Benchmarking water-use efficiency – a nationally consistent but regionally relevant approach

James Hunt and John Kirkegaard
CSIRO Sustainable Agriculture Flagship

Summary:

- GRDC requires a 10% increase in WUE and groups must assess current regional WUE performance in order to provide a benchmark with which to judge improvement
- Data to do this are typically limited, often consisting only of grain yields and corresponding rainfall figures
- Water-use must be estimated from these data in a nationally consistent but regionally relevant way
- If of sufficient quality, group's own data can provide regional benchmarks without reference to published figures

Background:

A stated aim of the GRDC national WUE initiative is to improve regional WUE by a relative value of 10%. That is, if a region is currently achieving an average of 10 kg/ha.mm, the initiative aims to lift that to 11 kg/ha.mm. Consequently, groups are required to assess their current regional WUE performance in order to establish a benchmark for comparison at the conclusion of the project. This fits under Tier 2 of the four tiered evaluation approach discussed at previous meetings and written-up in Ground Cover (Wilhelm 2009).

The boundary concept of WUE originally proposed by French and Schultz (1984, 20 kg ha^{-1} mm^{-1} TE and 110 mm 'least' evaporation) and furthered by Sadras and Angus (2006, 22 kg ha^{-1} mm^{-1} TE and 60 mm 'least' evaporation) represents an <u>upper-limit</u> (sometimes referred to as potential yield) for attainable yield i.e. the best yield achieved through skilful use of available technology.

Much of the 'yield gap' (the difference between realised actual farm yields and the boundary line) will <u>not</u> be due to poor agronomic practice, but attributable to less favourable meteorological conditions e.g. poor distribution of rainfall, stress during critical periods, high temperatures and low relative humidity resulting in high vapour pressure deficit (Doherty et al. 2008).

The important thing at this stage of the project is for groups <u>not</u> to be distracted by how they are performing relative to the published benchmarks, but to be able to state their current regional WUE performance in average terms. This article provides a guide for how each group might do this in a nationally consistent but regionally relevant way.

Hunt J. & Kirkegaard J 2010 – Benchmarking water-use efficiency – a nationally consistent but regionally relevant approach.
Mallee Sustainable Farming 2009 Research Compendium pp. 135 - 142
Also available at: http://www.msfp.org.au/research.php?page=compendiums

1. Selection of data

Most groups have now collected the datasets with which they intend to benchmark current WUE performance. In their simplest form these data will be (1) grain yields from whole farms, paddocks or trials; and, (2) corresponding rainfall figures, but should be representative of what groups feel they are currently achieving in their region. As a guide the data should include a range of years (at least five) and a representative group of growers or trial sites. The number of data points required will depend on variability in your region. As a guide, French and Schultz used 61 yield results from 23 sites over a 12 year period. Groups have between 80 and 300+ members, so around 50 data points would seem reasonable. As the upper limit of WUE will vary with soil type as the proportion of evaporation, run-off and drainage to transpiration changes, groups operating in areas where soil types vary markedly should make sure they consider this source of variation in their data.

Plans to re-evaluate the impact of management interventions on WUE at the conclusion of the project might also influence the choice of site selection and specific data collected. Geoff Thomas and Nigel Wilhelm will be providing some guidelines for this in the next issue of the newsletter.

2. Defining water-use

For the GRDC WUE initiative, water-use is defined as the combined transpiration, evaporation, deep drainage and net run-off during the life of a given crop. The proportions of these components of water-use form a major determinant of WUE (i.e. the aim is to maximise transpiration). It is difficult to measure these components separately so estimates of water-use from more readily available data are used. For example French and Schultz (1984) estimated water-use by choosing sites where run-off and deep drainage were unlikely to occur and measured plant available water (PAW) at sowing, subtracted PAW at maturity and added intervening (in-crop) rain. This is the best estimate of water-use that can be reasonably obtained and if you have these data available for benchmarking you should use them (all groups should definitely be measuring these in their WUE experiments). However, most groups will not have this sort of data for the purposes of their benchmarking so it will be necessary to estimate water-use based on growing season and out-of-season rainfall, the concept also originally proposed by French and Schultz (1984). Groups should be aware that that this method is likely to be associated with significant error (Hochman et al. 2009).

3. Defining growing season rainfall (GSR)

In order estimate GSR, the duration of the growing season must first be defined. This will vary with region, but should include the months during which crops are typically growing e.g. in northern WA this may be May to September whilst in Tasmania April to January might be more appropriate. Whatever you choose to use, make sure you state clearly exactly what you did when reporting results, particularly on any graphs and tables you produce. Growing season rainfall (GSR) will be the total quantity of rain that falls during the period you have defined.

4. Allowing for out-of-season rainfall

Unless you are in a region that allows double-cropping, the remaining months of the year form the out-of-season period. The total quantity of rain that falls during this period is out-of-season rainfall (OSR), which can contribute significantly to water that is used by a crop. Therefore, when estimating water-use based on rainfall data, an allowance for out-of-season rain needs to be made.

The amount of out-of-season rainfall that becomes available to a crop is defined as fallow efficiency. Fallow efficiency varies enormously from season to season from negative values (i.e. the soil loses water during the fallow) up to about 60% (60% of rain that falls is stored). It is primarily dependant on rainfall event size, distribution and soil type as well as management practices such as stubble management and weed control. Estimating fallow efficiency will be a large source of error in the benchmarking process. In the interests of providing a nationally consistent but regionally relevant approach, it is recommended that APSIM simulation be used to provide each group with an estimate of fallow efficiency for which calculations can be made.

Figure 1 shows APSIM output that provides an estimate of out-of-season fallow efficiency for a heavy clay soil at Condobolin assuming complete weed control and stubble retention. The amount of water from out-of-season rainfall that should be used in calculations of water-use efficiency for that area can be calculated from the regression line fitted to the data, in the case of Figure 1;

$$\text{PAW at start of growing season} = 0.36*(\text{out-of-season rainfall}) - 30$$

The intercept of the regression line with the x-axis is 83 mm, which is equivalent to the minimum amount of out-of-season rainfall required before any PAW will be stored. This method is far from ideal and will have considerable error associated with it, but it is the most consistent and regionally relevant method based on the data we have available.

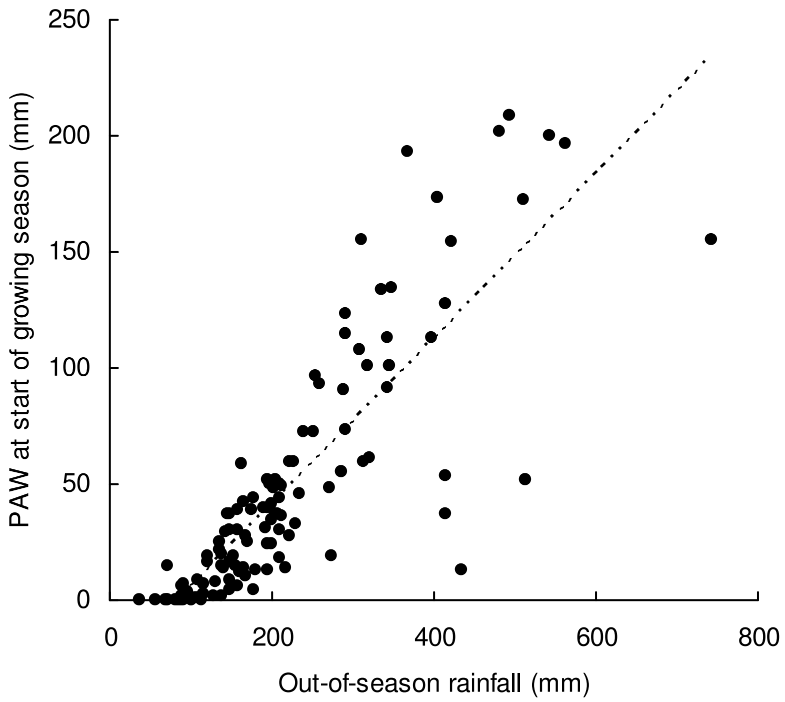

Figure 1. The APSIM simulated relationship between out-of-season rainfall and PAW at the start of the next growing season for a heavy clay soil at Condobolin. The dotted line was fitted to the data using least-squares regression (R^2=0.71) and is of the form $y = 0.36x - 30$.

5. Additional PAW at sowing and unused PAW at harvest

Be aware that there are factors other than out of season rainfall which can result in additional PAW being available at the start of the growing season e.g. long fallows, pulse, forage or green manure crops that leave carry-over water. For most groups these will be impossible to accurately account for given the data available, but be aware that it is a potentially large source of error and is often the reason why some data points may exceed previously published upper boundaries.

Rain falling late in the season on physiologically mature crops prior to harvest is unlikely to contribute to yield. This will result in an underestimate of WUE, but once again it will be difficult for groups to account for this given the data available.

6. Calculating water-use efficiency

Water-use can now be estimated as growing season rainfall plus PAW at the start of the growing season as calculated above. Water-use efficiency is simply grain yield in kilograms per hectare divided by your estimate of water-use. This value is your regional benchmark and what you must improve by 10% over the life of the WUE project. Average values typically vary between 5 and 20 kg ha^{-1} mm^{-1}.

7. Graphing water-use efficiency

You can create a scatter-plot of water-use efficiency similar to that of French and Schultz (1984), with your estimate of water-use in mm on the x-axis, and grain yield in kg/ha on the y-axis (Figure 2). The resulting cluster of data points should have a reasonably defined upper-boundary. Use a ruler or graphing software to fit a straight line to this upper boundary.

What is the slope and intercept of this line?
How different is it to that found by French and Schultz (1984) or Sadras and Angus (2006)?
How scattered are the points below the line?
Are there any other obvious boundaries to your points e.g. does your data have a 'top' boundary (e.g. Figure 2), and what could explain this? Low PAWC (Oliver et al. 2008) or lack of investment in inputs required to achieve attainable yield (risk aversion) e.g. nitrogen fertiliser?

If your dataset was sufficiently broad, your upper boundary should be the contemporary upper limit to attainable yield in your region.

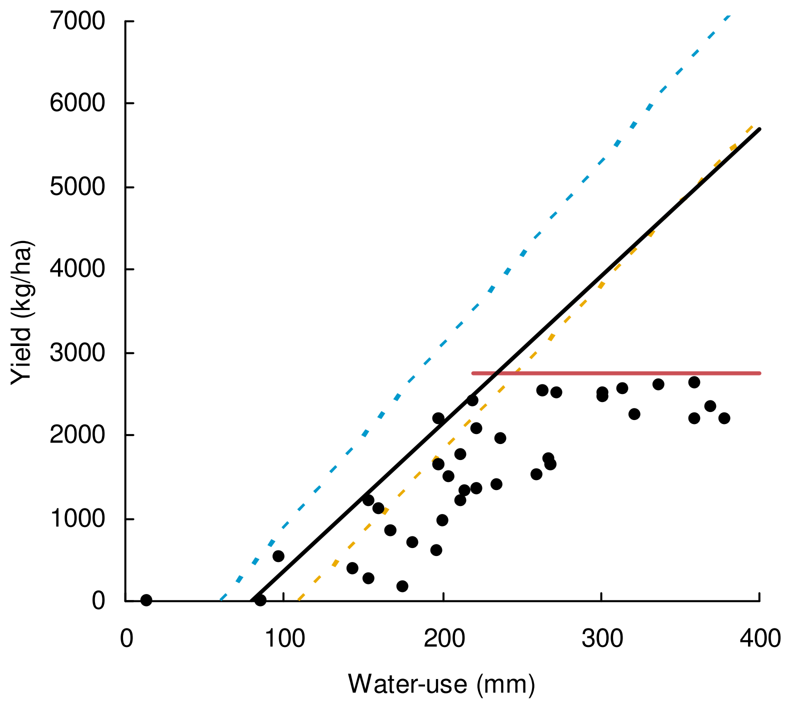

Figure 2. An example of how benchmarking data may look when grain yield is plotted against an estimate of water-use. It shows measured yield and water-use data (•), an upper boundary fitted to the data by eye (—) which has an x-intercept of 80 mm and slope of 17.8 kg/ha.mm, a 'top' boundary to the data (—) possibly caused by low PAWC or nitrogen limitation and the published boundaries of French and Schultz (---) and Sadras and Angus (---).

8. Diagnosing poor WUE

Collection and presentation of data as outlined above does not allow diagnosis of causes for low WUE. It is impossible to distinguish whether low WUE is the result of environmental constraints outside grower control, (e.g. poor distribution of rainfall or high vapour pressure deficit) or poor management (e.g. weeds, disease, nutrition).

However, some groups do have management data together with yield and rainfall data, which might provide some empirical evidence as to which practices lead to higher WUE. This information could be useful in focussing the research and extension component of regional projects. For example, Figure 3 shows a simulated example of WUE achieved in the Condobolin region for paddocks with a 0% out-of-season fallow efficiency (e.g. if summer weeds were allowed to grow unchecked and no stubble was retained), and 'best' attainable fallow efficiency (full control of summer weeds and stubble retention). It shows that good fallow management on average results in a 124% increase in WUE from 4.4 kg/ha.mm to 9.9 kg/ha.mm! Not surprisingly, CWFS nominated summer fallow management as one of their most important WUE interventions.

How much do you think your nominated interventions could increase WUE by? This is the information required by GRDC under Tier 3 of the four tier approach.

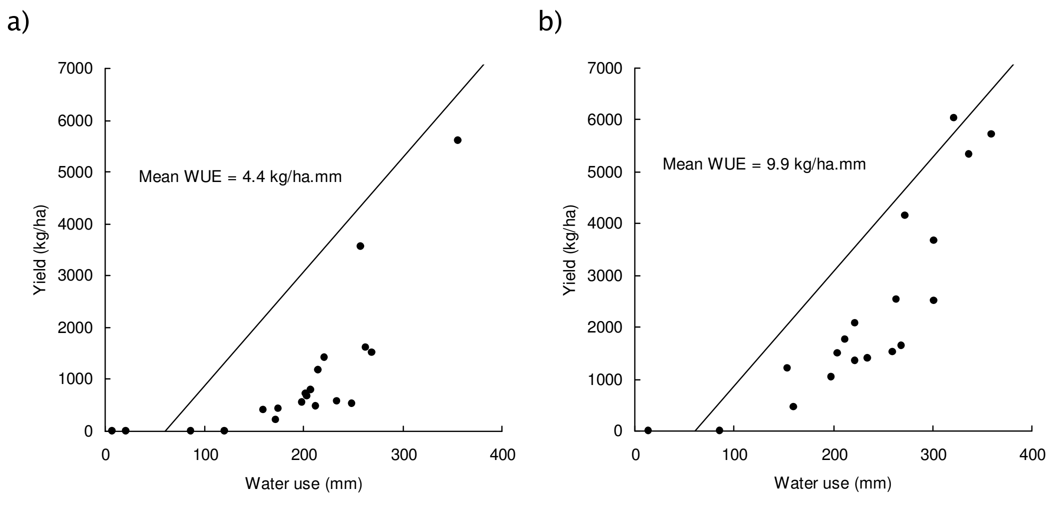

Figure 3. APSIM simulated wheat yield and water-use 1989-2008 for a heavy soil at Condobolin assuming a) 0% fallow efficiency (summer weeds allowed to grow, stubble not retained) and b) 'best' attainable fallow efficiency (full control of summer weeds and retention of stubble). Straight lines are the Sadras and Angus boundary of WUE; 22 kg ha^{-1} mm^{-1} minus a 'least' value of evaporation of 60 mm.

Glossary:

Attainable yield: The best yield achieved through skilful use of available technology.

Fallow efficiency: The percentage of rain that falls during the out-of-season fallow period and is available to a crop at sowing.

Growing season rainfall (GSR): The total quantity of rain that falls during the months of what is typically considered to be the growing season of a given region and crop. This could vary from May to September for spring wheat in the northern wheat-belt of WA to April to January for winter wheat in Tasmania.

In-crop rainfall: The total quantity of rain that falls between sowing and crop maturity (Zadoks GS89)

Out-of-season rainfall (OSR): The total quantity of rain that falls during the remaining months of the year not encompassed by the growing season (see 'growing season rainfall').

Potential yield: Definitions vary, but in the Australian agricultural industry potential yield is usually taken to mean an upper limit of attainable yield as defined by a WUE benchmark such as that of French and Schultz i.e. the yield of a crop grown under relatively benign climatic conditions and optimal agronomic management.

Water-use: The combined transpiration, evaporation, deep drainage and net run-off during the life of a given crop. The proportions of these components of water-use are one of the major determinants of water-use efficiency.

Water-use efficiency (WUE): The amount of a saleable commodity (typically grain or biomass) produced per mm of water-use.

Yield gap: The difference between realised actual farm yields and a defined upper boundary of attainable yield (potential yield). The difference may exist due to climatic conditions and/or management factors.

References:

Doherty A, Rodriguez D, Potgieter A, Sadras V (2008) A national benchmark for the Australian wheat industry: accounting for overlooked climate drivers. In 'Global Issues, Paddock Action - 14th Australian Agronomy Conference'. (Ed. M Unkovich). (Australian Society of Agronomy: Adelaide, South Australia).

French RJ, Schultz JE (1984) Water use efficiency of wheat in a Mediterranean-type environment: 1. The relationship between yield, water use and climate. Australian Journal of Agricultural Research 35, 743-764.

Hochman Z, Holzworth D, Hunt JR (2009) Potential to improve on-farm wheat yield and WUE in Australia. Crop and Pasture Science 60, 708-716.

Oliver YM, Robertson MJ, Stone P (2008) Modification to the French and Schultz formula to account for soil type and within-season rainfall. In 'Global Issues, Paddock Action - 14th Australian Agronomy Conference'. (Ed. M Unkovich). (Australian Society of Agronomy: Adelaide, South Australia).

Sadras V, Angus J (2006) Benchmarking water-use efficiency of rainfed wheat in dry environments. Australian Journal of Agricultural Research 57, 847-856.

Wilhelm N (2009) Concerted effort under way to maximise crop water use. In 'Ground Cover' pp. 28-31. (GRDC: Kingston, ACT).

For more information contact:
James Hunt and John Kirkegaard
CSIRO Sustainable Agriculture Flagship
PO Box 1600 Canberra, ACT 2600, Australia. Email
james.hunt@csiro.au and john.kirkegaard@csiro.au