GENETIC VARIABILITY OF SUNFLOWER CULTIVARS IN RESPONSE TO DROUGHT

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INTRODUCTION AND BACKGROUND

Yield of most crops is often limited by drought and sunflower is not an exception. Indeed, under the typical dryland growing conditions of Spain, sunflower yields are only a fraction of what can be obtained in similar environments where water does not limit crop production. Sunflower is becoming a very important crop in Spain. 1983 estimates indicate that the area cropped to sunflowers is approaching one million hectares, most of it under dryland conditions. Sunflower is usually planted in early or late spring depending on the area, and develops into the hot summer. Under a mediterranean-type rainfall pattern, dryland yields depend on the amount and distribution of winter and spring rains and on the water holding capacity of the soil to carry the crop through maturity. Dryland yields are low in Spain, oscillating between 500 and 1,500 kg/ha depending on the area and on the year. It is not unusual to obtain over 3,500 kg/ha under irrigated conditions with high nitrogen input. Thus, drought imposes in most of Spain a serious limitation to sunflower production and yield improvements under dryland conditions are badly needed to stabilize and increase farmers' income.

Water stress affects crops in many different ways and the yield reduction in a determinate crop is due to reductions in source size (leaf area), source intensity (photosynthetic rate), reproductive sink size and source duration (Hsiao et al., 1976). The effects of water stress on a sunflower crop operate through reductions in size and duration of plant leaf area, reduced number of grains per head and lower photosynthetic rates. Figure 1 presents a seasonal comparison between a dryland and an irrigated sunflower crop grown in 1982 at Cordoba under soil and climatic conditions typical of Sothern Spain. Leaf area is affected by water stress very early in the development of the crop and maximum leaf area index (LAI) values were 3.14 and 4.87 for the dryland and irrigated crop, respectively. After flowering, leaf senescence was hastened by water stress levels increasing in severity. The leaf area duration (LAD, the integral of LAI over time) of the dryland crop was only 44% of that of the irrigated treatment. The effects of water stress on the LAI and LAD of the dryland crop reduced the amount of radiation intercepted by the canopy. Such reduction, combined with lower photosynthetic rates, decreased drastically the rate of dry matter accumulation (Fig. 1). The final above-ground biomass produced under dryland conditions was 54% of that produced when water was not a limiting factor.

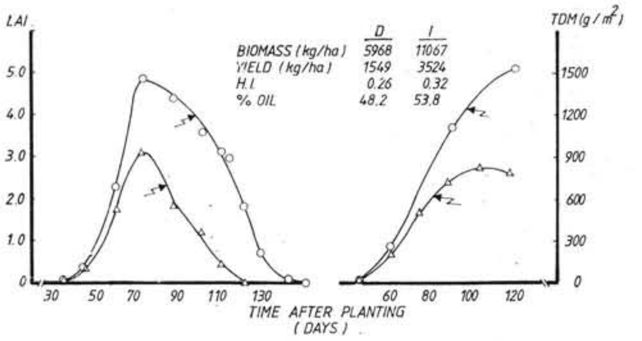

Fig. 1 — Leaf area index (LAI) and above-ground dry matter production (TIM) of the cultivar Sungro 380 at Cordoba, Spain under irrigated (I) and dryland conditions (D) during the 1982 season

Not included in the effects of water stress discussed above, are those directly affecting the reproductive sink size (inflorescence). By reducing the number of grains via impaired pollination and/or floret abortion, water stress directly affects yield independently of the effects on dry matter accumulation. It is possible to evaluate such direct effects by determining the harvest index (HI) of the crop which is the ratio of harvestable yield to the total biomass produced. The values stated in

Figure 1 indicate that HI of the dryland crop is less than that observed in the irrigated treatment. This means that, under the conditions of the experiment, water stress had more detrimental effects on harvestable yield than on total above-ground biomass production. The reduced seed oil content usually observed in dryland crops (Fig. 1) also contributes to the overall decrease in economic yield caused by water stress.

How can we improve yields under dryland conditions ? It has been known since long ago that plants adapt to water stress and numerous recent studies (e.g. Hsiao et al., 1976 ; Mussel and Staples, 1979 ; Turner and Kramer, 1980 ; and Monteith and Webb, 1981) have described key mechanisms responsible for the adaptation of crop plants to water stress conditions. Turner (1979) has classified the mechanisms of adaptation to drough according to their influence on drought escape or tolerance. Mechanisms of drought escape include developmental plasticity and rapid phenological development and are effective in allowing the crop to complete its life cycle before severe water stress levels reduce yields further. In fact, avoiding drought has been the most successful strategy used in improving the drought resistance of winter cereal crops (Begg and Turner, 1976). Drought escape mechanisms which contribute to adjust the crop life cycle to the available water supply, are most useful under more or less predictable drought patterns where little variation can be expected in the amount of water available to the crop.

Numerous mechanisms of drought tolerance have been found in crop plants (Turner, 1979). Among them the maintenance of turgor pressure through asmotic adjustment has received substantial attention recently (Hsiao, Acevedo et al., 1976 ; Turner, 1979). Other physiological mechanisms participate in dehydration tolerance and in maintaining high rates of photosynthesis under water stress. Included among the mechanisms of drought tolerance, changes in rooting depth and in root length density play an important role in plant adaptation to drought. It has long been known that the shoot-root ratio decreases under water stress because root growth is less sensitive than is shoot growth to water deficits. Rapid subsoil exploration by roots tends to improve the shoot water status in the presence of water stress. It should be pointed out, however, that excessive root proliferation under conditions of very limited water supply may be detrimental to final yield if all of the available water is transpired by the crop before completing its life cycle (Passioura, 1972).

From an agronomic viewpoint, drought resistance means the maintenance of acceptable yield levels under drought. Despite substantial work, it is not clear how most of the mechanisms described above influence crop productivity under water stress. This is one major reason why there have been relatively few efforts in breeding for drought resistance. It is apparent that drought resistance is a relatively complex feature of a crop community and it is not simple to evaluate how the various mechanisms, which operate at the tissue or organ level of organization, are integrated in determining crop yield under drought. Another limitation to breeding efforts has been the difficulties associated with developing screening techniques for drought resistance mechanisms. Most techniques available until recently are too slow to be used in screening large populations, thus identifying genotypic variability for most characters is not an easy task. Notwithstanding the above limitations, several groups around the world have undertaken breeding programmes for drought resistance in recent years. Blum (1979), Jordan and Miller (1980) and Sullivan and Ross (1979) have published their efforts in breeding sorghum for drought resistance. Other crops such as wheat (Fischer and Woods, 1979), rice (Reyniers and Jacquot, 1978) and pearl millet (Bidinger, 1980) have been the subject of drought resistance studies in relation to breeding. Fischer (1981) has proposed two approaches to breeding for drought resistance. One is the "black box" approach where screening is done solely on the basis of yield levels under drought. The other is based on identifying key morpho-physiological traits and incorporating them into drought resistant cultivars. Blum (1979) argues that incorporating characters which confer drought resistance into high yielding cultivars should improve their performance under drought.

We have initiated a breeding programme for drought resistance in sunflower at Cordoba, by combining the identification and evaluation of specific traits responsible for drought resistance and the overall yield performance of sunflower under drought. Aspects of our initial results are reported in this paper.

MATERIALS AND METHODS

An experiment to evaluate the performance of 25 cultivars under drought was carried out at Cordoba during 1981. Table 1 presents the list of cultivars involved. The typical soils of southwestern Spain on which sunflower is grown in a wheat-sunflower rotation, are deep vertisols with high water holding capacity. Annual rainfall is around 650 mm falling mostly between October and April. The experiment was conducted at the INIA farm at Cordoba on a deep alluvial soil of sandy loam texture with approximately the same level of extractable water in the root zone than the vertisols. Two treatments were imposed with four replications : a dryland and an irrigated

Table 1

List of sunflower cultivars tested during the 1981 season at Cordoba

Name	Origin
$A_1 \times R_2$	INIA, Spain
$A_{21} \times R_1$	INIA, Spain
PRIMASOL	France
$A_{23} \times R_7$	INIA, Spain
$A_{21} \times R_2$	INIA, Spain
IMPIRA INTA	Argentina
$A_2 \times R_1$	INIA, Spain
$A_6 \times R_7$	INIA, Spain
$A_{23} \times R_1$	INIA, Spain
$A_2 \times R_7$	INIA, Spain
$A_6 \times R_1$	INIA, Spain
$A_{22} \times R_{22}$	INIA, Spain
$A_{21} \times R_{23}$	INIA, Spain
$A_{INIA} \times R_{23}$	INIA, Spain
$A_4 \times R_7$	INIA, Spain
OSUNA H — 101 C	U.S.A.
P — 1161	Spain (commercial)
CONTIFLOR	Argentina
SUNGRO — 380	U.S.A.
$A_6 \times R_2$	INIA, Spain
$A_1 \times R_1$	INIA, Spain
$A_1 \times R_{17}$	INIA, Spain
$A_1 \times R_{23}$	INIA, Spain
PEREDOVIK	U.S.S.R.
SH — 3 000	Spain (commercial)

treatment where plants were never short of water. Individual plots were 4 m long and six rows, 70 cm apart. Planting date was 15 March, 1981 and four weeks later the crop was thinned to about 57,000 plants/ha.

Yield, harvest index, yield components and oil content were measured in all 25 cultivars. In addition, in six to 13 genotypes, soil water extraction by roots, LAI and LAD, leaf water potential and detailed inflorescence development were followed throughout the growing season under dryland and irrigated conditions.

RESULTS AND DISCUSSION

The first question that must be answered before undertaking any breeding effort is whether there is genetic variability in the character to be improved. To evaluate the genotypic variability of 25 sunflower cultivars in response to drought, we have plotted in Figure 2, the results of the 1981 experiment. In the horizontal axis, the ratio of dryland yield to irrigated (potential) yield is indicated as an overall measure of drought resistance. On the vertical axis, the irrigated yield is represented as an estimate of the yield potential of each cultivar. Overall seed yields under dryland conditions varied between 1,000 and 1,800 kg/ha as compared to yields of 2,700 to 4,400 kg/ha of irrigated controls. Four regions are then depicted in Figure 2. Region I has cultivars with high yield potential and low drought resistance. The Primasol hybrid is one example of a cultivar bred in a high yielding environment which does not perform well under the water stress and high temperature conditions of Southern Spain. Region II would have cultivars which have low yield potential and low drought resistance; fortunately very few cultivars fell in this region. Region III includes cultivars with high drought resistance but relatively low yield potential. Typically, some short-season types fell in this category. Finally, cultivars located in Region IV have the highest relative levels of yield potential and drought resistance and should be the most desirable.

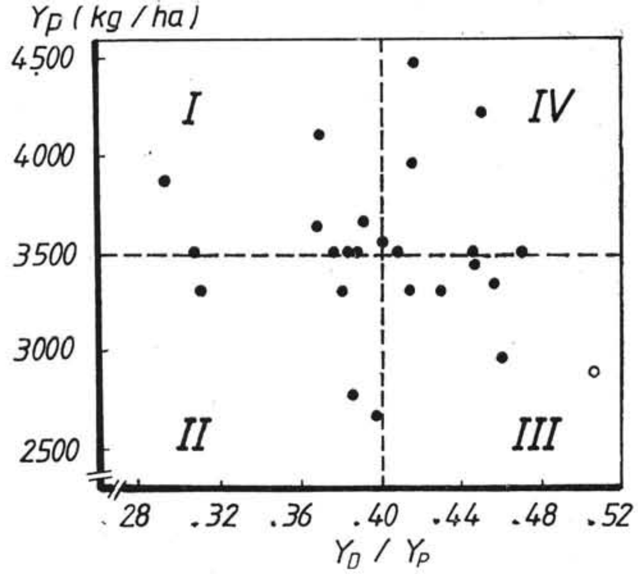

Fig. 2 — Relationship between yield under irrigated conditions (YP) and the ratio between dryland yield and irrigated yield (YD/YP) for 25 cultivars at Cordoba, 1981. For explanation see text

It is apparent from the results presented in Figure 2 that there is substantial genotypic variability in the response to drought of the 25 cultivars examined. Therefore, the prospects for improving the drought resistance of sunflower look good in principle. However, before a breeding programme is developed, much more should be known about the nature of the observed differences. In this report, we will focus on the possible differences among cultivars in root water extraction and in biomass production under drought.

Figure 3 presents the relation between seasonal evapotranspiration (ET) and the aboveground biomass produced by six cultivars in the dryland treatment. There were no significant differences among genotypes as the data from all six cultivars fell on a common regression line. This suggests that there is no evidence of genotypic differences in traspiration efficiency (the amount of biomass produced per unit water transpired). The recent review by Tanner and Sinclair (1983) indicates that there has been little or no improvement in the transpiration efficiency of crops since it was first measured by the end of last century. There are strong theoretical reasons to believe that, in the short run, basic improvements in the amount of CO_2 gained per unit water transpired are unlikely to occur within a given species.

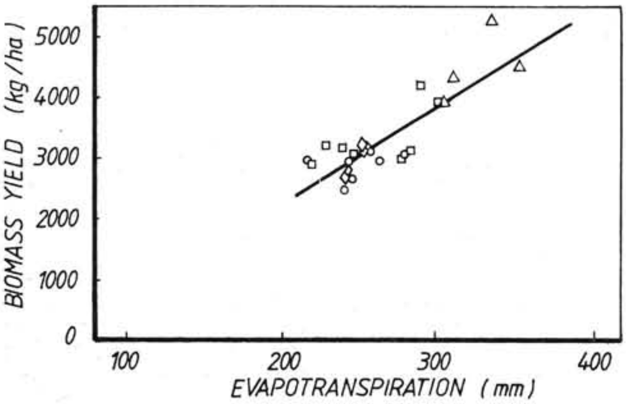

Fig. 3 — Relationship between evapotranspiration (ET) and the above-ground biomass production at Cordoba for six sunflower cultivars under dryland conditions

If most shoot characteristics in relation to drought resistance are difficult to evaluate, the difficulties appear even more hopeless in the case of root system characteristics. However, roots must play an important role in alleviating the detrimental effects of water stress on sunflower production. A good indirect method of evaluating the overall root system performance in response to drought is by determining its soil water extraction capability. In the absence of rain during the latter part of the growing season, as it occurs at Cordoba, any changes in subsoil moisture can be attributed to root activity. Figure 4 presents the initial and final soil water content as a function of depth for two cultivars representing the two extremes observed in this experiment. While the cultivar $A_{21} \times R_{23}$ depleted all extractable water down to a depth of 120 cm, the cultivar Contiflor used all extractable water down to 180 cm. Furthermore, the shallow-rooted cultivar did not extract water below 180 cm while cultivar Contiflor used appreciable amounts down to the lowest depth measured of 270 cm. The additional subsoil root activity of cultivar Contiflor resulted in the maintenance of green leaf area under water stress conditions which induced complete senescence in cultivar $A_{21} \times R_{23}$ 18 days before. The yields of cultivar $A_{21} \times R_{23}$ and Contiflor in the dryland treatment were 1,418 kg/ha and 1,874 kg/ha, respectively. Therefore, selection for deep rooting and complete subsoil water extraction is beneficial in sunflower under our conditions of significant soil water holding capacities and a high probability of refilling the soil profile each year because of the substantial winter rainfall.

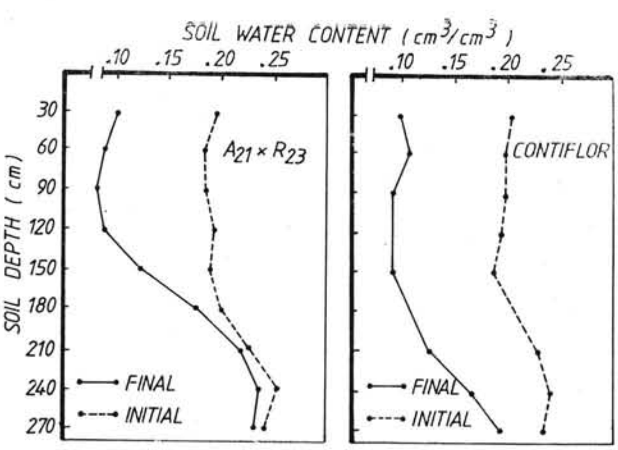

Fig. 4 — Soil water content as a function of soil depth for two sunflower cultivars at Cordoba, 1981

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LA VARIABILITÉ GÉNÉTIQUE DES CULTIVARS DE TOURNESOL COMME RÉPONSE À LA SÉCHERESSE

Résumé

On présente le comportement de 25 cultivars de tournesol essayés en culture irriguée et non-irriguée dans un climat méditerranéen semi-aride. On a évalué le rendement à l'hectare, l'indice de récolte, les composantes du rendement, le taux d'huile, de même que des caractères morpho-physiologiques tels que le potentiel de rétention de l'eau par les feuilles, la surface foliaire, la durée de la persistance de l'état actif du feuillage et l'aptitude d'extraire l'eau du sol.

Relativement à la résistance à la sécheresse il y a eu une grande variabilité entre les génotypes essayés. Le rendement en graines a été de 1 000—1 800 kg/ha en culture non-irriguée et de 2 700—4 400 kg/ha en culture irriguée. Le rapport entre le rendement enregistré en culture non-irriguée et celui enregistré en culture irriguée représentant le principal indice d'évaluation de la résistance à la sécheresse, a varié de 0,29 à 0,50.

L'aptitude d'extraire l'eau du sol a été utilisée en tant que méthode indirecte d'évaluation de la réponse du système racinaire en conditions de sécheresse. En culture non-irriguée, chez deux des formes biologiques essayées qui réprésentent les extrêmes de cet essai, la profondeur d'extraction de l'eau du sol a varié de 180 à 278 cm, avec l'épuisement de l'extraction de l'eau accessible jusqu'à la profondeur de 120 cm et respectivement de 180 cm. Cet essai conduit en conditions de sécheresse a mis en évidence les relations très étroites entre l'activité du système racinaire, la persistance de l'état actif du feuillage et le rendement.

VARIABILIDAD GENETICA EN CULTIVARES DE GIRASOL EN RESPUESTA A LA SEQUÍA

Resúmen

Se ha examinado el comportamiento de 25 cultivares de girasol en secano y riego en condiciones ambientales semiaridas de tipo mediterraneo. Se determinaron rendimiento, índice de cosecha, componentes del rendimiento y una serie de índices morfofisiológicos que incluían hídrico en hojas, índice de área foliar, duración de área foliar y extracción de aqua del suelo.

Se encontró una sustancial variabilidad genética entre cultivares en respuesta a la sequía. Los rendimientos de semilla en condiciones de secano variaron entre 1 000 y 1 800 kg/ha en comparación con los 2 700 a 4 400 kg/ha obtenidos en los controles regados. La relación rendimiento en secano/rendimiento en regadio, usada como una medida de resistencia a sequía, osciló entre 0,29 y 0,50.

La capacidad de extracción de aqua del suelo fue usada como método indirecto para evaluar el papel del sistema radicular en respuesta a la sequía. Bajo condiciones de secano, para dos cultivares que representan los extremos de este experimento, la extracción de aqua del suelo se produjo hasta una profundidad que osciló entre 180 y 270 cm agotando toda el aqua extraible hasta 120 y 180 cm respectivamente.

Esta actividad radicular en el subsuelo estuvo estrechamente relacionada con el mantenimiento del área foliar así como con el mayor rendimiento bajo condiciones de stress.