WATER USE EFFICIENCY

FACT SHEET

GRDC Grains Research & Development Corporation

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NORTHERN REGION

Converting rainfall to grain

Increasing the amount of water stored in fallows is an important strategy in managing the risks associated with highly variable rainfall in the northern region to improve water use efficiency and potential crop yields.

PHOTO: EMMA LEONARD

What is water use efficiency?

Water use efficiency (WUE) is the measure of a cropping system's capacity to convert water into plant biomass or grain. It includes both 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).

Water is the principal limiting factor in rain-fed cropping systems in northern Australia.

The objective of rain-fed cropping systems is to maximise the proportion of rainfall that crops use, and minimise water lost through runoff, drainage and evaporation from the soil surface and to weeds.

Rainfall is more summer dominant in the northern region, and both summer and winter crops are grown. However, rainfall is highly variable and can range, during each cropping season, from little or no rain to major rain events that result in waterlogging or flooding.

Storing water in fallows between crops is the most effective tool growers have to manage the risk of rainfall variability, as in-season rainfall alone – in either summer or winter – is rarely enough to produce a profitable crop, especially given high levels of plant transpiration and evaporation.

Fortunately, many cropping soils in the northern region have the capacity to store large amounts of water during the fallow.

KEY POINTS

- Fallow management, including the sequencing of fallows and crops, offers the greatest opportunity to improve water availability to plants and increase water use efficiency in the northern region.
- A realistic understanding of the soil's capacity to store water and assess available water prior to planting will help identify planting opportunities and potential crop yields.
- Good agronomic practices that maximise plant health and growth will allow crops to use water more effectively, improving yield potential.

As northern cropping systems consist of a sequence of fallows and crops, three components of water use efficiency (WUE) are important:

Fallow efficiency: the efficiency with which rainfall during a fallow period is stored for use by the following crop.

$$\text{Fallow efficiency (\%)} = \frac{\text{change in plant available water during the fallow} \times 100}{\text{fallow rainfall (mm)}}$$

Crop water use efficiency: the efficiency with which an individual crop converts water transpired (or used) to grain.

$$\text{Crop WUE (kg/ha/mm)} = \frac{\text{grain yield (kg/ha)}}{\text{crop water supply (mm)} - \text{soil evaporation}}$$

Systems water use efficiency: the efficiency with which rainfall is converted to grain over multiple crop and fallow phases.

$$\text{SWUE (kg grain/mm rainfall)} = \frac{\text{total grain yield (kg)}}{\text{total rainfall (mm)}}$$

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An understanding of soils and available water can help growers take advantage of opportunities for continuous cropping.

PHOTO: REBECCA THYER

TABLE 1 KEY BEST PRACTICES FOR MAXIMISING THE CONVERSION OF RAINFALL INTO GRAIN

Practice	Impact
Zero tillage	Maintain high cover levels, maximise water infiltration and minimise evaporation and soil loss, extend planting windows
Crop rotation	Regularly include crops that produce high stubble cover, for example cereals on narrow row spacing or a summer cover crop
Controlled traffic farming	Reduced soil compaction maximises water infiltration and plant growth
Opportunity cropping	Capitalise on planting opportunities and minimise fallow length
Know your plant available water (PAW) and plant available water capacity (PAWC)	Assist in determining yield potential
Assess yield potential and likely crop profitability at planting	Assist in making the decision whether to plant now or wait until the next opportunity
Invest in a planter with the required capabilities and capacity	Enable planting of adequate areas when opportunities arise – requires capability to handle stubble, moisture seek, achieve good establishment in less than optimal conditions and apply required fertilisers at planting
Manage weeds in fallow and crop	Maximise fallow efficiencies and minimise in-crop competition for water
Good management of other aspects of crop agronomy	Maximise crop water use efficiency

Soils and stored moisture

Plant available water capacity

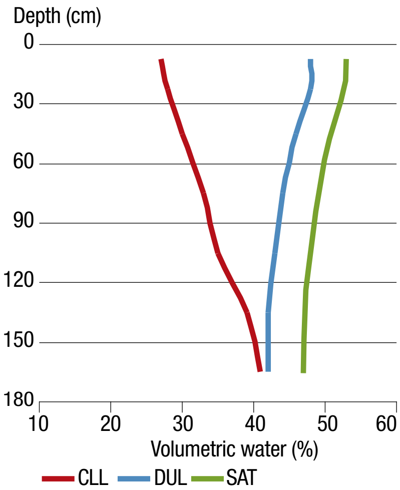
Plant available water capacity (PAWC) is the total amount of water a soil can hold that a particular crop can extract from a particular soil.

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 (Figure 1) 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). Not all soils are capable of storing the same amount of water, or of releasing stored water to plants.

- Some crops are more efficient than others at extracting soil moisture; crops with deeper roots are also able to access deeper subsoil moisture.
- Soil chemistry affects crops differently – for example the presence of chlorides reduces PAWC for chickpeas to a greater extent than for wheat.
- The PAWC of cropping soils in the northern region can vary between 100 and 350 millimetres.
- Knowledge of PAWC, and in particular CLL, is necessary to calculate available soil water at planting from soil sample results. Not all water stored in the soil will be available to plants.
- Information on 500 different soil types and their PAWC is available from the APSoil database (www.apsim.info) and Australian Soil Resource Information System (ASRIS) website (www.asris.csiro.au/index_other.html). Geospatial location of the soils can be viewed and data downloaded using the Google Earth link available at these sites.

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)



Compaction is a soil constraint that reduces water infiltration and the crop's ability to extract water. It can be addressed with the introduction of controlled-traffic farming systems.

PHOTO: EMMA LEONARD

Available soil moisture

Plant available water (PAW) is the amount of water in the soil actually available for crop production – often far less than PAWC, given rainfall and moisture extracted by previous crops. It is also less than total water stored in the soil, as various soil physical and chemical constraints will prevent plants accessing all soil moisture. A number of methods can be used to estimate PAW:

- soil cores can be taken and dried to determine water content at various depths and PAW calculated using a knowledge of CLL for that soil (see *Soil matters* under 'Useful resources', page 6);
- a simple push probe can be used to determine depth of wet soil. As a rule of thumb, vertosols hold around 2mm of PAW per centimetre of wet soil, though this factor will vary with soil and crop type. Conversion factors for a range of crops and soils are available (see *Soil matters* under 'Useful resources', page 6);
- the software program '*HowWet*' can be used to estimate PAW during a fallow period from daily rainfall figures input by the user (www.apsim.info); and
- PAW at the end of a fallow can be estimated directly from fallow rainfall using an estimate of fallow efficiency (FE). FE averages around 20 to 25 per cent for 'normal' fallows in the northern region, although this value can vary between 0 and 50 per cent, depending on rainfall patterns, fallow length, weed control and other fallow management practices (see page 4, Improving water capture and storage).

Estimating yield potential

With an assessment of stored soil moisture prior to planting, growers can estimate potential yields for their crop, and therefore potential return on their investment, although the high degree of variability in rainfall during the growing season makes it difficult to accurately predict crop yields (see page 4, the French-Schultz approach).

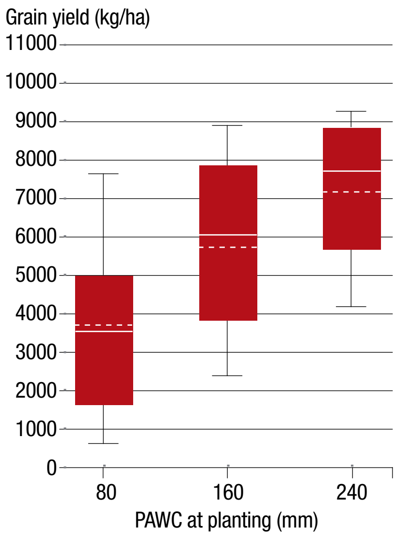
Crop simulation models

More sophisticated crop simulation models such as APSIM, and its commercial derivatives Yield Prophet® and WhopperCropper®, can also combine detailed data about soil types, PAWC, soil moisture at planting, long-term climate data and current weather information to help assess potential crop yields based on available moisture and additional inputs such as fertiliser (Figure 2).

This can provide a more accurate cost-benefit analysis for management decisions and allow growers to test different management scenarios before putting them in place.

Given rainfall variability, soil moisture at planting is the most critical factor in deciding to plant a crop.

FIGURE 2 YIELD DISTRIBUTION FOR SORGHUM AT DALBY, PLANTED 15 SEPT, 240 MM PAW SOIL



SOURCE: QPI&F

Note on reading box plots - solid line is median yield, dotted line is average yield, bottom of box is yield exceeded in 75% of years, top of box is yield exceeded in 25% of years, bottom whisker is yield exceeded in 95 % of years, top whisker is yield exceeded in 5% of years

Improving water capture and storage (or improving fallow efficiency)

Soil texture, 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 allow plants to develop stronger root systems.

If left uncontrolled, weeds will use water from the deep subsoil – water that can be extremely valuable to crops during a dry finish to the growing season. Research at Emerald, Queensland, indicates that during a short fallow weeds can use up to 90mm of soil moisture (Figure 3).

Reducing tillage and introducing controlled traffic systems can help to maintain and improve soil structure, improve water infiltration and reduce water runoff (and soil loss).

Reduced tillage or zero till systems also maximise surface stubble cover, which reduces the rate of evaporation and protects the surface soil from the compacting impact of raindrops. Mulch that keeps the topsoil wet for longer will enable follow-up rain to penetrate deeper into the soil and also extends planting opportunities.

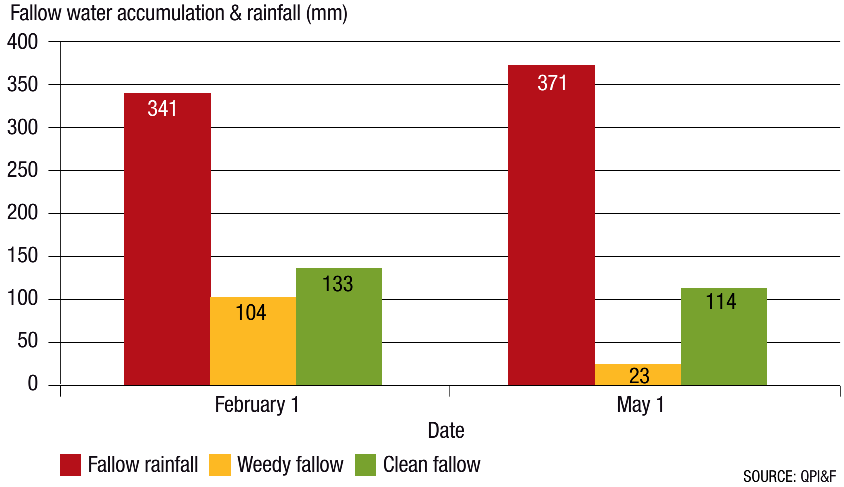
In some situations, for example at the beginning of long fallow periods when surface residues from previous crops are low (for example, after a skip row sorghum crop), cover crops can improve surface cover and fallow efficiency. A cover crop is grown for a short period of time (three to six weeks) and then sprayed out to provide extra surface cover while minimising the amount of water used to grow the cover crop.

Research as part of the Central Queensland Sustainable Farming Systems project indicates that longer fallows are generally less efficient at storing water than shorter fallows because more water is lost as evaporation, runoff and deep drainage.

Improving crop WUE

The healthier a crop is the more able it is to extract and use water from the soil. All aspects of good agronomy – such as timeliness of planting, weed control, appropriate nutrition, and control of pests and diseases – help a crop capture and use as much of the seasonal water supply as possible. 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.

FIGURE 3 WATER ACCUMULATION UNDER CLEAN AND WEEDY FALLOWS – THE MEAN OF SIX FALLOWS BETWEEN 2003 AND 2005 AT EMERALD, QLD



SOURCE: QPI&F

The French-Schultz approach

In southern Australia the French-Schulz model is widely used to provide growers with a benchmark of potential crop yield based on available soil moisture and likely in-crop rainfall.

In this model, potential crop yield is estimated as:
Potential yield (kg/ha) = WUE (kg/ha/mm) x (Crop water supply (mm) – estimate of soil evaporation (mm))
(where crop water supply is an estimate of water available to the crop, that is, soil water at planting plus in-crop rainfall minus soil water remaining at harvest).

In the highly variable rainfall environment in the northern region, estimating in-crop rainfall, soil evaporation and soil water remaining at harvest is difficult. However, this model may still provide a guide to crop yield potential.

The French-Schultz model has been useful in giving growers performance benchmarks – where yields fall well below these benchmarks it may indicate something wrong with the crop's agronomy or a major limitation in the environment. There could be hidden problems in the soil such as root diseases, or soil constraints affecting yields. Alternatively, apparent underperformance could be simply due to seasonal rainfall distribution patterns which are beyond the grower's control.

TYPICAL PARAMETERS THAT COULD BE USED IN THIS EQUATION ARE:

Crop	WUE (kg/ha/mm)	Soil evaporation (mm)
wheat	18	100
Chickpea	12	100
Sorghum	25	150

Note – these parameters will vary with location, management and season are a guide only. WUE values listed are those that could be achieved in the most favourable seasons.

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

Planting

- Select varieties best suited to local conditions, including soil types, climatic conditions and with 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.
- For winter crops, earlier planting improves the conversion of water into biomass and grain because it allows the crop to mature in more favourable climatic conditions in early spring. This benefit of early planting needs to be balanced against the increased risk of frost associated with early planting.
- For summer crops, planting times should be selected to avoid the crop flowering during periods of potential heat stress.
- Faster, larger and better-designed farm machinery allows more timely seeding and other operations. These outcomes can improve water use efficiency through either earlier seeding or a healthier crop.

The most water efficient crop is not necessarily the most profitable and growers need to evaluate the risks of their decisions against the potential benefits, for example, the risk of frost effecting early sown crops, versus the potential yield increase.

Improving conversion of biomass to grain

Low WUE can be the result of a crop failing to convert biomass into grain.

Distribution of rainfall can also reduce WUE. Rain falling at flowering or early grain-fill can make a significant contribution to yield; rain falling at the end of grain filling may make none.

The 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 good harvest index for wheat is about 40 per cent in a well-managed crop.

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 but suffer from a low harvest index.

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

Canopy management techniques include:

- for winter crops, planting 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 and row spacing to planting date, region and yield potential, to reduce the size of the crop canopy early in the growing season; and
- wide rows and skip rows in sorghum can help conserve water in the inter-row areas during the early stages of crop development, which is then available to the crop during grain fill. Skip rows can reduce yield variability and can increase yields in low-yielding years.

A well-managed fallow can help improve soil moisture available to following crops.

PHOTO: REBECCA THYER

Crop sequences

The sequence of crops and fallows impacts on the WUE of the whole cropping system. Conservative cropping systems, where crops are only planted when soil moisture levels are high, will result in high individual crop yields, but relatively fewer crops and long, inefficient fallow periods. More aggressive cropping systems that include double cropping will result in a greater number of lower-yielding crops and generally more efficient use of available rainfall. The appropriate balance between aggressive and conservative systems will depend on a whole range of factors including a grower's attitude to risk, and is the subject of ongoing research. Table 2 (for a representative situation in central Queensland) illustrates some of the trade-offs that occur.

Systems' WUE

Systems' water use efficiency can be calculated simply as total grain produced (kg/ha)/total rainfall (mm), over single or multiple crop time periods. This integrates the effects of fallow and crop management and crop sequences to provide a simple indicator of how efficiently the cropping system converts rainfall to grain. Preliminary research in the northern region indicates a system WUE of 6kg grain/ha/mm rainfall may be an appropriate target.

TABLE 2 EFFECT OF SOIL WATER THRESHOLD FOR PLANTING ON SYSTEMS WATER USE EFFICIENCY AND OTHER SYSTEM PERFORMANCE PARAMETERS*

System		Conservative	Moderate	Aggressive
Planting threshold	mm	150	100	50
Number of crops		35	45	72
Crops/year		0.69	0.88	1.41
Total grain produced	t/ha	141	172	197
Average yield	t/ha	4.04	3.82	2.73
Average cover	%	40%	49%	55%
SWUE	kg/ha/mm	4.55	5.53	6.32
% rainfall ending up as:				
Transpiration		21%	26%	32%
Evaporation		56%	55%	55%
Run-off		18%	16%	11%
Drainage		5%	3%	2%

* This table presents the results of a simulation modelling analysis for a cropping system at Emerald from 1955 to 2006.

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
Subsoil constraints to crop production in north-eastern Australia	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
Whopper Cropper®	www.apsim.info/apsim/Products/NationalWhopperCropper.pdf

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