al.,* 1978; Lawlor *et al.,* 1981), and grain sorghum (Blum, Mayer & Golon, 1989). The relative decrease in plant height under water stress was found to be well correlated with that of biomass yield (Fig. 3). Thus, IB 85/43 and BD 83/019 sugarcane genotypes with relatively smaller decrease in height due to water stress had the best yield stability (Table 3).

In conclusion, expansive growth, measured as

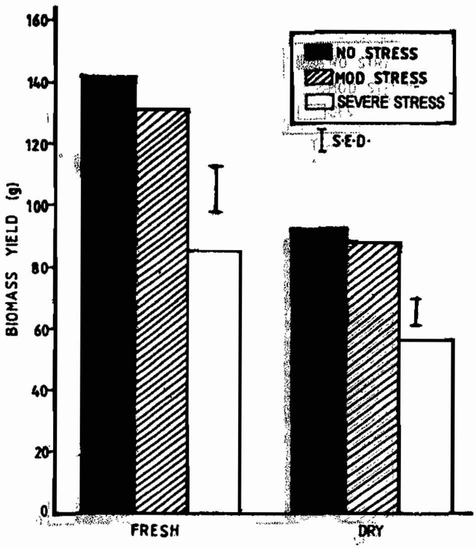

Fig. 2. Effect of water stress on fresh and dry biomass yields across five genotypes.

leaf extension and plant height of sugarcane plant, showed measurable responses to water stress, decreasing when water is limiting as reported for other crops. This effect was also found to be genotype dependent (Tables 1, 2 and 3; Fig. 1). Thus, the results of this study showed that the measurement of expansive growth could be very useful in distinguishing between genotypes in their responses to water stress in sugarcane. Moreover, using a ruler to measure leaf length and plant height as was done in this study is simple, fast and inexpensive and, therefore, could be a good selection criterion in large-scale selection programme. This was supported by an earlier report that growth response in terms of plant height was found to serve well as one component of multiple selection index for drought resistance in maize (Fischer, Johnson & Edmeads, 1983).

TABLE 3

Effect of Water Stress on Biomass Yields and Yield Stability in Five Sugarcane Genotypes

Sugarcane	*Water stress*	*Fresh biomass yield*		*Dry biomass yield*	
		Yield	*Yield percent*	*Yield*	*Yield percent*
BD 83/019	No stress	113.44a	100.0	78.07a	100.0
	Moderate stress	109.03a	96.1	77.85a	99.7
	Severe stress	94.4a	83.2	67.98a	87.1
BD 83/035	No stress	107.42a	100.0	78.29a	100.0
	Moderate stress	103.29a	92.2	67.91a	86.7
	Severe stress	70.70b	65.8	49.19b	62.8
IB 85/43	No stress	124.33a	100.0	67.36a	100.0
	Moderate stress	129.58a	104.2	83.52a	124.0
	Severe stress	104.95a	83.6	58.81a	87.3
USRI 86/4	No stress	127.25a	100.0	81.61a	100.0
	Moderate stress	107.04a	84.1	78.00a	96.8
	Severe stress	74.02b	58.2	46.71b	57.2
USRI 86/4	No stress	236.26a	100.0	158.85a	100.0
	Moderate stress	205.30a	86.9	131.46a	84.9
	Severe stress	79.66b	33.7	56.92b	36.7

Figures followed by the same letters in each column are not significantly different on Duncan's New Multiple Range Test at $P<0.05$

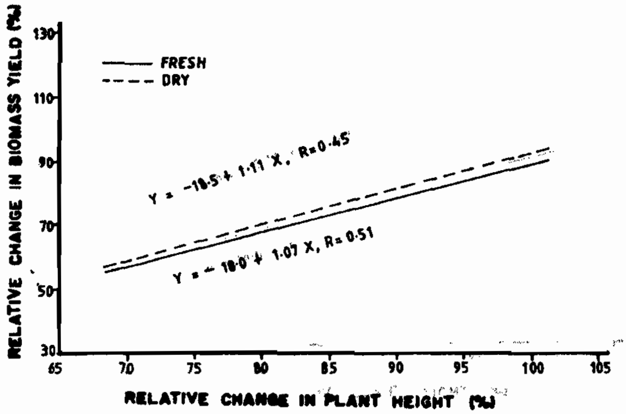

Fig. 3. Relationship between relative charges due to water stress in plant height and biomass yields.

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