PROGRESS TOWARDS IMPROVING THE DROUGHT TOLERANCE OF SUGAR BEET

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ABSTRACT

Insufficient soil moisture during summer months is now the major cause of sugar beet yield losses in the UK and parts of Europe where the crop is not normally irrigated. However, selection for increased drought tolerance has not been a breeding priority until recently. With this aim, the objectives of the project over the past 4 years were to 1) assess the degree of genotypic diversity for drought tolerance; 2) identify sources of germplasm with increased drought tolerance over current commercial varieties; 3) identify key morpho-physiological traits associated with high or low drought tolerance. A total of 51 beet genotypes have been tested in the field under large polythene covers to impose a terminal drought beginning approximately 40 d after emergence. There were more than two-fold differences in drought susceptibility index between genotypes at the extremes, and some lines showed consistently better performance than a benchmark variety. Under drought conditions there was significant genotypic variation for wilting score, rates of water use, leaf expansion rates, osmotic adjustment, and stomatal conductance. The percentage loss in biomass production due to drought was significantly correlated with specific leaf weight, leaf succulence index, water use, and percentage green crop cover. Divergent lines showing consistent, contrasting responses will be crossed to create mapping populations. Using another approach, yield data from official variety testing trials were combined with a drought stress index computed using historical weather data and trial site soil profile information. Varieties were identified that showed significantly different responses to increasing water deficit.

PROGRESSION DANS L'AMÉLIORATION DE LA RÉSISTANCE À LA SÉCHERESSE POUR LA BETTERAVE À SUCRE

La quantité d'eau insuffisante présente dans la terre durant l'été est à présent la plus importante cause de pertes de rendement des betteraves à sucre au Royaume Uni et dans les zones de l'Europe ou l'irrigation n'est pas employée. Quoi qu'il en soit, j'usqu'à récemment, le résistance à la sécheresse n'était pas un critère de sélection prioritaire. Dans ce but, les objectifs du projet mené au cours des 4 dernières années furent: 1) évaluer le degré de diversité genotypique pour la résistance à la sécheresse; 2) identifier les sources de germoplasmes possédants une résistance accrue à la sécheresse dans les variétés actuellement commercialisées; 3) identifier les traits morphophysiologiques clés associes à une haute ou faible résistance à la sécheresse. Un total de 51 génotypes de betterave fut testé dans un champ expérimental sous couverture de polythène permettant d'imposer une sécheresse terminale commençant à peu près 40 jours après émergence. Il y eu une différence de plus de deux fois la valeur de l'index de sensibilité a la sécheresse entre certains extrêmes de génotypes. Certaines lignes de cultures montrèrent de meilleures performances que celles des variétés repérées. Sous des conditions sèches, il y eu de significatives variations genotypiques en ce qui concerne les points de flétrissement, les taux d'utilisation de l'eau, les taux d'expansion du feuillage, les ajustements osmotiques et les conductivités stomatiques. Le pourcentage de pertes biomassiques de la production du à la sécheresse fut significativement corrèlé aux poids spécifiques des feuilles, index de succulence, utilisation de l'eau et pourcentage de couverture des cultures vertes. Des lignes divergentes, montrant des réponses concordantes, et d'autres opposées seront croisées afin de créer une cartographie des populations. Utilisant une autre approche, les données sur les rendements venant d'essais officiels sur des variétés données, furent combinées avec un index de stress du à la sécheresse, calculé grâce à l'utilisation de données météorologiques historiques et des informations sur le profile de la terre d'un site expérimental. Les variétés qui furent identifiées montrèrent des différences de réponse significatives à l'augmentation du déficit en eau.

FORTSCHRITTE BEI DER VERBESSERUNG DER TROCKENTOLERANZ DER ZUCKERRÜBE

Unzureichende Bodenfeuchtigkeit während der Sommermonate ist derzeit die Hauptursache für Ertragsverluste der Zuckerrübe in Großbritannien und in Teilen Europas, wo die Feldfrucht normalerweise nicht bewässert wird. Eine Selektion auf gesteigerte Trockentoleranz hatte jedoch bis vor kurzem keine Priorität bei der Züchtung. Mit diesem Ziel wurden im Laufe der vergangenen 4 Jahre bei diesem Projekt folgende Absichten verfolgt: 1) Bewertung des Ausmaßes von genotypischer Diversität für Trockentoleranz; 2) Identifizierung von Herkünften von Genotypen mit gesteigerter Trockentoleranz unter vorhandenen kommerziellen Sorten; 3) Identifizierung von wichtigen morphophysiologischen Merkmalen, die mit hoher oder niedriger Trockentoleranz assoziiert werden. Insgesamt wurden 51 Zuckerrüben-Genotypen im Feld unter großen Polythenabdeckungen getestet, um eine bis zum Ende der Vegetationszeit dauernde Trockenheit zu erzeugen, die ungefähr 40 Tage nach dem Auflaufen begann. Es gab beim Trockenempfindlichkeitsindex im Extrem mehr als den zweifachen Unterschied zwischen den Genotypen und einige Linien zeigten eine konsistent bessere Leistung als eine Vergleichssorte. Unter Trockenbedingungen bestand eine signifikante genotypische Variation in Bezug auf den Welkepunkt, die Wasserverbrauchsraten, das Blattwachstum, die osmotische Anpassung und die stomatäre Leitfähigkeit. Der prozentuale Verlust der Biomassenproduktion aufgrund von Trockenheit korrelierte signifikant mit dem spezifischen Blattgewicht, dem Index für Blattsukkulenz, dem Wasserverbrauch und dem Prozentanteil an grüner Blattfläche. Divergente Linien, die konsistente, kontrastierende Reaktionen zeigen, werden zur Erzeugung von Kartierungspopulationen gekreuzt. Bei der Verfolgung eines anderen Ansatzes

wurden Ertragsdaten von offiziellen Sortenversuchen mit einem Index für Trockenstress kombiniert, der unter Verwendung historischer Wetterdaten und Bodenprofilinformationen des Versuchsstandorts berechnet wurde. Die Sorten, die bedeutend andersartige Reaktionen auf einen steigenden Wassermangel zeigten, wurden identifiziert.

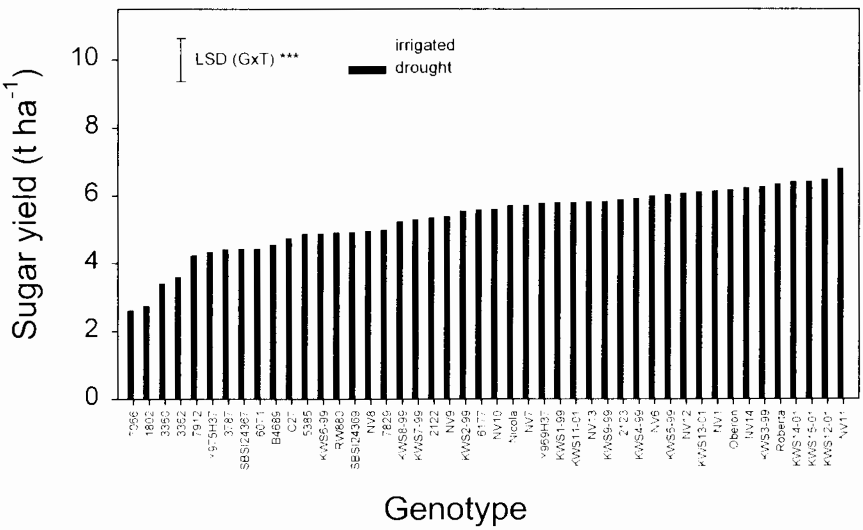
INTRODUCTION

Drought is the major environmental limitation to the production of most crops world-wide (BOYER, J., 1982), and sugar beet is no exception (JAGGARD, K.W. *et al.*, 1998). The problem is acute in regions such as the eastern UK where the summer rainfall is often limited and farmers do not have access to irrigation. Other regions are also susceptible to yield losses when the supply of water is insufficient to keep pace with the potential evapotranspiration rate from the crop. Several days without rain and a high evaporative demand coupled with sandy soils quickly leads to a damaging water deficit. The stress history of the crop also affects productivity later in the season, as repeated water deficits hasten the senescence of the canopy. Climate change models predict that for many regions of Europe, drought losses will increase in the future (JONES, P.D. *et al.*, in press).

Until recently, however, decreasing the sensitivity of sugar beet to water deficits and increasing the tolerance to drought has not been a breeding objective. This paper highlights progress in two areas of current improvement efforts: 1) identification of germplasm that can be used to increase the drought tolerance of sugar beet varieties; 2) identification of physiological and morphological characters that can be used as indirect traits to screen for drought tolerance. Briefly, the overall strategy is to screen germplasm in the field to identify lines showing the extremes of tolerance or sensitivity to drought or in component traits related to drought performance. These divergent lines are crossed to create a mapping population, which is then genotyped and phenotyped to hopefully identify QTLs and associated molecular markers that could be used in a marker-assisted breeding programme. The work is still at the initial stages but it is a straightforward approach used with success in other crops (e.g., BRUCE W.B. *et al.*, 2002). The difficulty lies in obtaining accurate knowledge of the key traits and how to screen for them effectively and efficiently. The choice of parental lines and the quality of the phenotypic data largely determine the success of marker development.

Fields at or near Broom's Barn, UK, were used for the field trials from 1999-2001. Large polythene covered tunnels were used to impose drought about 40 days after emergence (or mid-June), once the crop was well established. The plots were covered and the plants were dependent on stored soil moisture until harvested by hand, early to mid-October. Drip-irrigated control plots were also covered by the polythene tunnels. The effect of the tunnels on crop microclimate was minimal and did not create combinations of weather factors that are unlikely to occur in practice. Standard cultural practices for the beet crop were followed.

Fig.1. Response of sugar yield to drought and irrigation among 46 diverse sugar beet genotypes tested in the field from 1999-2001. Bar represents LSD for genotype x treatment interaction term, P<0.001.



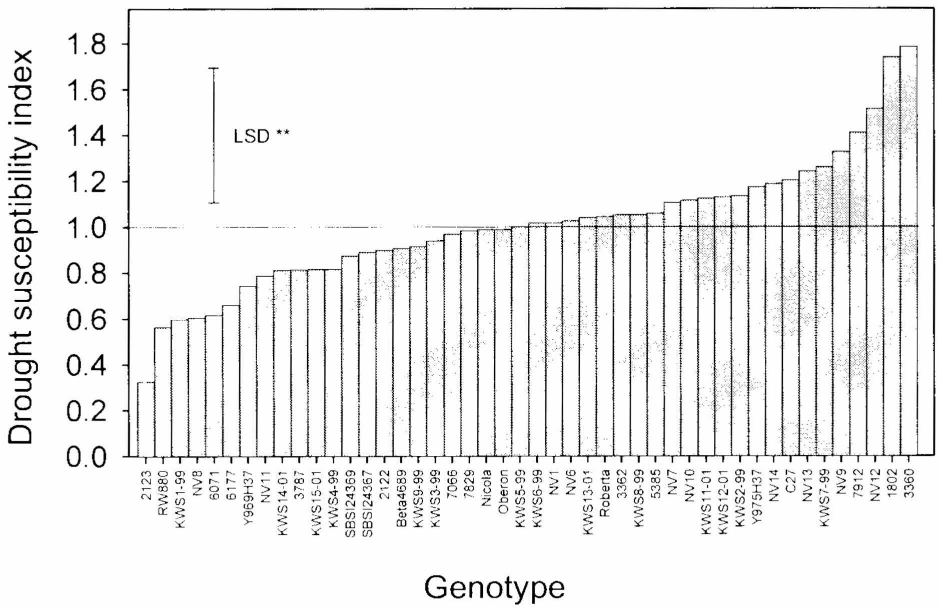
RESULTS AND DISCUSSION

There was significant variation for sugar yield among 46 genotypes under droughted and irrigated conditions (Fig. 1). Genotypes range from commercial varieties, hybrid breeding material, open pollinated lines and older genebank accessions. Genotypes differed in their yield characteristics: some had high yield potential (irrigated conditions) or high yield under dry conditions, and a few had both.

Drought tolerance was defined as the percentage loss in yield relative to the irrigated yield potential. This percentage loss was normalised for each trial to compute a susceptibility index (SI). The average sugar yield loss was around 30-40%, which is near to the UK national yield loss experienced by farmers in 1995 (JAGGARD, K.W. *et al.*, 1998). There was also significant genotypic variation for drought SI (Fig. 2), as reported previously (SADEGHIAN, S.Y. *et al.*, 2000; OBER, E.S. & LUTERBACHER, M.C., 2002). However, there were a large number of lines showing intermediate responses to drought that could not be differentiated.

In an effort to understand which physiological or morphological traits are important in conferring drought tolerance in sugar beet, measurements of several parameters were made in the field on a set of six unrelated hybrids and six male-sterile lines. (Table 1). There was significant genetic variation for most of the variables, but little genotype by treatment interaction. This means that the genotypes responded to drought similarly, except in respect to potassium, sodium, green crop cover and succulence index.

Fig. 2. The susceptibility index (SI) based on the ratio of droughted to irrigated sugar yields, and normalised for the average yield loss across all genotypes in each year (see OBER *et al., 2002 for more details). The horizontal line indicates the mean response; genotypes with SI less than 1 were more drought tolerant than average. Bar indicates the LSD for genotype effect (P < 0.01).*



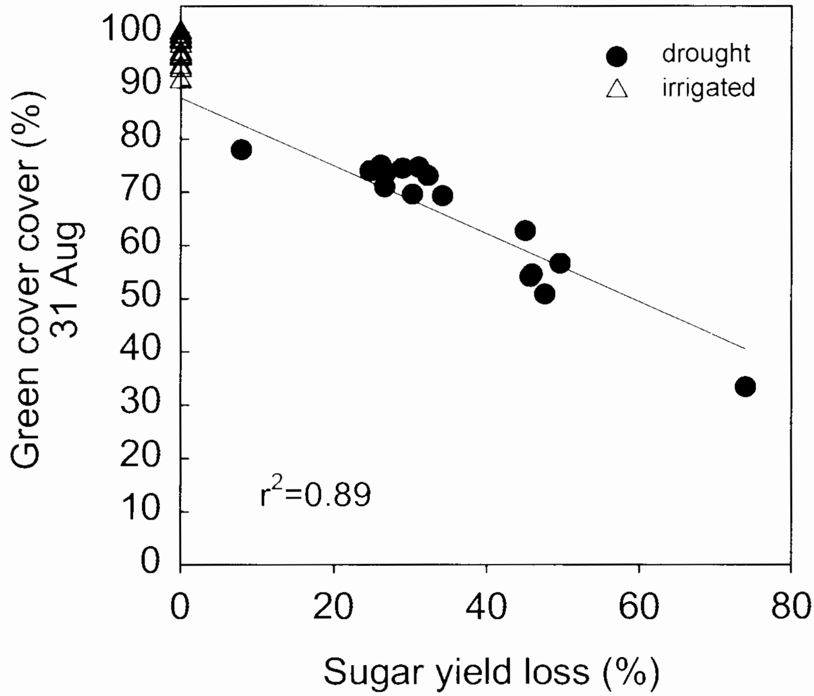
The percentage green crop cover, measured by a spectral ratio meter on droughted plots, correlated well with losses in sugar yield across all genotypes (Fig. 3). This indicates that the better performing genotypes during drought were better able to maintain crop cover, whereas more susceptible genotypes senesced earlier. Therefore, late season crop cover, which is fast and cheap to measure, may be a good indirect indicator of drought tolerance.

Another trait correlated with sugar yield loss under drought is the wilt score (Fig. 4). There is considerable variability in part because of the subjective nature of assigning a score to each plot, but it clearly shows that genotypes more susceptible to wilting are those least able to maintain their yield potential when water is limiting.

A third trait that was associated with total growth under dry conditions is the succulence index, or the amount of water per unit leaf area (Fig. 5). This so-called 'xeromorphic' trait may well help plants survive, but in this case it is a good indicator of slow growth and poor yield. Again, this trait is cheap and easy to measure in the field.

Perhaps the most important traits are those that allow the plant to avoid stress, rather than tolerate it. In other words, genotypes with deeper roots that can supply more water to the plant and delay the onset of wilting may be most successful. There were significant differences between genotypes in rooting patterns (OBER E.S. *et al.*, 2002). For example, NV8 extracted more water from deeper in the soil profile earlier in the season than KWS7. In this experiment, this translated to greater top growth in NV8, but not more sugar. With more data it should be possible to identify genotypes that have root system development favourable for greater water extraction and drought avoidance.

Fig. 3. The relationship between green crop cover measured on 31/8/00 with a spectral ratio meter, and the loss in sugar yield measured at harvest (4/10/00) for each genotype.



CONCLUSION

Based on the available data, a drought tolerant ideotype (at least for the UK environment) would be characterised by: maximised water use through increased soil water extraction and increased hydraulic conductance; maintenance of radiation interception and photosynthetic efficiency of the crop canopy; greater heat tolerance of leaves; and, if it's possible, increased osmotic adjustment (although all tested genotypes were reasonably good at osmotic adjustment). In summary, there is significant genotypic diversity for drought tolerance in a wide selection of beet germplasm and there appear to be sources of greater drought tolerance that could provide a source of favourable alleles. The search continues for lines showing highly contrasting drought tolerance traits. Certain secondary traits such as wilting score and succulence index may show promise as indirect selection criteria. More work is needed to refine the screening procedures into useful selection tools.

Fig. 4. The relationship between the wilt score determined on 24.7.01 for each genotype and the loss in sugar yield measured at harvest (8/10/01). The wilt score is the average of four plots per genotype. A score = 0 indicates no wilted, 1 = only lowest leaves wilted; 2 = most mature leaves wilted; 3 = mature and larger expanding leaves wilted; 4 = all but small, expanding emerging leaves wilted; 5 = all leaves flaccid.

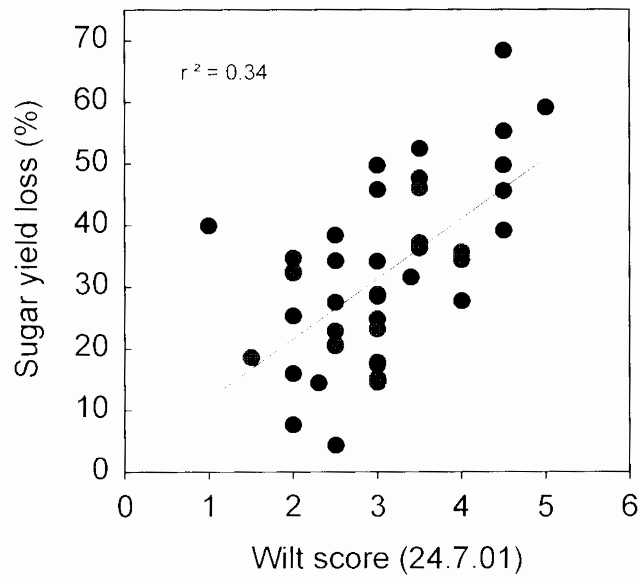
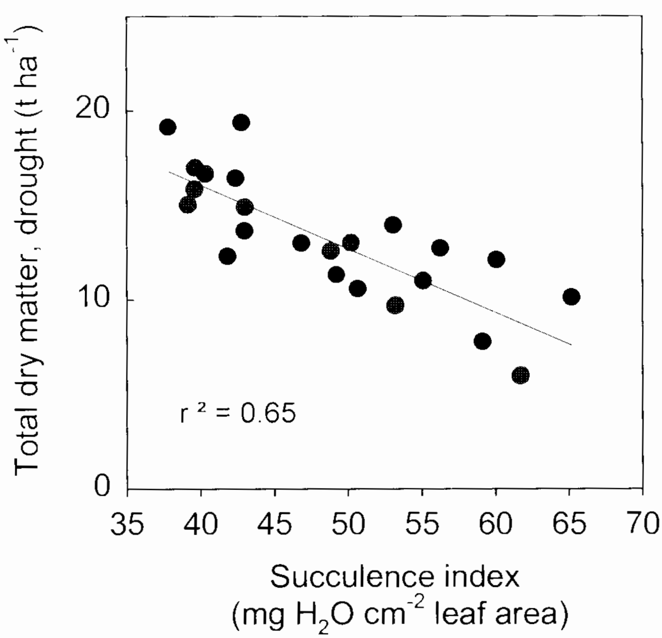


Fig. 5. The relationship between the succulence index measured on 17/9/01 for each genotype and the loss in sugar yield measured at harvest (8/10/01). The succulence index is shown for each individual plot, three plots per genotype, 1 plant per plot. Succulence index was determined by harvesting 15, 1.4 cm diameter disks from a newly expanded leaf, then subtracting the oven dry weight from the fresh weight to derive the amount of water per unit leaf area.



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