WATER USE EFFICIENCY

FACT SHEET

GRDC Grains Research & Development Corporation

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SOUTHERN AND WESTERN REGION

Converting rainfall to grain

Growers can improve crop water use efficiency by using strategies to increase stored soil moisture prior to sowing, and focusing on healthy, early-sown crops with suitably sized canopies that are better able to convert water into grain.

KEY POINTS

- Benchmarking crop performance against its potential, based on available water, can help growers identify and act on otherwise hidden problems.
- A realistic understanding of the soil's capacity to store water will improve decisions about the potential return on crop inputs and other management practices.
- Improving water use efficiency may require effort over several years to improve the soil's ability to capture and store water, or to make stored water available to plants.
- The time of sowing and canopy management can significantly improve a crop's water use efficiency.

What is water use efficiency?

Water use efficiency (WUE) is a measure of a crop's capacity to convert water into plant biomass or grain. It includes the use of water stored in the soil and rainfall during the growing season.

Water use efficiency relies on:

- the soil's ability to capture and store water;
- the crop's ability to access water stored in the soil and rainfall during the season;
- the crop's ability to convert water into biomass; and
- the crop's ability to convert biomass into grain (harvest index).

Calculating water supply

Water is the principal limiting factor in rain-fed cropping systems throughout southern and western Australia.

Water use efficiency can be used to calculate the potential yield of a crop given the available moisture. Growers can use this information to assess the costs and benefits of different management decisions, in order to improve their profitability and manage risk.

In the 1970s and 1980s, South Australian researchers Reg French and Jeff Schultz developed a model for water use efficiency in cereal crops that established a 'best yield' benchmark for wheat of 20 kilograms per hectare for every millimetre of water used by the crop.

Water lying on the surface is more likely to be lost to evaporation than stored by the soil, but would be included in measured rainfall. Benchmarking crop performance against potential and actual water use can help identify areas of inefficiency.

PHOTO: EMMA LEONARD

Water supply in the French-Schultz model includes:

Available soil water at sowing. This can be measured through soil sampling, or estimated based on the previous crop or pasture growing in the paddock and the amount of out-of-season rainfall. For example, a paddock that grew a pea crop in the previous year might leave 20mm of water that is available to a wheat crop in the current year. If the paddock also receives 120mm of out-of-season rainfall and summer weeds are controlled and stubble retained, 25 per cent of this might be stored and available for this year's crop (30 mm). Therefore, total stored water at sowing is equal to 20mm + 30mm = 50 mm.

In-crop rainfall. This is the total amount of rain that falls between sowing and crop maturity.

Available soil water remaining at crop maturity. This is subtracted from the available soil water at sowing and the in-crop rainfall to provide a total water supply to the crop. If there is a dry finish to the growing season, available soil water at maturity can be assumed to be zero; that is, the crop has used all available water.

April to October rainfall is also often used as a simplified estimate of water supply for the French-Schultz model. However, this can lead to significant errors as it does not take stored soil water into account.

When calculating water use efficiency, an allowance must also be made for in-crop evaporation, which is dependent on soil type and amount of in-crop rainfall. In seasons with between 150-450mm of in-crop rainfall and on soils with no production constraints (for example, salinity or compaction), a figure of 110mm is often used. In seasons with less than 150mm of in-crop rainfall and on lighter soil types, evaporation may be as low as 60mm.

The three most common calculations for potential crop yields are (kg/ha):

Wheat:
Water supply – 110mm* x 20

Barley:
Water supply – 90mm* x 20

Oilseeds:
Water supply – 110mm* x 12

*** = evaporation**

French and Schultz conducted their research on 'tall' wheat varieties. Recent research has shown that the upper limit of water-use efficiency in modern semi-dwarf varieties may be 22kg/ha/mm.

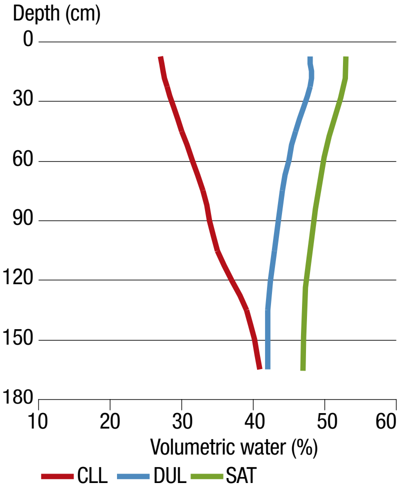
The French-Schulz model has been useful in giving growers performance benchmarks. Where yields fall well below these benchmarks it indicates there may be something wrong with the crop's agronomy or a major limitation in the environment. There could be hidden problems such as root diseases or soil constraints affecting yields.

Refining analysis

While the French-Schulz model provides a basic guideline of possible yields in southern Australia given good seasonal conditions and good soils, it has limitations. More sophisticated analysis and modelling tools are available today.

Other factors growers may consider that will also influence crop potential. Distribution of rainfall – depending on when rain falls and how much at a one time, crops will be better able to make use of it. For example, rain falling at flowering/early grain-fill can make a very large contribution to yield, whereas rain falling at the end of grain filling is of little use.

FIGURE 1 A TYPICAL STORAGE PROFILE FOR A HEAVY-TEXTURED SOIL SHOWING THE POTENTIAL WATER STORAGE OF THE SOIL (PAWC) AS DEFINED BY THE DRAINED UPPER LIMIT (DUL), CROP LOWER LIMIT (CLL) FOR AN INDIVIDUAL CROP, ie WHEAT, AND SATURATION (SAT)



PLANT AVAILABLE WATER CAPACITY (PAWC)

- PAWC is related to the soil type and the crop being grown on that soil. PAWC is less than the total water held in a saturated soil and varies between crops grown on the same soil type. It is defined by a soil's drained upper limit (DUL – the water content of a soil when it is fully wet but drainage has ceased) and its crop lower limit (CLL – the water content of a soil when a crop has extracted as much water as it can) (see Figure 1).
- Crops grown on soils with very low PAWC, for example coarse sands often achieve low water use efficiencies due to the soil's inability to store water.
- Heavy soils with high PAWC can hold more water for use by a crop in wet years, but can lose a lot more water to evaporation in comparison with lighter soils in dry years.
- Knowledge of PAWC, and in particular CLL, is necessary to calculate crop-available soil water at sowing (required for French-Schultz model) from soil sample results.
- Information on 500 different soil types and their PAWC is available from the APSoil database, www.apsim.info, and the Australian Soil Resource Information System (ASRIS) website, www.asris.csiro.au/index_other.html

Crop simulation models

- Sophisticated crop simulation models such as APSIM (and its commercial interfaces Yield Prophet® and WhopperCropper®) can combine detailed data about soil water-holding capacity, soil moisture at sowing, long-term climate data, weather data, potential crop responses to available moisture, and additional inputs, in order to estimate potential yield.
- This provides a more accurate cost-benefit analysis for management decisions and allows growers to test different management scenarios before putting them in place.

SOIL CONSTRAINTS ON WATER USE EFFICIENCY

PHOTO: STEPHEN DAVIES

Water use efficiency benchmarks can help growers identify and address soil constraints, such as compaction, that reduce water infiltration and restrict root growth. Deep ripping in this example has increased the depth of root growth to 40cm on the left, compared with only 30cm in unripped soil on the right.

PHOTO: EMMA LEONARD

Compaction is a soil constraint that reduces water infiltration and can be addressed with the introduction of controlled-traffic farming systems.

Crop water use efficiency benchmarks can help growers identify if a crop has not achieved its potential. One cause of poor performance could be soil constraints.

Soil constraints can be physical (for example surface crusting and hard pan or sheet rock) or chemical (for example extremes of pH, salinity, toxic levels of chemicals). They can limit plant rooting depth or the ability of plants to establish roots and access water and nutrients.

Research has identified that even with the best agronomy, soil constraints can restrict yields to 50-75 per cent of water-limited potential. Not all soil constraints can be rectified. In some cases growers have to live with lower yield potentials because of their soils, and perhaps reduce inputs accordingly.

More than 90 per cent of land used for cropping suffers from one or more of the following soil constraints:

- primary or transient salinity;
- high soil strength;
- nutrient deficiency;
- sodicity;
- toxic concentrations of boron, aluminium, bicarbonate;
- waterlogging;
- extremes of pH; and
- poor water infiltration.

Soil constraints such as poor soil structure can reduce yields by causing run-off and water logging. Excessive sodicity restricts water entry into the soil and excessive subsoil salinity restricts root exploration and soil water use and can kill plants. High boron concentrations can directly affect plant cell metabolism.

Where water use efficiency calculations and actual crop yields suggest there may be soil constraints, strategic soil testing and observation can help identify specific constraints.

Determine the potential costs versus the benefits of amelioration.

Soil amelioration can improve the ability of plant roots to access the subsoil for moisture and nutrients, where there has been sufficient rain to recharge subsoil moisture.

Research through the Healthy Soils for Sustainable Farms program suggests however that in low-to-medium rainfall zones across southern Australia some amelioration treatments, such as deep ripping and deep placement of amendments, will not be profitable.

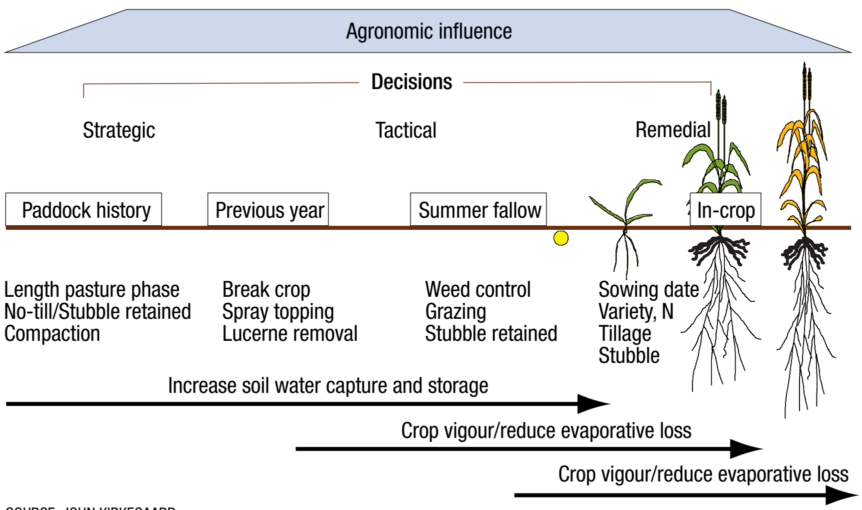
IMPROVING WATER CAPTURE

Improving the soil's ability to capture and store water relies on long-term, strategic decisions such as addressing soil constraints where possible, conversion to no-till or minimum-till, and controlled-traffic farming.

Soil structure, organic matter and beneficial microbial activity all contribute to the soil's ability to capture water and store it for use by plants, to provide nutrients to crops, and to allow plants to develop stronger root systems.

Legume-based pasture phases can also help to increase infiltration of water through the soil and improve plant access to water and nutrients.

FIGURE 2 AGRONOMY TO IMPROVE WATER CAPTURE AND EFFICIENT USE BY CROPS STARTS EARLY



SOURCE: JOHN KIRKEGAARD

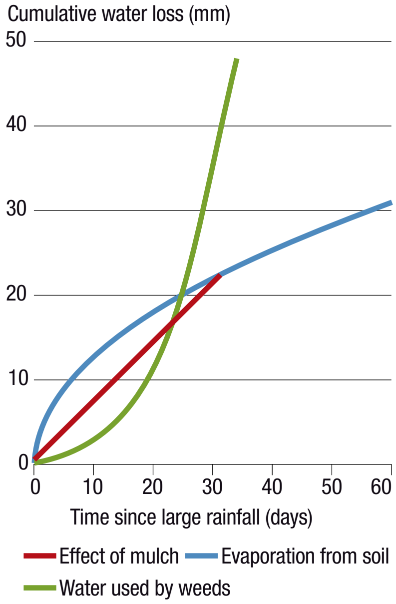
INCREASING STORED WATER

- Opportunities to capture more water and use it efficiently begin in the year preceding a crop and during the summer/autumn fallow immediately before sowing.
- Control of summer weeds can improve the preservation of summer rainfall as soil moisture. Research in NSW and Western Australia indicates that summer weeds can use 50 to 75mm of soil moisture, and may reduce the yield of subsequent crops by 0.5t/ha to 1t/ha.
- Retained stubble shades the soil surface and increases the infiltration of rainfall into the soil better conserving out-of-season rainfall. Mulch that keeps the topsoil wet for longer will enable a follow-up rain to penetrate deeper into the soil.

Research at Wagga Wagga in NSW and Hopetoun in Victoria indicates that summer weed control has a greater effect on preserving soil moisture than stubble management as shown in Figure 3. Weeds will use water from the deep subsoil – water that can be extremely valuable to crops during a dry finish to the growing season.

If cropping follows lucerne pasture, the lucerne should be removed as early as practicable to allow maximum recharge of the soil profile before sowing the crop.

FIGURE 3 DELAYING EFFECT OF MULCH



SOURCE: John Passioura

IMPROVING PLANT WATER USE

Good agronomy – timeliness of sowing, weed control, appropriate nutrition, control of root diseases – contributes to a crop capturing and using as much as possible of the seasonal water supply.

The healthier a crop is, the more able it is to extract and use water from the soil. Balanced nutrition and control of diseases and pests will allow the crop to extract water efficiently from the soil profile.

Weed control before and during the cropping season is important to reduce competition for moisture. Between-season management of weeds can also reduce the risk of pests and disease carried over from the previous season.

PHOTO: BRAD COLLIS

Stubble retention for mulch can increase rain infiltration and better conserve out-of-season rainfall.

PHOTO: SARDI

Crop growth is less dense in the central strip where summer weed control was missed and weeds have used the stored soil water that would otherwise have been available to the crop.

Early sowing with appropriate nutrition and effective control of root diseases is a key to improving water use efficiency. The use of no-till and stubble retention helps improve rainfall capture and retention.

PHOTO: EVAN COLLIS

SOWING

- Early sowing can maximise opportunities to use stored water.
- Select varieties best suited to local conditions – soil types, climatic conditions, resistance to likely pests and diseases (including root diseases) – to increase the likelihood of the crop thriving and making best use of available soil moisture.
- Earlier sowing improves the conversion of water into grain because it allows the crop longer to develop and to produce more biomass and grain. Crops have access to more water that would otherwise be lost to evaporation, run-off or drainage, and crop presence in the paddock also reduces evaporation of soil moisture.
- Narrow rows (less than 30cm) and high seeding rates provide greater coverage of the soil surface as the crop establishes, reducing evaporation losses and improving WUE. Wide rows have largely developed to improve stubble handling at seeding and do not in themselves directly improve crop production. There are some exceptions to this rule, for example, wide row pulses sown into standing stubble in some regions.

Faster, larger and better-designed farm machinery allows more timely seeding and other operations. Both of these outcomes can improve WUE through either earlier seeding or a healthier crop.

The most water-efficient crop is not necessarily the most profitable. Growers need to evaluate the risks of their decisions against the potential benefits; for example, the risk of frost affecting early sown crops versus the potential yield increase, or increased nitrogen application versus spring crop failure.

IMPROVING CONVERSION OF BIOMASS TO GRAIN

Low water use efficiency can be the result of a crop failing to convert biomass into grain. Harvest index – the proportion of a crop's biomass that is converted into grain – provides an indication of a crop's ability to convert plant biomass into grain yield. A very good harvest index for wheat is about 40 per cent in a well-managed crop.

Canopy management aims to improve the balance between water use before and after flowering, which can improve a crop's harvest index. This is generally achieved by limiting canopy growth early in the season, which results in less water use initially, saving more for the critical stages of flowering and grain filling.

PHOTO: EMMA LEONARD

A soil's capacity to hold water is determined by the content of clay and organic matter; chemical and physical constraints may prevent crops accessing all available water.

Canopy management techniques include:

- sowing earlier in the season, which brings forward flowering and grain filling to a time when more soil moisture is potentially available to support crops at these critical stages. However, it also increases the chance of frost damage;
- matching seed rates to sowing date and region, to reduce the size of the crop canopy early in the growing season;
- withholding applications of nitrogen fertiliser until after tillering, which produces a smaller crop canopy in comparison with pre-drilling nitrogen fertiliser; and
- grazing cereal crops, which removes biomass and results in a smaller crop canopy.

Heat, frost and water deficits at critical periods can prevent plants converting biomass to grain. Conditions that are too good during the crop's vegetative growth can also reduce yield because the crop canopy becomes too large and not enough water is left at flowering and grain filling. Such crops may produce large amounts of biomass or crop canopy but suffer from a low harvest index.

Overly lush canopies or crop biomass can result in too much water being used before grain fill, resulting in a poor harvest index. Sowing date, seed rates, grazing and strategic use of fertiliser all help control the canopy growth.

PHOTO: EMMA LEONARD

Useful resources:

Australian Soil Resource Information System (ASRIS) website	**www.asris.csiro.au/index_other.html**
APSoil database of soil water characteristics	**www.apsim.info**
Soil matters – Monitoring soil water and nutrients in dryland farming	**www.apsim.info**
Healthy Soils for Sustainable Farms project website	**www.soilhealthknowledge.com.au**
***Identifying, understanding and managing hostile subsoils for cropping*, Dr Roger Armstrong, 2009**	**www.grdc.com.au**
***Estimating Plant Available Water Capacity*, GRDC 2009**	**Ground Cover Direct, 1800 11 00 44**
Yield Prophet® website	**www.yieldprophet.com.au**
Subsoil constraints to crop production in south-eastern Australia	**www.grdc.com.au**

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