Physiology of Cotton under Irrigated and Dryland Conditions in Spain

J. Gorham[1], E.O. Leidi[2], J. Bridges[1] and J.C. Gutiérrez[3]
[1]Centre for Arid Zone Studies, University of Wales, Bangor, LL57 2UW, U.K.
[2]IRNAS-CSIC, 41012 Sevilla, Spain
[3]CIFA Las Torres, 41200 Alcalá del Rio, Spain.

ABSTRACT

The main cotton-producing area in Spain is Andalucia, where it is grown mainly under irrigation (about 100,000 ha). Efforts are being made to increase the efficiency of irrigation water use. This investigation compares responses of five cultivars of upland cotton to growth under irrigated (Las Torres field station at Alcalá del Rio) or rainfed conditions (Tomejil, both managed by Dpto. del Algodón, CIFA). Plants at Tomejil were much smaller than those at Las Torres and gave lower yields of seed cotton. Stomatal conductance (gs), measured either with a porometer or infra-red gas analysers, was lower at Tomejil than at Las Torres. Gas exchange parameters (net photosynthesis, transpiration and instantaneous water use efficiency) were also lower, while leaf temperatures (measured with an infra-red thermometer) were higher. Some variation in the ratio of adaxial to abaxial stomatal conductance was observed, especially at the dryland site at Tomejil. Carbon isotope discrimination (Δ) values were related to the development of water deficits but did not correlate with instantaneous gas measurements at Tomejil. Concentrations of Na^{+}, K^{+}, Mg^{++}, Ca^{++}, Cl^{-}, SO_4^{--} and malate in leaf sap were very much higher at Tomejil than at Las Torres. Glycinebetaine, a quaternary ammonium osmoprotectant, increased in concentration to about 90 mol m^{-3} in leaf sap under severe water deficit at Tomejil compared to 30 mol m^{-3} at Las Torres. Physiological differences only partly accounted for varietal differences in yield at Tomejil.

Introduction

The most important cotton-producing area in Spain is in Andalucia (in the South West), where about 100,000 ha is grown mainly under irrigation with a small percentage under dryland conditions. Efforts are being made to increase the efficiency of irrigation water use in view of the potentially conflicting requirements of industry, agriculture and the domestic sector for the finite water resources of the region.

This investigation compares the physiological responses of five varieties of upland cotton in 1996 to growth at two sites under irrigated (Las Torres field station at Alcalá del Rio) or rainfed conditions (Tomejil). Previous work (Lopez *et al.*, 1993) demonstrated genotypic variation for photosynthetic rate, stomatal conductance, water use efficiency and leaf temperature among 70 cotton cultivars grown under water deficit stress in this region.

Material and Methods

Twenty six cotton cultivars were sown in 1996 at an irrigated field site (Las Torres, Province of Seville, S.W. Spain, Typic Xerofluvent sandy loam soil) and at a nearby dryland site (Tomejil, Typic Chromoxerert clay soil). Both sites are managed by Dpto. del Algodón, CIFA. A randomised complete block design was used with 6 replicates of 15 m rows at 5-7 plants m^{-1}. Row spacing was 0.75 m at Tomejil and 0.95 m at Las Torres. Physiological measurements on five varieties were made at both sites during August.

Gas exchange measurements were made on young expanded leaves in the late morning with a CIRAS-1 infra-red gas analyser (PP Systems Ltd.) and a broad-leaf chamber at saturating photosynthetic (400-700 nm) photon flux densities (>1,500 μmol m^{-2} s^{-1}). Dry air was fed to the leaf chamber at 350 μmol mol^{-1} CO_2. Measurements were also made on the same day with an LCA2 infra-red gas analyser (ADC Ltd.).

Further stomatal conductance measurements were made with an AP4 porometer (Delta-T Devices Ltd.). The instrument was carefully calibrated each morning, and used with the limits specified for this porometer. Both abaxial and adaxial surfaces were measured. Leaf temperatures were measured with a Raytec infra-red thermometer.

Osmotic potentials were measured in frozen-thawed samples using a Wescor HR33 microvoltmeter and C-52 thermocouple psychrometer chambers. Dry leaves were powdered and analysed for C isotope composition by mass spectrometry in the laboratory of Prof. G. Farquhar in Canberra, Australia. Fresh leaf samples were frozen in microcentrifuge tubes and taken to Bangor, Wales, for chemical analysis. Sap was extracted by centrifugation after thawing the samples, and inorganic ions measured by ion chromatography. Quaternary ammonium compounds (mainly glycinebetaine) were measured using a modified periodide assay, and the results compared with data obtained on selected samples by HPLC on a Na^+-form cation exchange column (Gorham, 1996).

Results

Photosynthetic gas exchange

Analysis of variance (GLM) showed that differences in varieties for gas exchange parameters were insignificant. The data presented below are therefore means of all 5 varieties. Table 1 shows gas exchange parameters at both the irrigated and the rainfed sites and are means of readings taken on several days. Differences between the sites were highly significant. Values obtained using a different infra-red gas analyser (LCA2) were similar, although net photosynthetic rates were slightly lower (27 and 25 μmol CO_2 m^{-2} s^{-1} at Las Torres and Tomejil respectively) and transpiration rates higher (17 and 14 mmol CO_2 m^{-2} s^{-1}).

Net photosynthetic rates were only modestly reduced under dryland conditions, so that the main limitation to primary productivity was the reduced leaf area at Tomejil (data not shown). The lower internal CO_2 concentrations at Tomejil suggest that reduced stomatal conductance was an important factor in the lower rate of net photosynthesis under dryland conditions. Instantaneous water use efficiency was higher under water stress than in the irrigated plants.

Stomatal conductance measured by porometry

Analysis of variance (GLM) again showed that differences in varieties for stomatal conductance were insignificant, and the data presented below in Table 2 are means of all 5 varieties. Stomatal conductance values obtained with the AP4 porometer were somewhat higher than those calculated by the CIRAS (Table 1). Nevertheless, the same trend of reduced stomatal opening under dryland conditions was observed. This occurred despite an increase in stomatal density under dryland conditions (because of limited leaf expansion). Stomata were more frequent on the abaxial surface, and stomatal conductance consequently greater in the irrigated plants at Las Torres. At Tomejil, however, there were, relative to the abaxial surface, slightly more stomata on the adaxial surface, but a much larger contribution of this surface to total stomatal conductance. Changes in anisolaterality of stomatal conductance in the field have been observed in the field at other sites (Gorham, unpublished).

Leaf temperature

Again there were no significant differences in leaf temperatures between the five varieties. The mean leaf temperature at Las Torres was 25.46^{o}C for air temperatures of 26.8 to 29.2^{o}C, while at Tomejil the mean leaf temperature was 23.22^{o}C at air temperatures of 22.0 to 23.3^{o}C. Thus leaf temperatures at Las Torres were lower than ambient air temperatures, whereas the leaf temperatures were similar to or higher than air temperatures at Tomejil.

Carbon isotope discrimination

Tashkent 7 had a higher carbon isotope discrimination value (Δ = 27.2 ‰) than the other four varieties (Crema 111, Victoria, Deltapine 90 and Sicala 33; Δ = 25.8 - 25.9 ‰) in the dryland plot at Tomejil. For all 26 varieties there was a significant ($P \leq 0.01$) correlation (0.67) between yield and Δ (Leidi *et al.*, in preparation). Carbon isotope discrimination (Δ) values were related to the development of water deficits during the season, and to final yield, but did not correlate with instantaneous stomatal conductance measurements or other gas exchange parameters at Tomejil.

Osmotic adjustment

Data for osmotic pressure and solute concentrations (Table 3) are again presented as means of the 5 varieties because of lack of significance for varietal differences. Some of the apparent increase in leaf osmotic pressure shown in Table 3 can be explained by the lower leaf water content of the plants at Tomejil. Mean leaf water contents were 4.42 g H_2O g^{-1} DW at Las Torres and 2.6 g H_2O g^{-1} DW at Tomejil, *i.e.* just over half the water content at the irrigated site. However, the percentage concentration increases at the dryland site over the irrigated site were not the same for all solutes. There were proportionally greater increases in malate, glycinebetaine, potassium and sodium concentrations than in the concentrations of the other solutes. The increase in malate was offset by lower increases in chloride and nitrate (actually decreases when calculated at full hydration). Calcium was the main cation at both sites, but whereas chloride was the dominant anion at Las Torres, at Tomejil malate concentrations were highest.

The mean concentration of the putative compatible solute glycinebetaine was three-fold higher at Tomejil than at Las Torres. These high concentrations suggest that a considerable proportion of the glycinebetaine must be in the vacuoles (otherwise concentrations would be several molar if it was confined to the cytoplasm). Increases in glycinebetaine concentrations in responses to water stress in cotton have also been reported for field-grown plants in Pakistan (Gorham *et al.*, 1998) and for plants grown in greenhouse conditions in Bangor (Gorham, 1996).

Yield

With the exception of Tashkent 7, which had the lowest yield, there was little difference in seed cotton yields at Las Torres (Table 4). At the dryland site (Tomejil), yields were severely reduced to about 1/10th of the irrigated values, but Tashkent 7 had much the highest yield under these conditons. A more detailed evaluation of cotton cultivars from a previous experiment at Tomejil can be found in Lopez *et al.*

(1995). In this, and in other studies (Lopez *et al.*, 1993; Leidi *et al.*, in preparation), Tashkent 7 had good seed cotton yields in water-stressed conditions.

Conclusions

Tashkent 7 gave the highest seed cotton yields of the five varieties reported here under dryland conditions at Tomejil, but only moderate yields at the well-irrigated site at Las Torres. There were no significant differences between the varieties for physiological parameters, but large differences between the irrigated and dryland sites. Seed cotton yields were not correlated with physiological parameters, with the possible exception of carbon isotope discrimination (Δ). Reduced yield was mainly the result of reduced leaf area, and not principally of reduced photosynthetic rates per unit leaf area. Osmotic adjustment (in the broad sense) was mainly achieved by a reduction in leaf water content, but increases in glycinebetaine, malate and potassium concentrations also made a contribution.

Acknowledgements

This work was supported by Project INIA SC95-084, and an Acciones Integradas grant (Ministerio de Educación y Cultura, and the British Council).

References

Gorham, J. (1996): Glycinebetaine is a major nitrogen-containing solute in the Malvaceae. Phytochemistry 43: 367-369.

Gorham, J., J. Bridges, M.N.A. Malik and I.A. Khan. (1998): Physiological responses of cotton to water deficit in Pakistan. In: Proc. World Cotton Res. Conf. –2: New Frontiers in Cotton Research. F. Gillham (Ed). WCRC-2 Organizing and Scientific Committees, Athens, Greece. (in press).

Lopez, J.M., Leidi, E.O., Lopez, M. and Gutierrez, J.C. (1993): Fotosintesis, conductancia estomatica, eficiencia en el uso del agua y temperatura foliar de cultivares de algodon en resuesta al estres hidrico. Investigación Agraria. Producción y Protección Vegetales 8: 17-27.

Lopez, M., Gutierrez, J.C. and Leidi, E.O. (1995): Selection and characterization of cotton cultivars for dryland production in the South West of Spain. Eur. J. Agron. 4: 119-126.

Table 1. Gas exchange parameters at Las Torres (irrigated) and Tomejil (dryland) measured with a CIRAS-1 infra-red gas analyser.

Parameter	Units	Las Torres	Tomejil
Net photosynthesis	μmol CO_2 m^{-2} s^{-1}	31 ± 0.4	29 ± 0.2
Transpiration	mmol H_2O m^{-2} s^{-1}	12 ± 0.2	10 ± 0.1
Stomatal conductance (gs)	μmol m^{-2} s^{-1}	768 ± 21	518 ± 10
Internal CO_2 concentration	μmol mol^{-1}	235 ± 2	215 ± 1
Water use efficiency	μmol CO_2 $mmol^{-1}$ H_2O	2.66 ± 0.05	3.04 ± 0.03

Table 2. Stomatal conductance (mmol H_2O m^{-2} s^{-1}) measured by porometry, and stomatal density (stomata mm^{-2}) at Las Torres (irrigated) and Tomejil (rainfed).

Parameter	Las Torres	Tomejil
Adaxial gs	557 ± 28	372 ± 14
Abaxial gs	826 ± 13	329 ± 13
Total gs	1384 ± 61	701 ± 25
Adaxial stomatal density	65 ± 3	152 ± 5
Abaxial stomatal density	116 ± 4	200 ± 5
Abaxial/Adaxial gs ratio	1.48	0.88
Abaxial/Adaxial density ratio	1.78	1.32

Table 3. Leaf osmotic pressures (bar) and solute concentrations (mol m^{-3}) in sap of cotton plants grown at Las Torres (irrigated) or Tomejil (dryland).

Parameter	Las Torres	Tomejil	% increase
Osmotic pressure (bar)	10 ± 1	20 ± 1	100
Sodium	12 ± 1	27 ± 1	125
Potassium	69 ± 4	162 ± 5	135
Magnesium	67 ± 2	109 ± 3	63
Calcium	132 ± 2	247 ± 6	87
Chloride	94 ± 3	121 ± 6	29
Nitrate	7 ± 1	9 ± 1	29

Malate	69 ± 3	215 ± 6	212
Sulphate	53 ± 1	103 ± 3	94
Glycinebetaine	31 ± 2	90 ± 2	190

Table 4. Seed cotton yields (kg ha^{-1}) of five varieties of cotton at Las Torres (irrigated) and Tomejil (dryland) in 1996.

Variety	Las Torres	Tomejil
Crema 111	6073	508
Victoria	5884	380
Deltapine 90	5984	436
Sicala 33	5864	711
Tashkent 7	4579	956
Mean	5677	598