A new approach to estimate the components of water-use

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Summary:

- Using a French and Schultz approach for regional benchmarking is acceptable, but when assessing the performance of particular crops or experimental treatments, a more accurate estimate of the components of water-use may be of interest
- A different approach is discussed here which may more accurately define the components of water-use, particularly when analysing experimental data
- This article lists a 'minimum dataset' for researchers wishing to explore the water-use efficiency of experimental data

French whispers?

I highly recommend setting aside some time to read French and Schultz (1984a) and the companion paper (French and Schultz 1984b). Some of the elegance and thought in their original work has been lost in transmission. It always impresses me that 25 years ago they discussed many of the same issues around water use and yield that are still being debated today.

The original paper does not directly introduce the potential yield formula for which it is so well known (this honour belongs to earlier authors):

yield = (water use – soil evaporation) x transpiration efficiency

but estimates the soil evaporation (110 mm) and transpiration efficiency (20 kg ha^{-1} mm^{-1}) terms, and implies the formula in the well-known graph.

The original paper also does not foreshadow the popular current use of the formula in benchmarking, which is to re-arrange it so that 'transpiration efficiency' is being estimated (usually called 'water use efficiency'). A more sensible, alternative use of the formula in benchmarking is to express an actual yield as a per cent of the French and Schultz potential yield, but for some reason calculating 'water use efficiency' is more popular.

The original paper also discusses variation in soil, the importance of stored water and some corrections that might be needed to use monthly (e.g. April-October) rainfall. These considerations are often neglected from the benchmarking exercise which means that the 'water-use efficiency' figures calculated can be misleading. James Hunt and John Kirkegaard have discussed in previous articles in this publication, some measures that can be taken to reduce the erroneous effects on benchmarking.

The aim of this article is to present an alternative and more robust method of examining and presenting water-use. The method may help to diagnose some of the causes of below-potential yield, particularly in field experiments.

Stronger assumptions:

One of the weaker assumptions of the formula above is the estimate of soil evaporation (110mm). French and Schultz (1984a) describe situations where this may vary between 30 and 170 mm (p753), depending on environment and soil type. Soil evaporation is also likely to vary with treatments that change the canopy or surface condition.

An alternative to estimating soil evaporation is to instead estimate transpiration efficiency for biomass and to measure biomass. This allows actual transpiration by the plant to be estimated. The other components of water use (soil evaporation, drainage and runoff) can be assumed to be what's left over after transpiration has been taken out.

Transpiration efficiency for biomass can be calculated from physiological principles to be about 55 kg ha^{-1} mm^{-1} in optimum (cool, humid) conditions. This was also the maximum efficiency estimated for biomass in French and Schultz (1984a). APSIM also estimates quite consistent transpiration efficiency for biomass across a range of environments, soil types and treatments. Transpiration efficiency would ideally be corrected for different environments (humidity, temperature) but in field experiments all treatments share similar conditions and at most this will cause small differences. A reasonable estimate seems to be 50-55 kg ha^{-1} mm^{-1}.

In dry springs it is quite usual for measured biomass to decrease between anthesis and maturity. This may be due to leaf fall and/or measurement errors, but could also be because of high respiration rates and/or breakdown of dead material on the plant by microorganisms. To capture the maximum biomass (and hence better estimate water-use), it is probably necessary to measure biomass at anthesis as well as at maturity. Grain yield should also be measured on the maturity sample. These measurements also facilitate other diagnoses (e.g. calculation of harvest index).

Estimating components of water use - Checklist:

A. Measured soil water pre-sowing or soon after sowing (mm)

B. Estimate of soil crop lower limit (mm)

C. Rainfall between soil sampling and physiological maturity of the crop (mm)

D. Biomass measured at anthesis (kg ha^{-1})

E. Biomass measured at maturity (kg ha^{-1})

F. Yield measured on the maturity biomass sample (kg ha^{-1})

G. Your estimate of transpiration efficiency for biomass (eg. 50-55 kg ha^{-1} mm^{-1})

Total water use (mm) is estimated as C + A – B

Maximum biomass (kg ha^{-1}) is the maximum of D and E

Total transpiration (mm) is maximum biomass divided by G

Transpiration for grain (mm) is F divided by G

If biomass decreases between anthesis and maturity, this can be represented as (E-D) divided by G. A biomass increase (anthesis to maturity growth) can be represented as (D-E) divided by G.

Soil evaporation (and drainage and runoff) is then Total water use – Total transpiration.

Examples:

One way of presenting the components of water use is to produce a 'stacked bar graph' with different colours for each component. This integrates water use (evaporation, transpiration, unused) and harvest index (yield / biomass).

The first example is for farmer paddocks monitored as part of a BCG/Vic No Till project. In the Minyip pair, the Till paddock has higher total water use and similar evaporation to the No Till paddock, but much lower yield because of poor harvest index (Minyip, Figure 1). In the Sea Lake pair, the Till paddock (in a fallow rotation) has slightly more water and less evaporation, translating directly to additional grain compared to the No Till paddock (in a continuous rotation).

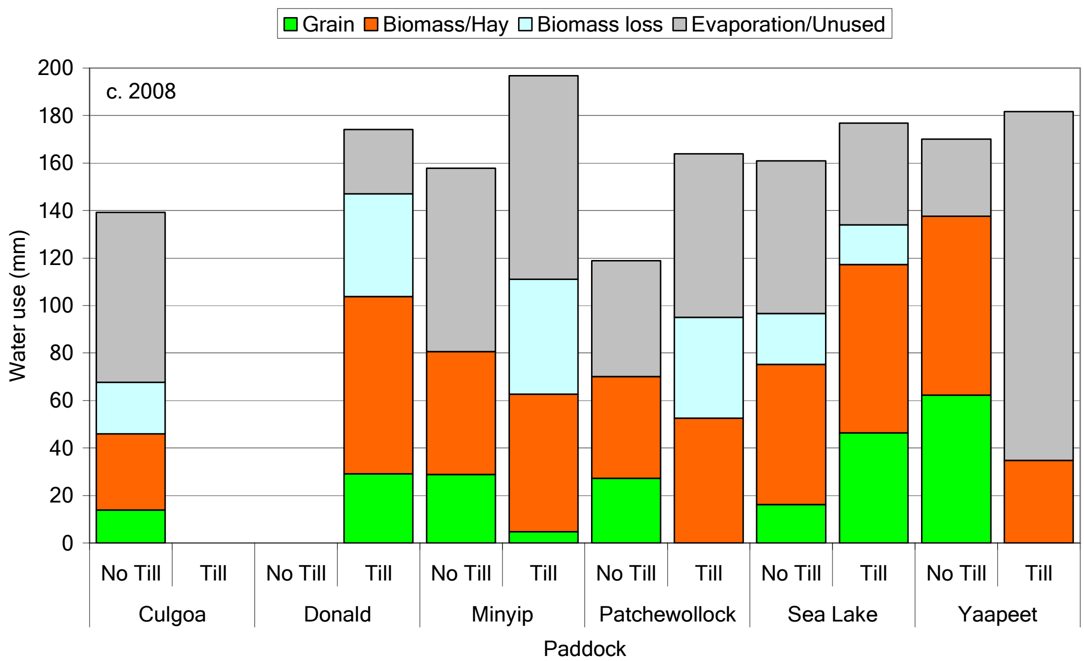

Figure 1. Breakdown of water use for Till and No Till farmer paddocks in the southern Mallee/northern Wimmera in 2008. All crops were barley or wheat apart from Patchewollock Till (pea).

The next example is from some APSIM nitrogen fertiliser simulations. In APSIM, water remaining at the end of the season can be output and this was included as a further component of water use. APSIM calculates actual soil evaporation and transpiration and these can be used in this presentation without needing to estimate transpiration efficiency.

Nitrogen fertiliser increases total water use (less water remaining) and decreases evaporation, but there is also less growth between anthesis and maturity (Figure 2). Nitrogen fertiliser also increases harvest index (water for grain is larger compared to biomass).

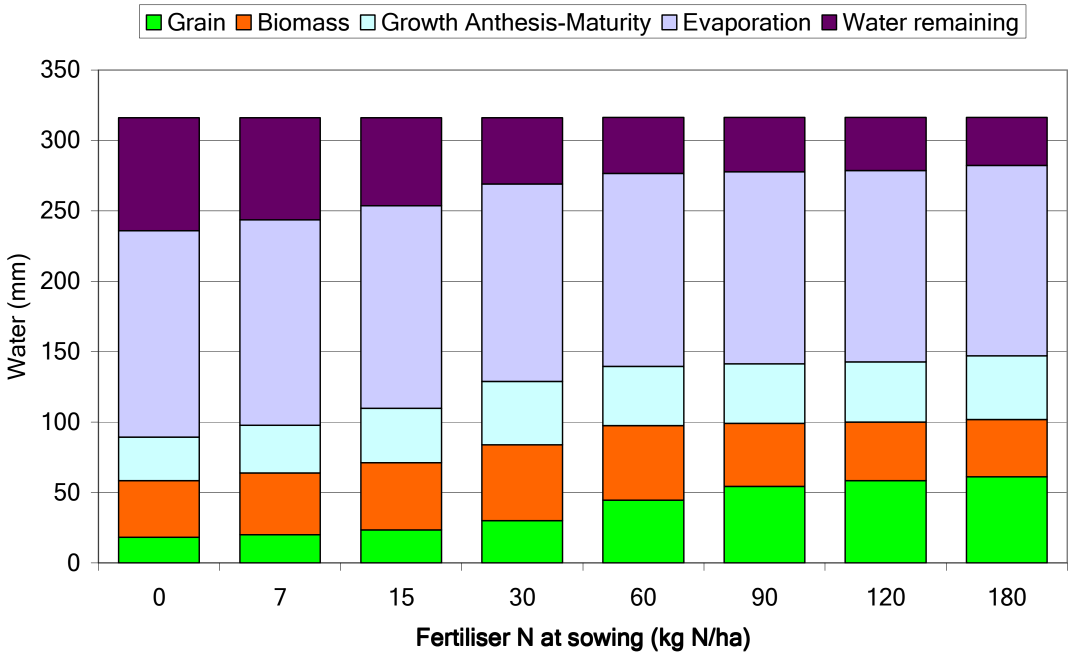

Figure 2. Breakdown of wheat water use for APSIM simulations of different fertiliser rates at sowing on an unconstrained soil type in Carwarp in 2000.

Conclusion:

Assuming constant transpiration efficiency for biomass rather than constant soil evaporation may help to interpret experimental results. Soil evaporation, transpiration and harvest index can be separated out if the right measurements are made. Where possible, soil water, anthesis and maturity biomass and grain yield should be measured on experiments to allow components of water use to be estimated.

References:

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

French RJ, Schultz JE (1984b) Water use efficiency of wheat in a Mediterranean-type environment. II. Some limitations to efficiency. Australian Journal of Agricultural Research 35, 765-775.

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