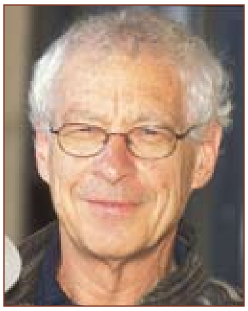
SECTION 1
OVERVIEW
This section brought to you in association with
CASE IH AGRICULTURE

Drought resistant crops: Wet dream or pipe dream?

By John Passioura, CSIRO Plant Industry, Canberra



John Passioura.

DROUGHT RESISTANCE OR WATER-USE EFFICIENCY?

After a run of poor seasons many grain growers have been hoping that plant breeders would produce varieties that perform well during droughts – varieties that are 'drought resistant'.

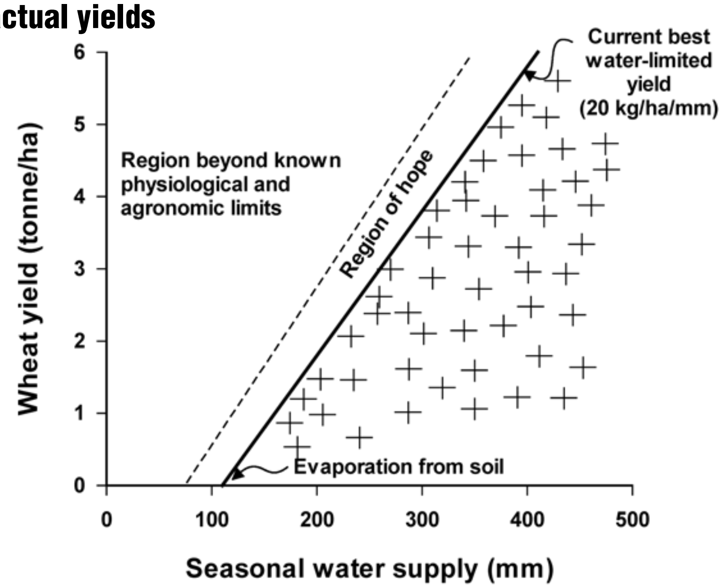
Yet most growers are aware of the revolution in agronomic thinking that Reg French and Jeff Schultz stimulated with their work on water-use efficiency in South Australia in the 1970s and 1980s. They concluded that in practice, the best yield of a cereal crop we can get – in other words, the benchmark of water-use efficiency (WUE) – is about 20 kg per hectare for every mm of water used by the crop (Figure 1).

If 'drought resistance' means getting crops that give yields well beyond the 'region of hope' (see Figure 1), then it is unrealistic to think we can achieve it.

This French and Schultz (F&S) benchmark has been a great stimulus to growers. This is because any yield that is well below 20 kg/ha/mm may mean that something is wrong with the crop's agronomy or that there are hidden problems in the soil, such as root diseases or acidity, which the grower can take steps to deal with.

But the F&S benchmark is a rough rule of thumb, and there can be many other, uncontrollable reasons for having a low WUE such as badly distributed rainfall during the season or unfavourable conditions around the time of flowering leading to poor seed set.

FIGURE 1: Schematic summary of field experience and what it means, with the crosses representing the range of actual yields



"Seasonal water supply" includes available water in the soil at sowing as well as the seasonal rainfall.

AT A GLANCE

- Prospects for getting crops that yield well during a drought – that is, greatly exceeding the benchmark of 20 kg/ha/mm – are very remote.
- Some of the factors leading to a crop having a low WUE are easily recognised by a grower; others are not. It helps in diagnosing the less obvious causes of low WUE to ask:

  – Is the above-ground biomass too small in relation to the seasonal water supply?, and/or;

  – Is the harvest index unaccountably low?

  A close examination of the crop to help answer these questions may also uncover previously hidden agronomic problems or help guide the choice of a more suitable cultivar.
- The agronomic causes of low biomass are typically different from those of low harvest index.

THE WUE BENCHMARK

Although the benchmark has been very helpful, now is the time to look more deeply inside it. We need to see if we can do substantially better than 20 kg/ha/mm, or at least find ways of improving the reliability of getting close to this benchmark.

In essence, the benchmark has three components embedded in it, namely:

- The evaporative loss of available water from the soil;
- The ratio between the water used by the crop (transpiration) and the crop's above-ground biomass (called the transpiration efficiency, TE); and,
- The proportion of the biomass that is converted into grain (the Harvest Index).

Pre-breeding explores novel traits or genes that may lead to better yields.

It turns out that the transpiration efficiency does not vary much – for example, it is not much affected by nutrition.

This means that the main difference in the production of biomass between a poorly-growing crop and a vigorous one is in the evaporative loss of water from the soil, as shown in Figure 2.

So the main targets for improvement are in reducing the loss of water from the soil, and increasing the harvest index, both of which can vary several fold among crops.

Capturing more water for the crop

Water stored in the soil during the summer and autumn fallow can add greatly to the seasonal water supply. It can be increased by astute management, with stubble retention and especially weed control being important to protect summer rain from being lost. Occasional reports of very high WUE are probably because this starting water was not taken into account when doing the simple F&S analysis.

Many growers subtract 110 mm from the seasonal rainfall to account for evaporative losses from the soil during the growing season, leaving the remainder for possible transpiration by the crop and for use in calculating WUE.

But as SARDI researcher Victor Sadras points out, that 110 mm is roughly the average amount of rain that comes in falls of less than five mm during most seasons in south-eastern Australia. There seems little hope of capturing water from these small falls, so a loss of 110 mm is about the least we can hope for, except on lighter soils where such losses may be substantially less.

Good agronomy – timeliness of sowing, weed control, good nutrition, control of root diseases – all contribute to a crop capturing as much as possible of the seasonal water supply, as well as possibly increasing that supply. However, conditions that are too good during the crop's main vegetative growth can reduce yield because not enough water is left for the crucial periods around flowering and grain filling.

Such crops may produce a lot of biomass but suffer from a low harvest index.

Can we boost harvest index?

A very good harvest index is about 40 per cent in a well-managed crop. This coupled with a TE of 55 kg/ha/mm means that we can realistically hope to get a WUE for grain yield of about 22 kg/ha/mm.

A harvest index of 50 per cent can be achieved in gentle grain-filling environments (cool nights, long days, low evaporation rates), but these are rare Australia.

Harvest index is often well below 40 per cent owing to a wide range of factors, including:

- Unfavourable conditions around the time of flowering, such as frost, severe water deficits, or high temperatures;
- Too few seeds set (not enough biomass by flowering; ill-adapted cultivar);
- Flowering too late;
- Too little water left for use during grain-filling;
- Inadequate extraction of seemingly available water in the subsoil;
- Lodging after flowering; and,
- Too little movement of stored carbohydrates from the stems and leaves to the grain.

Any one of these factors can be more or less important across a range of crops and seasons. According to a drought's intensity and timing, it can influence many of these factors differently.

Agronomically, management options that improve the balance between water use before and after flowering can often improve performance.

But it also means plant breeders are always faced with large genotype x environment interactions in drought years that are very hard to unravel.

Can we increase transpiration efficiency?

The estimate of F&S that TE of biomass is about 55 kg/ha/mm over the whole season still stands. There has been some success in improving TE, most notably by about five per cent in the wheat cultivars Drysdale and Rees (which were specifically selected for higher TE). Further progress may be difficult. Looking decades ahead, improvements in the efficiency of photosynthesis or respiration (via genetic

...20▷

SECTION 1
OVERVIEW
This section brought to you in association with

CASE AGRICULTURE

◁19...WET DREAM OR PIPE DREAM?

modification) may bring about improvements in yield of about 10 per cent each.

But it is also worth noting that commercial breeders have managed to achieve about a 10 per cent increase in yield per decade during most of the last century AGT's *Gladius*, a good performer across a range of environments, suggests they are continuing to do so.

Genotype x environment interactions in drought years are hard to unravel.

DROUGHT RESISTANCE AND PRE-BREEDING

Breeding varieties that perform in the 'region of hope' in Figure1 is very difficult and may require novel traits.

Commercial plant breeders are busy people who don't have much time to explore unproven traits, no matter how promising, that lie outside their imperatives to produce varieties that are resistant to the major diseases, of good grain quality, of the right height, which flower at the right time, and whose yield is at least as good as the current best varieties.

They must leave the exploration of novel traits to the molecular biologists, biochemists and physiologists who are hoping to discover traits, or novel genes, that may lead to better yields. This type of activity has come to be called 'pre-breeding'.

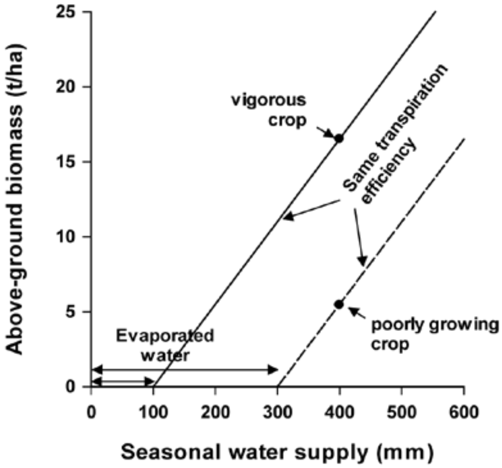
Pre-breeding initiative

With the sponsorship of the GRDC, the Australian Winter Cereals Pre-Breeding Alliance was created earlier this year. It comprises the many institutions around the country involved in pre-breeding. The Alliance held a workshop recently looking at 'Pre-Breeding for Better Performance Under Drought'.

This workshop brought together breeders, molecular biologists, crop physiologists and agronomists and it came to several notable conclusions:

- Because farmers get almost all of their income in moderate to good seasons and little or none during severe droughts, it is better to invest predominantly in ensuring that they can make the best of the moderate to good

FIGURE 2: Transpiration efficiency is often not much affected by how well a crop is growing. It is the loss of water by direct evaporation from the soil that changes markedly



seasons. This conclusion was backed by the breeders who pointed out that with the current system of endpoint royalties, they too depend on moderate to good seasons for their income. If a new variety does well in poor seasons as well as good then that is a bonus – but specifically targeting poor seasons does not interest them.

- In terms of breeding crops that yield well in a severe drought, the message needs to be broadcast that there are major, well-understood, limits to the performance of water-limited crops (consistent with the F&S benchmark) which will be exceedingly hard to break.
- This is not say that we should give up this hope, for there are some possibilities – for example making photosynthesis more efficient – that offer hope of moving the benchmark substantially higher. But these are at least 20 years away from fruition, and even then are likely to deliver no more than about a 10 per cent increase in water-use efficiency.
- Most of the novel traits being explored, especially those in an advanced stage of development, aim not at exceeding the current benchmark of water-use efficiency (for example, breeding for long coleoptiles, which enable better establishment of a crop), but at helping to ensure that a crop uses more of the available water supply, and that it more reliably gets closer to the benchmark.
- Recent improvements in water-use efficiency have come largely from agronomic changes (for example, direct drilling) giving more effective management at the start of the season. This happened in 2006 with the frequently successful technique of dry sowing.
- One of the main limitations to faster progress in pre-breeding for better performance under drought is inadequate 'phenotyping'. That is, the characterisation of traits that we hope will improve water-limited yield.
- Almost all such phenotyping in the laboratory relies on screening plants for their ability to survive severe water stress, yet better survival rarely means better production. Furthermore, cereal crops are already very tough. Many wheat crops that were harvested for hay in 2006 because they looked as though they were dying, started growing new leaves after they had been cut, even though the drought persisted.
- Similarly, in the field, there have been almost no good agronomic studies of new varieties said to be able to yield well when water is strongly limiting. Without these studies it is hard to discern what are the features of these varieties and whether or not we can learn from them.
- This led to one of the workshop's recommendations that field sites be set up in major cropping regions which will enable good phenotyping in realistic environments, using controlled drought treatments at various stages of a crop's development. These facilities would be shared by breeders, agronomists, crop-physiologists, and pre-breeders, and allow interactions that would greatly improve the effectiveness of pre-breeding.
- Finally, because the terms 'drought tolerance' and 'drought stress' have proven to be confusing and without agreed meaning in the context of pre-breeding for water-limited environments, it is better to avoid them. Pursuing traits that enable crops to capture more of a limiting water supply and to use that water more effectively in developing grain yield, whether by breeding or by improved agronomy, is a surer path to better performance.

For more information: John Passioura
Ph: 02 6246 5087; Email: john.passioura@csiro.au ■

There are limits to the performance of water-limited crops.