**British Beet Research Organisation**

**---------- FINAL REPORT ----------**

**06/23 - Using multi-environment variety trial data to screen for drought tolerance**

**Executive Summary**

* A drought stress index (DSI) was calculated for each variety trial site from 2006-2009. The DSI was based on total available water using detailed soil samples collected from each field, plus site-specific rainfall (when these data were collected).
* A database of soil characteristics for most of the variety trial sites used in UK variety trials has been established, which includes soil texture class, stoniness, soil depth and available soil water.
* A small number of varieties showed statistically significant regressions that differed in slopes, indicating differences in sensitivity to moisture supply.
* Certain varieties showed little slope, little variation about the regression line, and intercepts greater than 100%, indicating above-average yield potential combined with yield stability across environments.
* However, robust varietal evaluations that could be published with confidence were not possible. Reasons for this include:
  + - Reductions in recent years to the number of test sites to four
    - Elimination of sites with soils that would allow stress to develop
    - Two out of four years with plentiful rainfall and little water deficit
* Protocols for routinely evaluating varietal differences in performance according to moisture availability have been established, and can be continued for each year.
* Some of the test sites still do not have routine measurement of rainfall during the growing season.
* The confidence with which these variety rankings can be published and used by growers to make planting decisions depends on the number of sites that are permitted to experience stress, which currently is too limited unless a variety is tested over a span of several years.
* Nevertheless, it is recommended that this variety trial data evaluation continues because some varietal information can be gained, depending on the season, with little extra cost.

***Background***

Insufficient moisture during summer months limits UK sugar beet production more than any other single factor. Compared with potential production without stress, yield losses are on average 10%, worth ~£30M per year in the UK. Climate change models predict that summers will get hotter and drier, giving production areas with deep, water retentive soils a competitive advantage. To maintain productivity in the UK under these conditions, new, more drought-tolerant varieties are required. In addition, varieties that are less sensitive to the prevailing moisture supply should exhibit greater site-to-site and year-to-year yield stability, improving management decisions for growers and the processor. Currently, there is no mechanism in place for judging the relative drought performance of varieties entered into official variety trials, which are conducted across a range of sites, and there is no characterisation of the environmental conditions at each site. Therefore, the frequent change in genotype ranking depending on site remains a nuisance, which is ignored and only overall means are reported.

In a previous BBRO-funded project (00/11), we showed that by assigning a drought stress index (DSI) to each trial location, certain varieties showed significantly better yields when water was limiting, while other showed good performance in the absence of drought, but performed poorly when conditions were dry (Pidgeon et al, 2006). This type of information should be extremely useful if included as a standard characterisation of all variety trial entries every year. By evaluating data already gathered in variety trials, additional value is added to this investment. It will also provide an incentive to breeders to improve drought tolerance of their varieties to avoid a publicised adverse rating, as well as providing valuable feedback data for them.

Around the world, with numerous crop species, it is common to test for varieties that could be best grown in production areas that are frequently water-limited. These test procedures usually include sites that represent those conditions, in order to capture the adaptability and responsiveness of varieties to prevailing environmental conditions (e.g., Rizza *et al*., 2004). Various evaluation methods are used, from the sophisticated to the quite simple. In this project we assessed the relative drought tolerance of varieties by applying a drought stress index (DSI) to individual multi-environment trial sites from 2006-2009. Briefly, the approach was to assign a DSI to each trial, and then plot the regression of relative yield performance of each variety against the range of DSI. This is similar to the Finlay-Wilkinson technique (see References), except that an actual weather-based factor was used as an environmental descriptor instead of the overall trial mean. The actual evapotranspiration for each trial was derived from the Broom’s Barn crop growth model using site-specific soil and weather inputs (Qi *et al*., 2005). Varieties were classed according to their intercept (yield potential under low-stress conditions) and their slope, which indicates relative drought tolerance or susceptibility (Pidgeon *et al*, 2006).

***Objectives***

1) Evaluate NIAB trial data beginning with the 2005 season to discover which varieties were relatively drought tolerant and drought susceptible.

2) Install automatic rain gauges at trial sites with inadequate means to collect rainfall data, beginning in 2006.

***Achievements and progress***

Sugar yield data from the Recommended List and National List (RL/NL) variety trials from 2006-2009 have been analysed. Soil samples were taken at each site to determine the site-specific soil texture, stoniness and the presence or absence of physical barriers to rooting within the upper 70 cm of the soil profile. Weather variables including rainfall were measured using automatic recording weather stations at some sites, but rainfall records were often incomplete or missing. For other sites, rainfall from the nearest Met Office site were used, but with hit-and-miss summer downpours, this is not an ideal substitute as the trial site could easily miss rainfall recorded only 10 km away. For certain weather parameters such as global radiation, which varies little across the sugar beet growing area on a given day, Broom’s Barn weather data were used. Soil, weather, sowing and harvest date data were input into the Broom’s Barn Growth Model to calculate actual and potential crop water use for each trial. These calculations were used to derive a Drought Stress Index (DSI) for each site (see also Fig. 1 legend). Then, using a Finlay-Wilkinson regression approach, relative sugar yield for each variety or National List (NL) entry at each site was regressed against the DSI.

In 2007 and 2008, the quantity of rainfall over the entire UK growing area prevented any significant stress from developing on any of the sites. Therefore, data from these years were not useful in this variety evaluation exercise. However, in 2006 a significant level of stress developed on a sufficient number of sites, which produced a range of DSI values (Fig. 1). There were 12 genotypes (including four named varieties) that showed significant slopes, indicating relative differences in sensitivity to soil moisture deficit. Of these 12, three showed loss of sugar yield (compared to the overall trial mean) on drier sites, while nine showed relatively better performance on the drier sites. Seven varieties (including one named variety) showed a combination of slopes near zero with intercepts ≥ 102%, which indicates good yield potential combined with yield stability (wide environmental adaptability, or low sensitivity to prevailing environmental conditions). Examples of these responses are shown in Fig. 3.

In 2009, some stress developed on three of the four sites, which allowed differentiation of varietal responses (Fig. 4). However, with only four datapoints, and slopes heavily weighted by yield performance on the one non-stressed site, these data could not stand alone as a basis for a published varietal description.

While these annual data are statistically sound, they nevertheless represent the variety responses in one year. Therefore, the data are too limited and comprise an insufficient basis for recommendation to growers. Even when data were combined across years—for entries that were tested in more than one year—the regressions were little improved because of the scarcity of datapoints at greater DSI values (Fig 5). Therefore, the confidence in classification of varieties into those better or less suitable for drought-prone land is small.

***Conclusions***

The protocols and soils database have been established to routinely produce a score for each RL variety that indicates its performance for water-limited conditions relative to other varieties. However, it is unlikely at present that these scores would be published as part of a list of variety characteristics. This is because currently there are too few test sites, and few if any of these develop significant levels of stress. Hence, there remains no guide to growers which varieties would be better suited for light land and drought-prone conditions, which describes a large proportion of contracts in the UK in most years. Nevertheless, it is recommended to continue this evaluation of variety trial data that are already collected as part of the official variety trial programme: if a variety is tested over three or more years, and sufficient stress develops on at least three sites in each year, the minimum number of datapoints could be achieved to establish a drought sensitivity and yield stability ranking, and this information would be valuable to growers.

***Future directions***

**Proposals for implementation of this work into practice**

We have submitted a Concept Note to the BBRO to extend this work so that current and future RL/NL entries can be judged in terms of yield stability and the responses to water availability as described in this project. However, there are potential impediments to the successful application of this evaluation process that will limit the value and access of this information for growers.

One shortcoming is the number of current test sites that are conducted on drought-prone land. The number of sites in general is limited, but these are sufficient to judge the yield potential and other characteristics currently incorporated into the RL descriptions. High quality yield data can be obtained on the best land in the absence of stress; however, it is impossible to evaluate responses to less than optimum conditions if the test varieties are not grown on soils or at sites that permit stress to develop. An additional two or more test sites on uniform but drought-prone land are required. This incurs additional expense on the part of the industry, but there is no substitute and the benefits are clear.

A second but absolutely essential component of this test procedure is the availability of accurate and complete weather data for each trial location. Currently, rainfall data records (the most critical site-specific variable) are often incomplete and collected sporadically so that timely access to these data has been problematic. A solution would be to install weather stations (or at least automatic recording rain gauges) at each trial location at the time of drilling, with immediate access to logged data by researchers connected with the trial.

We did not have access to the breeders’ codes for year 1 entries that later became named varieties. However, by linking data on named varieties with earlier data when they appeared in year 1 trials, we could extend the number of datapoints used to describe each variety.

Depending on the availability of funding, these trials can be used as a ready-made resource for more detailed varietal comparisons based on information on drought tolerance-related traits coming out of project 07/14 (*Physiology-based selection methods for improving sugar beet productivity under water-limited conditions*). If stress develops on a test site, useful information could be generated by making simple measurements on these plots to further characterise high-yielding varieties and their associated traits. Such data would complement data gathered under managed drought conditions used in project 07/14, and would provide information for breeders about performance and characteristics of their materials under UK stress conditions.

***Output and dissemination of Results***

This evaluation of data from multi-environment test sites has been cited internationally as a useful approach (Cattivelli *et al.,* 2008). The impact of BBRO investment in this area goes further, benefitting growers beyond just the sugar beet sector. A recent project evaluated winter wheat variety trial data (RL and breeders’ trials) in collaboration with the British Wheat Breeders and HGCA to screen for drought tolerance as part of a Defra LINK project. The methods used were based on the BBRO-funded work on sugar beet trial evaluations.

Over the years we have worked with breeders at Syngenta and KWS, first analysing their Europe-wide multi-environment trial data, then by helping train seed company staff to use the Growth Model to make the calculations of DSI independently. As far as we know, these companies have been using and are benefiting from this analysis of trial data. SESVanderHave have not collaborated with us and perhaps use a different approach, and it is not known what if any methods Strube use for in-house trial data. We remain open to work with all breeders so that material emerging from these seed houses has already been assessed for drought tolerance, performance on drought-prone sites and yield stability; these varieties that would benefit the UK industry.

* Talk given at AAB Conference on Resource Capture, Nottingham, Sept. 08, “Traits associated with genotypic variation in radiation and water use efficiency”
* Talk given at Rothamsted Reasearch Association workshop on Water Resources, Broom’s Barn, Oct, 08, ”How to breed new varieties with improved drought tolerance and water use efficiency”
* Talk given at Farming Futures Workshop, Broom’s Barn, Oct., 08, “Crop water use and Climate Change"
* Talk given to NFU Sugar Board, BB, 19.5.09
* Talk given to AICC Meeting, RRES, 10-9-09
* Talk given at InterDrought III Conference, Shanghai, 11-16 Oct, 2009

***References***

Cattivelli L, Rizza F, Badeck F-W, Mazzucotelli E, Mastrangelo AM, Francia E, Marè C, Tondelli A, Stanca, AM (2008) Drought tolerance improvement in crop plants: An integrated view from breeding to genomics Field Crops Research 105: 1-14.

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***Staff who have contributed to this project***

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**Figures and Tables**



**Fig. 1**. The mean sugar yield at each site in 2006 plotted vs. the drought stress index (DSI) calculated for each site. The negative slope indicates that water availability alone explained a significant proportion (but not all) of the variation in yield differences between sites. The DSI was calculated according to this formula:



Where Ta is the actual crop water use and Tp is the potential (stress-free) crop water use. Further details are described in our paper (Pidgeon JD, Ober ES, Qi A, Clark CJA, Royal A, Jaggard KW (2006) Using multi-environment sugar beet variety trials to screen for drought tolerance. Field Crops Research 95: 268-279.)

**Fig. 2**. The mean sugar yield at each site from 2006-2009 plotted vs. the drought stress index (DSI) calculated for each site. Each site/year is shown plotted as the year for that site. The negative slope indicates that water availability alone explained a significant proportion (but not all) of the variation in yield differences between sites.



**Figure 3** (previous page). Examples of varieties from the 2006 dataset that show different responses to the availability of water. Cinderella, Leonarda and Carissima showed positive slopes, indicating that they performed better than the trial average as conditions became drier. In contrast, Palace and HI0501 had negative slopes, indicating that good yield potential could not be maintained as well as the trial mean as conditions became dry. Opta and HI0435 are examples of entries that had above-average yield, but showed little responsiveness to water availability. This indicates wide adaptability, and if combined with low variance, good yield stability.

**Table 2**. Summary of variety trial data sets. Entries include RL and NL hybrids. Stage 1 NL entries were tested only at Stage 1 sites; stage 2 entries were tested at all sites. The number of entries with signficant regression is shown (P < 0.05). A significant regression indicates that for a given variety, the DSI explained a significant proportion of the variation in relative sugar yield observed between sites. In other words, that the data points fell onto a positive (drought tolerant) or negative slope (drought susceptible) with a reasonable fit.

|  |  |  |  |
| --- | --- | --- | --- |
| Year | No. sites harvested | No. entries | No. varieties with significant regressions |
| 2006 | 14 | 111 | 12 |
| 2007 | 8 | 114 | 0 |
| 2008 | 4 | 103 | 0 |
| 2009 | 4 | 103 | 9 |

**Table 3**. Monthly summer rainfall over the UK sugar beet growing area in 2007 and 2008. These data document that it was more likely that *too much* rather than too little water was received during these two seasons. Shown are figures from the MET Office site nearest to variety trial sites. Rainfall data for actual test sites were not available, or datasets were incomplete.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Weather Station Site | 2007 | | | 2008 | | |
|  | June | July | August | June | July | August |
|  | mm | | | | | |
| Broom's Barn | 110.5 | 71.1 | 94.3 | 29.8 | 43.1 | 78.2 |
| Cranwell | 171.7 | 117 | 25.4 | 44.8 | 78.4 | 62.4 |
| Emley Moor | 263 | 99.2 | 20.2 | 62.3 | 90.7 | 148 |
| Marham | 117 | 80 | 75.4 | 47.8 | 59.8 | 109 |
| Waddington | 200.6 | 124.8 | 35.3 | 53 | 105.6 | 61.8 |
| Wittering | 97.2 | 84.4 | 39.4 | 34.8 | 39.4 | 66.4 |

**Table 4**. Variety trial sites listed by year, with the calculated drought stress index (DSI) value. In 2008, Hillington, Risby and the Palgrave sites failed, and Langtoft was rejected because of high coefficients of variation (cvs).

|  |  |  |  |
| --- | --- | --- | --- |
| Year | Site | DSI | |
| 2006 | ROCKLAND | | 16.2 |
|  | STETCHWORTH | | 16.6 |
|  | BARDWELL | | 18.5 |
|  | HOLME | | 18.9 |
|  | HIBALDSTOW | | 19.4 |
|  | HORNCASTLE | | 20.5 |
|  | FINCHAM | | 21.0 |
|  | BRACEBRIDGE | | 21.3 |
|  | CODDENHAM | | 21.6 |
|  | STODY | | 21.8 |
|  | FULBOURN | | 22.2 |
|  | TELFORD | | 27.0 |
|  | PATTINGHAM | | 27.0 |
|  | BEAL | | 33.1 |
| 2007 | HORNCASTLE | | 1.5 |
|  | FINCHAM (BARTON BENDISH) | | 2.2 |
|  | FULBOURN | | 3.6 |
|  | BRACEBRIDGE | | 1.4 |
|  | STETCHWORTH | | 3.7 |
|  | HOLME | | 2.4 |
|  | LANGTOFT | | 1.6 |
|  | HIBALDSTOW | | 1.5 |
| 2008 | FULBOURN | | 7.2 |
|  | ROCKLAND ST MARY | | 5.3 |
|  | BRACEBRIDGE | | 7.7 |
|  | HOLME | | 7.1 |
| 2009 | CAYTHORPE | | 5.8 |
|  | EAST RUDHAM | | 18.0 |
|  | HINDOLVESTON | | 15.3 |
|  | RISBY | | 19.3 |

R2 = 0.94

r2 = 0.91

r2 = 0.93

**Fig. 4**. Responses of selected varieties tested in 2009. Note that the spread of points from only four trials gives large weighting to the one trial that was not stressed. However, the slopes may indicate better relative tolerance to dry conditionsowHo (positive slopes). Varieties with good yield potential (Y-intercept), no slope (little sensitivity to stress) and little variance from the regression line indicate a good combination of yield and yield stability across environments (e.g. Sentinel and MA2010).

MA2010



Sentinel



HI0944

Aimanta

Tempest

HI0807



**Fig. 4**. Varieties with contrasting responses in 2009.



**Bobcat**



**Carissima**

**Goya**

**Fig. 5**. Three varieties that were tested from 2006-2009 that showed interesting slopes. Each site/year is shown plotted as the year for that site. There is significant scatter, and slopes are sometimes strongly affected by a small number of outliers. More datapoints for each variety are needed before a ranking of varieties for suitability for dry conditions can be made with confidence.