The value of out-of-season rainfall – a national summary

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Summary:

- Simulation shows that the value of out-of-season rain to wheat production varies dramatically across the GRDC WUE regions.
- In some regions such as the central west of NSW, it contributes on average as much to wheat yield as growing season rainfall, and conserving it can improve WUE of subsequent crops by 100%.
- In other regions, particularly those with high growing season rainfall and soils with small plant available water capacity, the contribution of out-of-season rainfall to wheat yield and WUE is on average negligible.

Introduction:

In the grain growing regions of southern Australia dominated by cool-season rain, out-of-season rainfall has not traditionally been valued as a resource for cool-season crops (Freebairn et al. 2006). This is because generally in-crop rainfall in this environment has historically been adequate to achieve the attainable yield of cereal crops, particularly wheat, as determined by non-water limiting factors such as nutrient availability, root diseases etc (Angus and Good 2004). However, recent increases in water productivity (e.g. increased use of fertiliser nitrogen, control of pathogens with break crops) and years of below average growing season rainfall, particularly during spring, has increased awareness of the contribution that out-of-season rain can make to subsequent wheat crop yield. Better capture and use of out-of-season rainfall has been identified by many groups in the GRDC WUE initiative as a management intervention likely to achieve the GRDC's aim of a 10% increase in regional WUE. Significant research effort is currently being applied to the investigation of management practices that better capture, store and use out-of-season rainfall (e.g. control of summer weeds, stubble retention, controlled traffic, stock containment areas etc.).

With few exceptions of limited regional scope (Fischer et al. 1990; Hunt et al. 2008; Kirkegaard et al. 2007a; O'Leary and Connor 1997), no effort has been made to quantify the potential value of out-of-season rainfall as a resource across the grain growing regions of Australia with cool-season dominant rainfall. Without knowing the value of this resource it is difficult to tell whether better managing out-of-season rainfall is an effective means by which to achieve GRDC's aim of a 10% increase in water-use efficiency. It is also difficult for farm managers to decide if adopting management practices that better capture, store and use out-of-season rainfall will be economically viable.

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Out-of-season rainfall is captured by the soil and made available as stored soil water to subsequent crops. In many environments, it is likely that contribution to wheat yield from out-of-season rainfall will be significant. French and Schultz (1984) in their seminal work on water-use efficiency noted that soil water stored prior to sowing was more effective in promoting yield than in-crop rainfall. In theory, out-of-season rain that is stored in the sub-soil and accessed by wheat during critical growth periods will be converted to grain very efficiently (Kirkegaard et al. 2007b). Climate change scenarios for Australia indicate that the proportion of annual rainfall arriving out-of-season will increase (CSIRO and BOM 2007), and thus out-of-season rainfall will be making a greater contribution to grain yield in the future. Better capturing and making use of out-of-season rainfall is likely to be a critical adaption to climate change.

This article uses existing and publicly available databases of soil (Dalgliesh et al. 2009; Johnston et al. 2003; McKenzie et al. 2005) and climate (Jeffrey et al. 2001) coupled with the farming systems model APSIM (Keating et al. 2003) to quantify the value of out-of-season rainfall to wheat yield in the grain growing regions of Australia dominated by winter rainfall. In doing so it establishes a prima facie case for management interventions which seek to better capture and make use of this resource.

Methods:

Locations for simulation analysis were chosen where possible to represent regional environments of groups in the GRDC WUE initiative, but were limited by the coincidence of measured soil characterisations (Dalgliesh et al. 2009; Johnston et al. 2003; McKenzie et al. 2005) and patched point met stations (Jeffrey et al. 2001) . APSIM 7.0 was parameterised with sowing rules taken from farmer behaviour observed in Yield Prophet (Hochman et al. 2009; Hunt et al. 2006), and expert opinion of regional researchers, consultants and farmers (Table 1). Crops were sown at 150 plants m^{-2} in all locations if more than 15 mm fell over a three day period during the sowing window specified. If the rainfall criteria were not met during the sowing window, a crop was sown at the conclusion of the sowing window such that a crop was sown in every year of the simulation.

Two continuous wheat simulations (1889-2008) for each location were paired, with one simulation resetting plant available water (PAW) to zero at harvest and accumulating soil water from out-of-season rainfall, the other resetting PAW to zero at harvest and again at the start of the sowing window. This mimicked a situation where poor management of weeds or stubble used all the water that would otherwise have been available for storage during the fallow. Soil nitrate in the top three soil layers was maintained above 100 kg ha^{-1} so as not to limit yield. Stubble from crops was fully retained (50% left standing) and no summer weeds were allowed to grow during the out-of-season fallow period. Grain yields were calculated at 12% moisture.

Table 1. Rainfall, soil and management parameters for the eighteen locations used in the simulation study.

Location	Mean annual rain (mm)	Mean April-October rain mm)	Sowing window	APSIM wheat cultivar maturity	APSoil file	PAWC
Buntine	332	263	7 May – 1 Jun	Early (e.g. Wyalkatchem, Bonnie Rock, Perenjori)	Duplex sandy gravel (Buntine No24)	89 (0-90 cm)
Mingenew	406	352	7 May – 1 Jun	Early (e.g. Wyalkatchem, Bonnie Rock, Perenjori)	Pale deep sand (Mingenew No422)	52 (0-120 cm)
Kellerberrin	327	256	7 May – 1 Jun	Early (e.g. Wyalkatchem, Bonnie Rock, Perenjori)	Acid loamy sand (Wongan Hills No402)	73 (0-120 cm)
Borden	388	296	7 May – 1 Jun	Early (e.g. Wyalkatchem, Bonnie Rock, Perenjori)	Sandy earth (Kellerberrin No410)	95 (0-130 cm)
Salmon Gums	344	233	7 May – 1 Jun	Early (e.g. Wyalkatchem, Bonnie Rock, Perenjori)	Alkaline shallow sandy duplex (Salmon Gums No454)	88 (0-100 cm)
Minnipa	343	258	25 Apr – 1 Jul	Early to mid (e.g. Yitpi, Correll, Gladius)	Red loam (Minnipa No377)	135 (0-120 cm)
Cummins	428	349	25 Apr – 1 Jul	Early to mid (e.g. Yitpi, Correll, Gladius)	Clay loam over red clay (Shannon) (EL037)	117 (0-130 cm
Morchard	352	248	25 Apr – 1 Jul	Early to mid (e.g. Yitpi, Correll, Gladius)	Loam over medium-light clays (Morchard Plain No603)	136 (0-110 cm)
Hart	458	346	25 Apr – 1 Jul	Early to mid (e.g. Yitpi, Correll, Gladius)	Clay loam over medium-heavy-medium clay (Hart No286)	190 (0-135 cm)
Lameroo	385	277	25 Apr – 1 Jul	Early to mid (e.g. Yitpi, Correll, Gladius)	Loamy sand over sand over sandy loam (Lameroo No253)	72 (0-110 cm)
Bordertown	479	356	25 Apr – 1 Jul	Early to mid (e.g. Yitpi, Correll, Gladius)	Dark grey medium clay (Wolseley No344)	253 (0-140 cm)
Hopetoun	342	230	25 Apr – 1 Jul	Early to mid (e.g. Yitpi, Correll, Gladius)	Loamy sand (Hopetoun No716)	153 (0-130 cm)
Inverleigh	553	369	25 Apr – 1 Jul	Late (e.g. Bolac, Kellalac)	Clayey sand (Inverleigh No737)	138 (0-130 cm)
Yarrawonga	509	332	25 Apr – 1 Jul	Early to mid (e.g. Ventura, Livingstone, Gladius)	Clay (Yarrawonga No208	120 (0-90 cm)
Cressy	628	419	25 Apr – 1 Jul	Late winter (e.g. MacKellar, Revenue)	Clay loam (No656)	209 (0-150 cm)
Mathoura	360	235	25 Apr – 1 Jul	Early to mid (e.g. Ventura, Livingstone, Gladius)	Sandy clay over medium clay (Barham Piv5 No203)	104 (0-90 cm)
Temora	510	310	25 Apr – 1 Jul	Mid to late (e.g. Gregory, Sunvale,)	Brown chromosol (Temora No 179)	125 (0-120 cm)

Tottenham	471	246	25 Apr – 1 Jul	Early to mid (e.g. Ventura, Livingstone, Gladius)	Sandy clay loam (Tottenham No200)	157 (0-120 cm)

Results and discussion:

The amount of out-of-season rain that falls on average across the GRDC WUE region varies considerably, which is both a function of rainfall distribution patterns (equi-seasonal vs. Mediterranean), and growing season length (Table 2). The ability for out-of-season rainfall to be stored and made available to a crop as PAW also varies and is dependent on both prevailing rainfall patterns (small amount of large falls vs. large amount of small falls (Sadras and Rodriguez 2007)) and soil type. Heavy soil types in which rainfall events of greater magnitude are required to penetrate below the evaporative layer (e.g. soils used at Morchard, Hart, Bordertown, Yarrawonga and Mathoura) tend to have low fallow efficiencies (Table 2).

Table 2. Mean values of sowing date, maturity date, water balance from maturity to the start of the sowing window, PAW at the start of the sowing window and out-of-season fallow efficiency taken from 120 year simulations for all locations.

Location	Mean sowing date	Mean maturity date	Mean rainfall from maturity to start of sowing window (mm)	Mean evaporation from maturity to start of sowing window (mm)	Mean drainage from maturity to start of sowing window	Mean run-off from maturity to start of sowing window	Mean PAW at start of sow window (mm)	Mean fallow efficiency (%)
Buntine	22-May	17-Oct	101	65	3	4	30	24
Mingenew	20-May	8-Oct	97	62	1	0	34	28
Kellerberrin	23-May	25-Oct	103	66	0	1	35	28
Borden	22-May	3-Nov	123	76	3	1	43	30
Salmon Gums	24-May	31-Oct	141	94	5	2	39	24
Minnipa	29-May	1-Nov	96	61	0	1	34	30
Cummins	21-May	2-Nov	97	85	0	0	13	10
Morchard	26-May	9-Nov	125	119	0	2	16	9
Hart	17-May	11-Nov	124	103	0	1	24	15
Lameroo	26-May	13-Nov	116	68	3	2	43	34
Bordertown	16-May	16-Nov	132	100	0	0	31	19
Hopetoun	29-May	18-Nov	117	71	0	2	43	32
Inverleigh	16-May	12-Dec	155	88	2	2	62	37
Yarrawonga	17-May	17-Nov	183	129	5	4	46	21
Cressy	11-May	8-Jan	142	55	1	1	85	55
Mathoura	25-May	14-Nov	136	113	1	1	25	13
Temora	18-May	20-Nov	205	138	9	4	57	26
Tottenham	23-May	1-Nov	251	146	6	11	86	30

The marginal value of additional PAW to a subsequent wheat crop is then dependent on soil PAWC and the magnitude and reliability of growing season rainfall (Table 3). For instance, Buntine in the northern WA wheat-belt has similar out-of-season rainfall to Hopetoun in the Victorian Mallee. However, because Buntine has less variable growing season rainfall and a soil type with less PAWC, the value of the out-of-season rainfall is 'overridden' by the growing season rainfall filling the soil to capacity, or providing adequate supply for the crops needs. Similarly at locations such as Inverleigh and Cressy where the amount of out-of-season rain is significant, fallow efficiency good and PAWC high, the amount of GSR overrides the impact of stored PAWC on crop growth. In such environments additional stored PAW at sowing may in fact be contributing to water logging, de-nitrification and nitrate leaching, the negative effects of which are not accounted for in this simulation.

Table 3. Mean PAW at sowing, dry matter, yield, harvest index and WUE with and without capture of out-of-season rainfall at each location.

	PAW at sowing (mm)		Dry matter (t ha^{-1})		Grain yield (t ha^{-1})		Harvest index		Water-use efficiency (kg ha^{-1} mm^{-1})		Potential increase in WUE (%)
Location	No OSR	With OSR	No OSR	With OSR	No OSR	With OSR	No OSR	With OSR	No OSR	With OSR	
Buntine	14	41	6.4	7.4	2.5	3.0	0.37	0.39	11	12	9
Mingenew	16	47	6.8	7.1	2.9	3.0	0.43	0.43	12	12	-2
Kellerberrin	14	47	5.9	7.0	2.3	2.8	0.37	0.39	10	12	14
Borden	16	56	7.0	7.3	2.9	3.1	0.41	0.42	13	13	-2
Salmon Gums	9	46	3.6	5.9	1.3	2.2	0.31	0.35	6	9	53
Minnipa	22	53	7.2	8.6	2.7	3.3	0.36	0.37	12	13	14
Cummins	18	28	9.7	10.2	3.9	4.1	0.39	0.39	13	13	3
Morchard	14	24	4.9	5.1	1.7	1.9	0.27	0.28	6	6	6
Hart	20	40	10.4	11.5	4.1	4.7	0.37	0.38	13	14	10
Lameroo	22	59	7.8	9.0	3.1	3.6	0.36	0.37	12	12	5
Bordertown	18	46	10.3	11.9	4.1	4.7	0.38	0.38	13	14	12
Hopetoun	18	58	5.8	8.4	2.0	3.1	0.32	0.34	9	12	35
Inverleigh	19	78	16.6	18.7	6.8	7.8	0.39	0.41	18	19	3
Yarrawonga	17	59	8.6	10.5	3.3	4.1	0.34	0.37	10	12	17
Cressy	25	108	19.2	20.5	7.1	7.8	0.35	0.37	15	15	0
Mathoura	15	35	4.4	5.8	1.5	2.0	0.27	0.29	5	7	32
Temora	19	70	8.1	10.9	2.9	4.0	0.33	0.34	9	11	23
Tottenham	19	102	4.1	8.5	1.3	3.1	0.26	0.33	5	10	100

Out-of-season rainfall is of greatest value to wheat yield in environments where it makes up a greater proportion of annual rainfall, fallow efficiencies are high, PAWC is large relative to GSR, and GSR is more variable. In these areas (e.g. Salmon Gums, Hopetoun, Mathoura, Temora and Tottenham), widespread adoption of good fallow management could on average see improvement in WUE far beyond the 10% required by GRDC (Table 3), depending on current fallow management practices. The impact of additional PAW at sowing on yield in these locations is twofold. Firstly, the increase in water supply results in more water-use, which leads to an increase in dry matter production. Secondly, greater availability of water during critical development periods of wheat results in greater harvest indices, which leads to an increase in water-use efficiency of grain (Table 3).

The mean values presented here (Table 3) do disguise the variable nature of yield increases resulting from stored out-of-season rainfall. Even in locations where mean additional yield is low (e.g. Mingenew, Borden, Cummins and Morchard), out-of-season rainfall can have a large impact that on yield and WUE in some seasons. This tends to occur in seasons where additional PAW at sowing is high and growing season rainfall is low (Oliver et al. 2009).

In terms of the wider GRDC WUE initiative, this simulation study identifies needs for both extension and research which are distinct. In areas where the marginal value of out-of-season rainfall is high (e.g. Hopetoun, Mathoura, Temora and Tottenham) validation, demonstration and extension of good fallow management is likely to result in significant increases in WUE on-farm. Pleasingly, these locations also largely correspond with regional groups who are focussing on fallow management as part of their WUE projects (BCG, FarmLink and CWFS). Research is required in areas such as Morchard, Hart and Mathoura, where out-of-season rainfall forms a significant proportion of annual rainfall, but low fallow efficiency (a function of rainfall pattern and soil type) mean that the marginal value of out-of-season rainfall to yield is currently low. These areas also happen to correspond well with regional research projects that are focussing on fallow management (UNFS, SARDI and HFSG). Critical research question in these regions might include: are there soil types in these regions which have higher fallow efficiencies than the ones selected for this study; and, should fallow management be varied according to soil type? Are there any management interventions that could improve fallow efficiency on soils with inherently low fallow efficiency?

As part of the CSIRO national WUE project, Anthony Whitbread has been investigating the impact of different soil types on fallow efficiency during the out-of-season period and initial findings from his studies will form the subject of a subsequent articles.

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