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A guide to consistent and meaningful benchmarking of yield and reporting of water-use efficiency

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Introduction

This document provides guidance for groups within the GRDC National Water-use Efficiency (WUE) Initiative on how to estimate and present WUE results from their experiments and focus paddocks in a consistent and meaningful way. It can also be used by groups as a resource for growers to benchmark their yields and WUE. The WUE calculations in this document proceed in 4 steps depending on the data available and provides worked examples to assist.

The steps:

1. Estimating water-use
2. Calculating water-use efficiency
3. Benchmarking yield
4. Estimating transpiration and unproductive water-use

1 Estimating water-use

The first step toward benchmarking crop WUE is to estimate water-use. Water-use is defined as the total amount of water used to grow the crop during the season, and includes transpiration (water used by the plant to grow), evaporation (water lost from the soil surface), run-off and deep drainage.

Water-use= transpiration + evaporation + run-off + deep drainage

There are several ways of estimating water-use depending on the data available;

Method 1 – an OK method

Water-use (mm) = 0.25 × summer fallow rainfall + growing season rainfall

Data needed

- Monthly rainfall

This method assumes that 25% of rain falling during the summer fallow is stored for crop use. It also assumes that there is no water carrying over from the previous season, which is not the case after long fallows, pulse crops etc.

The months of the year that constitute the summer fallow and growing season periods will vary with location; e.g. in Tasmania the growing season might extend from March to January, whilst in northern WA May to September could be more appropriate. It is important that the months that are assumed to constitute the growing season are specified when reporting results.

Method 2 – a better method

Water-use (mm) = plant available water at start of growing season + rain from then until physiological maturity

Data needed

- Soil water sampled at or near sowing (analysis from soil core or in-situ probe)
- Estimate of your soil's bulk density & crop lower limit
- Daily rainfall
- Dates of soil sampling and harvest

This method assumes the crop has used all available water at maturity – which is rarely true in wet springs or in high rainfall areas.

Method 3 – best method

Water-use (mm) = (soil water at sowing – soil water at maturity) + in-crop rain

Data needed

- Soil water sampled at (or near) sowing and maturity (from soil core or in-situ probe)
- Daily rainfall

This was the method employed by French & Schultz, who deliberately chose sites that were not prone to run-off, drainage or lateral water movement so:

Water-use = transpiration + evaporation

Be aware that for many crops there will have been run-off and drainage, but these will not be accounted for separately and are rarely measured. Evaporation, run-off and drainage can be thought of together as 'unproductive water-use';

Water-use = transpiration + unproductive water-use

A method for separating transpiration and unproductive water-use for further insight is described in Section 5.

2 Calculating water-use efficiency

Water-use efficiency (WUE) is simply grain yield (kg/ha) divided by water-use:

WUE (kg/ha.mm) = grain yield/water-use

A common error is to compare water-use efficiency to the French and Schultz (20 kg/ha.mm) or Sadras and Angus (22 kg/ha.mm) upper limits of transpiration efficiency– but this is incorrect! Remember these numbers are transpiration efficiencies and assume a given evaporation (110 or 60 mm); the calculation above includes evaporation which we know can vary with site, season and management. We are only interested in comparing the WUE of treatments with each other within a given season – and this is the basis on which GRDC are looking for a 10% increase when regionally scaled-up. It is not appropriate to compare WUE values between seasons.

3 Benchmarking yield using an upper-limit of water-use efficiency

French and Schultz (1984) proposed that the best possible wheat yield achievable for a given amount of water-use (potential yield) could be defined as;

Potential yield (kg/ha) = 20 × (water-use - 110)

Sadras and Angus (2006) updated this benchmark to allow for the introduction of semi-dwarf wheats, increases in atmospheric carbon dioxide and crops grown on sandy soils where evaporation is very low. Their estimate of potential yield is;

Potential yield (kg/ha) = 22 × (water-use - 60)

This provides a benchmark which can be used to assess paddock or experimental treatment performance. The best way to benchmark yield is to calculate what a crop yielded as a percentage of the benchmark.

% of potential yield achieved =
100 × (actual crop yield/potential yield)

For the sake of consistency within the GRDC WUE initiative, the Sadras and Angus benchmark should be used. Modern crops will often exceed the French & Schultz benchmark. When using Sadras and Angus, crops in some environments (particularly with heavy soils) will rarely come close to the benchmark (commercial crops yielding around 75% of Sadras & Angus will probably have achieved the most profitable yield at a reasonable level of input risk). The absolute WUE number is not as important as the relative differences between treatments or paddocks which can identify that something may be wrong with a particular paddock or its management.

It is worth noting that both French and Schultz and Sadras and Angus used dry grain yield to derive their relationships. When reporting results to industry it is more useful to report grain yield at deliverable moisture content (e.g. 12%), and it is recommended that this be done by groups within the WUE initiative. If comparing yield results at deliverable moisture content to a WUE benchmark, it is important to correct the benchmark value to the moisture content of the harvest yield.

Potential yield @ 12% moisture (kg/ha) = potential yield × 1.12

4 Estimating transpiration and un-productive water-use

If total dry matter at crop maturity is known, it is possible to separate and provide estimates of productive water-use (transpired by the plant) and unproductive water-use (lost to evaporation, drainage or run-off). This can be informative (see later Example C).

For wheat crops grown in southern environments we know that for each mm of water transpired by a crop, around 55 kg/ha of total dry matter is produced (this transpiration efficiency of 55 kg/ha.mm should be used for consistency within the GRDC Initiative). Therefore;

Transpiration (mm) = total dry matter (kg/ha)/55

Once estimated, the transpiration value can be subtracted from water-use to estimate unproductive water-use;

Unproductive water-use (mm) =
water-use (mm) - transpiration (mm)

This method cannot be used to compare experimental treatments which might have changed the transpiration efficiency (e.g. sowing time). However it can be used to compare treatments such as row spacing and plant density, or to partition the water-use in individual paddocks.

5 Worked examples

Example A: Real paddock example using water-use method 2

This example from the Victorian Mallee in 2009 benchmarks two paddocks on a farm using yields, growing season rain and plant available water measured at the start of the growing season. Paddock 1 was sown early into pea stubble; Paddock 2 was sown later into wheat stubble.

Paddock 1 was able to achieve 71% of the benchmark (Sadras and Angus potential yield), which is excellent for a commercial crop. Paddock 2 was only able to achieve 32% of the benchmark. This clearly demonstrates the additive WUE benefits of break crops (peas) and early sowing.

		PADDOCK 1 (WHEAT SOWN 23 APRIL 2009 INTO FIELD-PEA STUBBLE)	PADDOCK 2 (WHEAT SOWN 12 MAY 2009 INTO WHEAT STUBBLE)
A	PAW start of April	22 mm	6 mm
B	Growing season rain (April-October)	192 mm	192 mm
C	Water-use = A + B	214 mm	198 mm
D	Grain yield (12% moisture)	2700 kg/ha	1090 kg/ha
E	Potential yield = 22 × (C - 60)	3388 kg/ha	3036 kg/ha
F	Potential yield @ 12% moisture (E × 1.12)	3795 kg/ha	3400 kg/ha
G	% of potential yield @ 12% = 100 × (D/F)	71%	32%
H	Water-use efficiency = D/C	12.6 kg/ha.mm	5.5 kg/ha.mm

Example B: A comparison of methods to demonstrate differences

This example from the CSIRO and FarmLink research site at Temora in 2011 compares current practice (the mid-season variety Gregory sown 9 May at 100 plants/m²) with novel management (the very slow variety Eaglehawk sown early on 15 April at 40 plants/m²).

In this example all methods gave a similar increase in WUE – around 4.0 kg/ha.mm or a 26% increase based on 'best' method, but % of potential yield differed substantially due to Method 1 & 2 underestimating water-use. However, the relative difference between treatments was the same in all methods.

METHOD 1 - OK METHOD

		CURRENT PRACTICE - GREGORY 9 MAY 100 PLANTS/M²	NOVEL PRACTICE - EAGLEHAWK 15 APRIL 40 PLANTS/M²
A	Summer fallow rain (November-March)	510 mm	510 mm
B	Growing season rain (April-October)	207 mm	207 mm
C	Water-use = 0.25 × A + B	335 mm	335 mm
D	Grain yield (12% moisture)	5509 kg/ha	6809 kg/ha
E	Potential yield = 22 × (C - 60)	6050 kg/ha	6050 kg/ha
F	Potential yield @ 12% moisture (E × 1.12)	6776 kg/ha	6776 kg/ha
G	% of potential yield @ 12% = 100 × (D/F)	81%	100%
H	Water-use efficiency = D/C	16.4 kg/ha.mm	20.3 kg/ha.mm

METHOD 2 - BETTER METHOD

		CURRENT PRACTICE - GREGORY 9 MAY 100 PLANTS/M²	NOVEL PRACTICE - EAGLEHAWK 15 APRIL 40 PLANTS/M²
A	PAW start of April	121 mm	121 mm
B	Rain from sampling to harvest	207 mm	207 mm
C	Water-use = A + B	328 mm	328 mm
D	Grain yield (12% moisture)	5509 kg/ha	6809 kg/ha
E	Potential yield = 22 × (C - 60)	5896 kg/ha	5896 kg/ha
F	Potential yield @ 12% moisture (E × 1.12)	6603 kg/ha	6603 kg/ha
G	% of potential yield @ 12% = 100 × (D/F)	83%	103%
H	Water-use efficiency = D/C	16.8 kg/ha.mm	20.8 kg/ha.mm

METHOD 3 - BEST METHOD

		CURRENT PRACTICE - GREGORY 9 MAY 100 PLANTS/M²	NOVEL PRACTICE - EAGLEHAWK 15 APRIL 40 PLANTS/M²
A1	Total soil water at sowing	468 mm	470 mm
A2	Total soil water at maturity	340 mm	343 mm
B	Sowing to maturity rain	237 mm	229 mm
C	Water-use = A1 - A2 + B	365 mm	356 mm
D	Grain yield (12% moisture)	5509 kg/ha	6809 kg/ha
E	Potential yield = 22 × (C - 60)	6710 kg/ha	6512 kg/ha
F	Potential yield @ 12% moisture (E × 1.12)	7515 kg/ha	7293 kg/ha
G	% of potential yield @ 12% = 100 × (D/F)	73%	93%
H	Water-use efficiency = D/C	15.1 kg/ha.mm	19.1 kg/ha.mm

Example C: Estimating transpiration (if total dry matter at maturity is known)

A comparison of estimated transpiration based on total dry matter cannot be made in the two treatments used in Example B because they were sown at different times, which affects transpiration efficiency for dry matter. However, a comparison can be made between the same variety (Lincoln) sown on the same date (19 May) but at different plant densities (40 and 100 plants/m²).

The 100 plants/m² treatment performs better relative to the benchmark, and by estimating transpiration and partitioning the water-use components we can see that this is due to more unproductive water-use (evaporation) in the 40 plants/m² treatment (170 mm vs 143 mm). Transpiration efficiencies for grain are very similar between treatments.

		LINCOLN 19 MAY 40 PLANTS/M²	LINCOLN 19 MAY 100 PLANTS/M²
A	Water-use (method 3)	347 mm	347 mm
B	Grain yield (12% moisture)	4974 kg/ha	5625 kg/ha
C	Water-use efficiency = B/A	14.3 kg/ha.mm	16.2 kg/ha.mm
D	Potential yield = 22 × (A - 60)	6314 kg/ha	6314 kg/ha
E	Potential yield @ 12% moisture (D × 1.12)	7072 kg/ha	7072 kg/ha
F	% of potential yield @ 12% = 100 × (B/E)	70%	80%
G	Total dry-matter at maturity	9749 kg/ha	11230 kg/ha
H	Estimated transpiration = G/55	177 mm	204 mm
I	Estimated unproductive water-use = A-H	170 mm	143 mm
J	Transpiration efficiency for grain = B/H	28.1 kg/ha.mm	27.6 kg/ha.mm

References

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