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Water use by crops and pastures in southern NSW

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Key points

- Agricultural production seeks both high total water use (TWU) and high water use efficiency (WUE).
- High total water use influences the environment through minimising deep drainage, and associated waterlogging and salinity.
- Potential or water limited yield of wheat is about 20 kg/ha/mm of seasonal water use, and for broad-leaf crops is about 15 kg/ha/mm of seasonal water use (after deducting 100 to 120 mm).
- The water limited yield of annual pasture dry matter production is about 30 kg/ha/mm (after deducting about 30 mm).
- Potentially, dryland lucerne can yield about 12 kg/ha of dry matter for each mm of annual rainfall.
- Poor WUE can indicate management problems or constraints imposed by soil, nutrition, pests or disease.
- Identifying and addressing these agronomic constraints is the path to improved WUE.

Total water use

Total water use (TWU) refers to the amount of water used by a crop or pasture. Major differences in water use are due to different rooting depths of plants. Lucerne draws water from further down the soil profile (as deep as 3–4 m) than wheat (about 1.2 m) or annual pastures based on subterranean clover (60–70 cm). Lucerne has a greater capacity to access and use water, and so minimise deep drainage. Deep drainage and its associated salinisation are minimised by high total water use by plants. A cereal crop can obtain water, additional to rainfall during the growing season, if moisture is conserved in a fallow prior to sowing the crop. Ability to store fallow moisture is dependent on management (e.g. for weed control, stubble cover) of the fallow, and the soil's capacity to store water. However agricultural production is influenced by both the total water use and the efficiency of the plant in using water to produce grain or forage.

Water use efficiency in grain production of wheat

Water use efficiency (WUE) is a measure of the forage (biomass) or grain yield produced for each

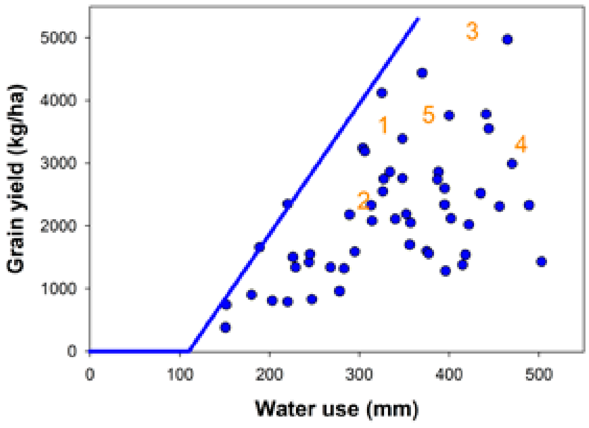

Figure 1. Relationship between grain yield of wheat and water use showing upper limits of water use (blue line, slope of 20 kg/ha/mm after allowing for 110 mm of water); data of French and Shultz 1984a (blue points); and data from five monitored crops in the Murrumbidgee Catchment in 2005 (numbers).

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millimetre of water used (i.e. transpired) by a pasture or crop.

Interest in Australia was spurred by the work of French and Schultz (1984a, 1984b; Figure 1) on water use efficiency for grain production by wheat. French and Schultz estimated growing season water use as equal to in-crop rainfall (sowing to harvest), plus any soil moisture at sowing, minus any unused water at harvest. This growing season water was used by crop transpiration or lost by evaporation from the soil surface. French and Schultz estimated that 110 mm of water ($W_{threshold}$; Figure 1) was lost by evaporation from the soil surface, and that grain yield was potentially 20 kg/ha/mm of water transpired (i.e. growing season water use – 110 mm of evaporation).

In their data for low rainfall sites and regions (Table 1) French and Schultz estimated a lower $W_{threshold}$ (70 mm). This was consistent with lower evaporative loss (due to less frequent rainfall events). However, other sources of water loss are in surface run-off from rainfall, and in deep drainage below the rooting depth of the crop and French and Schultz did not measure these losses. So at a site with high rainfall and a poor surface condition the estimated $W_{threshold}$ was higher (170 mm; Table 1). This was presumed to be due to unidentified runoff and the $W_{threshold}$ of 170 mm included both evaporation from the soil and surface runoff. The threshold amount of water ($W_{threshold}$) then was water which was lost by evaporation from the soil surface (range about 70–130 mm), but may under some circumstances include runoff and deep drainage if these are not independently estimated (up to 170 mm). Later authors (Robinson and Freebairn undated) have preferred to think of $W_{threshold}$ as the minimum amount of water needed before the plant will produce grain. A $W_{threshold}$ of 110 mm is a widely used estimate when determining WUE for grain production from cereals.

Other values determined in southern NSW for wheat are given in Table 1. The $W_{threshold}$ values are in the same range as French and Schultz, but WUE appears a little lower at 15–16 kg grain/ha/mm (Cornish and Murray 1989; Steiner *et al* 1985). These were estimates of the average values expected from reasonable agronomy and production conditions.

In contrast French and Schultz described the water limited or potential maximum (upper boundary of WUE) for grain yield production.

Similarly, WUE and $W_{threshold}$ can be estimated for broad leaf crops (Table 2). Maximum WUE was 13–15 kg/ha/mm, after deduction 80–110 mm ($W_{threshold}$).

Determining WUE will highlight inefficient use in a paddock or region. Data from southern NSW in 2005 indicated reasonable WUE (Figure 1), except for Site 4, which was well below the water limited potential yield. WUE can be improved by identifying and correcting limitations to crop growth, such as nutrient deficiencies, diseases and weeds, soil constraints and poor agronomy such as variety choice and delayed sowing.

Water use efficiency and dry matter production

The concept of water use efficiency can be extended to vegetative production of crops and pastures. French and Schultz (1984a) indicated that wheat had a potential WUE for total dry matter production at harvest (stubble + grain yield), of up to 55 kg/ha/mm, after allowing for 110 mm of water losses ($W_{threshold}$; Table 3).

Similar estimates can be made for pasture production. In Western Australia annual pastures yielded 30 kg/ha/mm of dry matter after deducting 30 mm of water use ($W_{threshold}$; Bolger and Turner 1999; Figure 2). As this data was obtained with high input pastures, the relationship probably represents the water limited (potential) yield. The dry matter yields of low input pastures reported by Bolger and Turner (1999) were less than indicated by this relationship, and data from central NSW were below this relationship (Blumenthal and Ison 1993). Data from southern NSW was near potential yield in 2006, but below potential in 2005. Site 4 in 2005 was well below water limited potential yield.

Lucerne can produce throughout the year and its dry matter production over the year can be related to annual rainfall (Figure 3). Data from central western NSW showed that lucerne dry matter production

Table 1. Estimates of water use efficiency (WUE) and threshold water ($W_{threshold}$) for grain production of wheat in South Australia and for southern NSW.

Location (reference)	$W_{threshold}$ (mm)	WUE (kg/ha/mm)	Comment
South Australia (French and Schultz 1984a)	110	20	Upper limit of data (all data)
	70	20	Upper limit of data (low rainfall sites)
	170	20	Upper limit of data (high rainfall, poor soil surface conditions)
Wagga Wagga (Cornish and Murray 1989)	70	15	Average of data, dryland crops
Griffith (Steiner *et al* 1985)	126	16	Average of data, irrigated crops

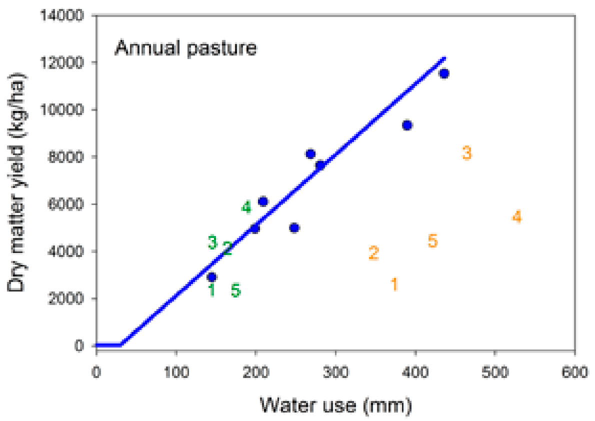

Figure 2. Relationship between water use and end of season dry matter production for annual pastures in WA (blue points and line; Bolger and Turner 1999), with data from southern NSW in 2005 (orange numbers) and in 2006 (green numbers).

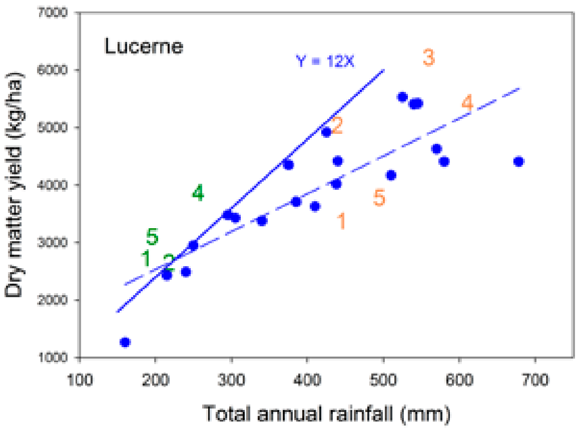

Figure 3. Relationship between annual rainfall and annual dry matter production for dryland lucerne pastures in central western NSW (blue points and lines; Bowman et al 2004). The broken line is the average data, and the solid line is the potential yield. Data from southern NSW in 2005 (orange numbers), and in 2006 (green numbers) is presented.

was related to rainfall and produced 6.7 kg/ha/mm of rainfall on average (Bowman *et al* 2004; Figure 3, broken line). An approximate water limited potential yield of about 12 kg/ha/mm was estimated from this data (Figure 3, solid line) with no $W_{threshold}$. Again data from southern NSW appears to confirm the potential yield estimate (Figure 3, numbers).

Estimating crop water use efficiency on farm

The water use efficiency concept is easiest to use in a Mediterranean climate. This is because the summers are dry, and April–October rainfall alone is a good estimate of water supply to crops (French and Schultz 1984b). Run-off and deep drainage are the unknowns, and may be unimportant in most seasons and in low rainfall regions. Crop water use is approximated by rainfall from shortly before sowing to harvest.

However in the equi-seasonal environment of southern NSW, where rainfall in summer is only slightly less than winter rainfall, a crop may be sown with substantial water from summer rain already stored in the soil profile, or the crop may mature with unused water still in the soil profile. Soil moisture can be measured at the start and end of the season, or the amount of water at these times can be estimated. Farmers need some simple rules of thumb to assist them in these estimations (Figure 4).

While no simple rules can fully account for soil moisture at sowing or at harvest some guidelines are available (Robertson and Kirkegaard 2005). Working with canola in southern NSW these authors used some experimental data and simulation modelling of rainfall at Narrandera from 1904–2003 to conclude the following:

- Soil moisture storage at sowing can be estimated by taking summer rainfall (post harvest to sowing), subtracting 80 mm, and then using 40% of the remainder. This estimate was determined over a range of fallow management, but weed control was consistently good.

Table 2. Indicative water use efficiency (WUE) and threshold water use ($W_{threshold}$) of broad leaf crops for grain production.

Crop, location (reference)	$W_{threshold}$ (mm)	WUE (kg/ha/mm)	Comment
Canola, southern NSW (Robertson and Kirkegaard 2005)	120	15	Average of data in seasons of favourable rainfall distribution
	120	11	Average (all data)
Lupins, estimate (D Luckett *pers. comm.*)	80	13	Approximate upper limit of data
Field pea (Siddique *et al* 2001)	100	15	Approximate upper limit of data
	100	10	Approximate average of data
Faba bean, WA estimates (Siddique *et al* 2001)	110	15	Approximate upper limit of data
	110	10	Approximate average of data

Table 3. Water use threshold ($W_{threshold}$) and water use efficiency (WUE) for potential dry matter production in wheat in South Australia (from French and Schultz 1984a).

Crop interval	Water use threshold ($W_{threshold}$; mm)	Water use efficiency (WUE; kg/ha/mm)
Sowing to end of tillering	40	25
Sowing to anthesis	80	60
Sowing to maturity	110	55

Estimating WUE of a crop

Example of Site 3 in Figure 1

Sowing in early May; anthesis in early October; maturing in early December. $W_{threshold}$ = 110 mm

Rainfall

Jan–Apr	May–Nov	Oct–Nov
103 mm	457 mm	130 mm

A = stored water at sowing

= (103 – 80) x 0.40

= 9 mm

B = in crop rainfall

= 457 mm

C = unused soil water at harvest

= (130 – 50) x 0.50

= 40 mm

Crop water use = **A + B – C**

= 9 mm + 457 mm – 40 mm

= **426 mm**

Grain yield = 5100 kg/ha

WUE of this crop = 5100 ÷ (426 – 110)

= 16 kg/ha/mm

Water limited potential yield = (426 – 110) x 20

= 6320 kg/ha

Estimating WUE of a crop

Your calculation

Sowing in ___; anthesis in___; maturity in____

Rainfall

Jan–Sowing	Sowing–Maturity	Anthesis–Maturity
mm	mm	mm

A = stored water at sowing

= (– 80) x 0.40

=   mm

B = in crop rainfall

=   mm

C = unused soil water at harvest

= (– 50) x 0.50

=   mm

Crop water use = **A + B – C**

=   +   –

= **mm**

Grain yield = kg/ha

WUE of this crop =   ÷ (– 110)

= kg/ha/mm

Water limited potential yield = (– 110) x 20

= kg/ha

Figure 4. An example of the calculation of WUE and water limited yield.

- In a similar manner, soil moisture remaining at harvest can be estimated from rainfall between anthesis and crop maturity (Oct–Nov or Dec), minus 50 mm, and the remainder halved. This estimate is very variable and was developed for canola, so care should be used.

Limitations of the water use efficiency concept

The French and Schultz approach takes no account of the timing of rainfall. This can result in apparently low water use efficiency when, for example, severe dry conditions late in the growing season result in poor grain fill in a season with otherwise reasonable rainfall. Unseasonal late frost can damage a crop at flowering resulting in low apparent water use efficiency. In both these situations the crop may yield to its potential under the prevailing conditions. The farmer has done all that is possible to achieve the water limited or potential yield, but the seasonal conditions (timing of rain, frost) have limited what can be achieved.

There are also regional differences. Crops use more water under dry conditions to get the same yield as under humid conditions. Therefore, crops grown in dry areas tend to have lower WUE than in humid areas. Also in the northern wheat areas of eastern Australia soil moisture at sowing accounts for a higher proportion of water used by wheat crops than in the south. This leads to more efficient WUE because stored soil moisture is used by the crop and evaporation of stored soil moisture is negligible. As a result of these limitations to the calculation, water use efficiency targets for water limited yield need careful use by growers.

Usefulness of water use efficiency

WUE is useful when comparing results from paddocks or whole farms within a season and region, but far less useful when comparing regions or seasons within a region. Poor WUE in a paddock, when other paddocks or growers in the same region and season have higher WUE, probably indicates the crop yield was below what was possible; that is yield was not water limited, and there was some important management or soil based constraint on yield. Identifying and addressing these agronomic constraints is the path to improved WUE (Figure 5).

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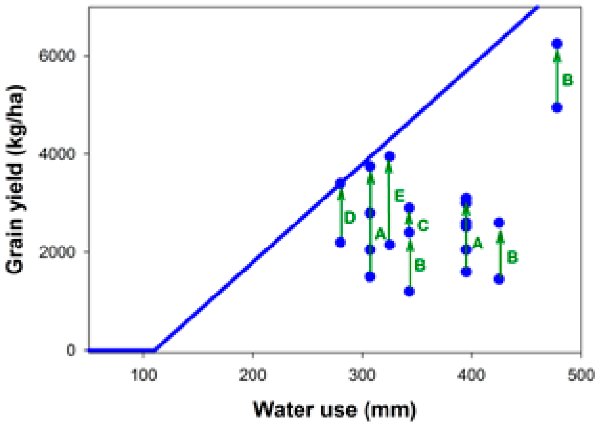

Figure 5. The relationship between grain yield of wheat and estimated water use (April–October rainfall in a Mediterranean climate). The water limited potential yield is shown (blue line) and the experimental data (blue points) show improved yield and WUE (green arrows) with earlier time of sowing (A), increased nitrogen (B) or phosphorus fertiliser (C), improved weed control (D) or multiple improvements in agronomic management (E) at different experimental sites (from French and Schultz 1984b).

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