Climate Indices and Trends

Dane Thomas and Bronya Cooper, SARDI Climate Applications, February 2021

Document outlining feedback on indices of climate risk (Activity 1). The report also shows the trends in these indices (Report on V1 of trends in climate for EP (Activity 2)).

The main indices that seem to be meaningful to busy advisers are 1) deciles of growing season rain; 2) deciles of GSR adjusted for 'summer' rainfall; and 3) APSIM simulated production.

Climate indices related to rainfall are amongst the most important for agricultural crop production. Indices such as growing season rainfall or the combined total of weighted 'summer' rainfall plus growing season rainfall are considered useful yearly summations describing the season. Growing season rainfall calculated as rainfall from April to October is the rain that directly contributes to crop growth. The inclusion of the weighted 'summer' rainfall which on Eyre peninsula is typically calculated as the sum of 1/3 of (monthly rainfall minus 20 mm) for the months of November to February plus 1/2 of (monthly rainfall minus 20 mm) in March accounts for the contribution of non-growing season rainfall to increasing stored soil moisture that will be available for crops during the following growing season. These indices are useful because of the long historical record of quality observations, and furthermore as they are impacted by climate drivers (e.g. ENSO, IOD) and owing to advances in seasonal forecasts this has contributed to their usefulness in both tactical and strategic decision making.

Indices that include evaporation such as the ratio of Rainfall:Evaporation (P:E), while useful in understanding the extent of the cropping zone and do show a declining trend indicating more water constrained and less productive seasons, are valuable for strategic but less useful for tactical decisions but are considered less useful than those of rainfall on its own accord.

APSIM simulated production being an integrator of climate, soil and management is an incredibly useful indice of agricultural production.

Indices related to temperature such as mean growing season temperature, or extremes such as frost or heatwaves are considered useful and do impact on management decisions by Eyre peninsula farmers, although in many locations the paucity of historical records does affect their usefulness, particularly those related to extremes (e.g. frost and heatwaves).

The year-to-year variation in the indices and their grouping by deciles is considered a practical, valuable and useful tool to aid decision making in the current year, and to understand and place current and previous years in context. Table 1 shows several useful climate indices for two locations; Cummins and Minnipa. The values for each year since 1990 are shown along with the decile to which they correspond. The coloured square serves as a visual indicator of the decile and are coloured from red (dry, warm) to blue (wet, cool). As can be seen, rainfall has considerable year-to-year variation and while there is no strong trend in non-growing season rain, there have been few above median years of growing season rain in the last 20 years, and similarly few years having above median 'summer' rain + growing season rain. In this same period temperatures have become warmer with more hot days. The number of frost days has remained stable or increased, but as mentioned previously the lack of high-quality temperature observations at many locations means that data relating to extreme temperature (frost and heatwaves) should be treated with caution, although it is not wise to discount them altogether.

The year-to -year variation in rainfall at Cummins and Minnipa are shown in Figure 1. These figures show the annual and running average (10 year and 20 year) non-growing season rainfall and growing season rainfall in the upper graphs. Both indices have considerable year-to-year variation and while the long term trends for non-growing season rainfall are reasonably stable, there appears a gradual decline in trends of growing season rainfall. However, these trends are not strong and do show periods of increasing rainfall. The lower graph shows the combined total of weighted 'summer' rainfall (PreSeason rain) plus growing season rainfall with rainfall within the growing season segregated by 2 or 3 monthly periods. These graphs highlight the within season variation in rainfall (along with the trend of declining rain but interspersed with wetting periods and the year-to-year variation seen in the upper graphs).

Table 1 Climate indices for Cummins and Minnipa. The values for each year since 1990 are shown along with the decile to which they correspond. The coloured square serves as a visual indicator the decile and are coloured from red (dry, warm) to blue (wet, cool). The deciles are calculated for years since 1900.

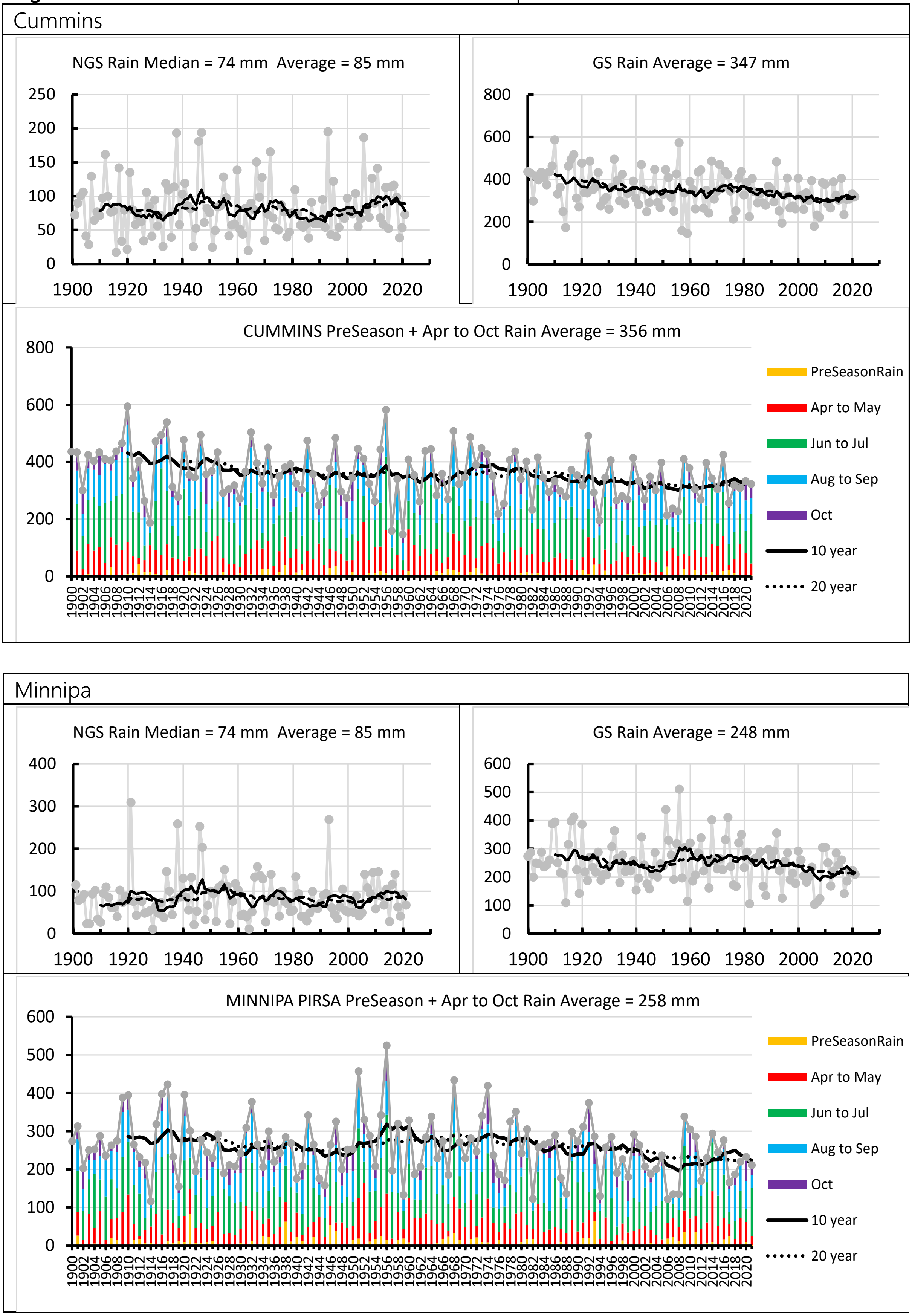
CUMMINS	NGS Rain (mm)	GS Rain (mm)	Summer Rain + GS Rain (mm)	RANK	GS (Rain/E) (mm)	GST (°C)	Tmax>25°C (days)	Tmax>30°C (days)	Tmin<2°C (days)
1990	60 (D4)	353 (D6)	353 (D6)	65	0.72 (D5)	14.5 (D8)	26 (D9)	8 (D10)	0 (D1)
1991	95 (D7)	294 (D3)	317 (D4)	42	0.64 (D3)	15.0 (D10)	22 (D8)	6 (D9)	0 (D1)
1992	54 (D3)	483 (D10)	492 (D10)	115	1.18 (D10)	13.7 (D2)	13 (D3)	4 (D6)	0 (D1)
1993	195 (D10)	252 (D2)	293 (D3)	30	0.52 (D1)	14.5 (D8)	24 (D9)	6 (D9)	1 (D5)
1994	43 (D2)	195 (D1)	195 (D1)	4	0.38 (D1)	14.7 (D9)	20 (D7)	5 (D8)	5 (D9)
1995	122 (D9)	326 (D5)	346 (D5)	60	0.73 (D5)	14.3 (D6)	14 (D4)	2 (D4)	0 (D1)
1996	40 (D2)	407 (D8)	407 (D8)	86	0.90 (D8)	14.1 (D5)	16 (D5)	3 (D5)	0 (D1)
1997	54 (D3)	266 (D2)	266 (D2)	16	0.62 (D3)	14.0 (D3)	14 (D4)	3 (D5)	4 (D8)
1998	72 (D5)	276 (D3)	281 (D2)	25	0.60 (D2)	14.1 (D4)	12 (D3)	5 (D8)	0 (D1)
1999	67 (D4)	261 (D2)	268 (D2)	19	0.53 (D2)	14.8 (D10)	15 (D4)	4 (D6)	2 (D7)
2000	97 (D8)	406 (D8)	414 (D8)	92	0.90 (D8)	14.4 (D7)	18 (D6)	1 (D2)	0 (D1)
2001	78 (D6)	323 (D5)	334 (D5)	51	0.71 (D5)	14.2 (D6)	12 (D3)	3 (D5)	0 (D1)
2002	74 (D5)	259 (D2)	268 (D2)	17	0.52 (D1)	15.0 (D10)	22 (D8)	8 (D10)	2 (D7)
2003	104 (D8)	337 (D5)	349 (D6)	62	0.76 (D6)	14.0 (D4)	12 (D3)	1 (D2)	0 (D1)
2004	55 (D3)	301 (D4)	301 (D3)	35	0.65 (D4)	14.7 (D9)	19 (D7)	5 (D8)	0 (D1)
2005	67 (D4)	395 (D7)	399 (D7)	81	0.80 (D6)	15.1 (D10)	25 (D9)	9 (D10)	1 (D5)
2006	187 (D10)	179 (D1)	214 (D1)	5	0.35 (D1)	14.4 (D7)	19 (D7)	5 (D8)	4 (D8)
2007	80 (D6)	233 (D1)	237 (D1)	9	0.46 (D1)	15.0 (D10)	28 (D10)	11 (D10)	11 (D10)
2008	69 (D5)	222 (D1)	227 (D1)	7	0.45 (D1)	14.7 (D9)	30 (D10)	10 (D10)	12 (D10)
2009	127 (D9)	385 (D7)	410 (D8)	90	0.87 (D7)	14.4 (D7)	20 (D7)	3 (D5)	2 (D7)
2010	90 (D7)	377 (D7)	380 (D7)	75	0.90 (D8)	13.7 (D2)	18 (D6)	3 (D5)	7 (D9)
2011	141 (D10)	283 (D3)	304 (D3)	37	0.64 (D3)	14.5 (D8)	23 (D9)	4 (D6)	4 (D8)
2012	68 (D5)	266 (D2)	268 (D2)	18	0.55 (D2)	14.4 (D7)	35 (D10)	10 (D10)	7 (D9)
2013	59 (D4)	388 (D7)	397 (D7)	80	0.81 (D6)	15.6 (D10)	32 (D10)	8 (D10)	5 (D9)
2014	113 (D9)	326 (D5)	342 (D5)	55	0.65 (D4)	15.2 (D10)	38 (D10)	13 (D10)	5 (D9)
2015	52 (D2)	303 (D4)	305 (D4)	39	0.71 (D5)	14.1 (D4)	21 (D8)	6 (D9)	8 (D10)
2016	114 (D9)	406 (D8)	425 (D8)	95	1.01 (D9)	14.1 (D4)	20 (D7)	4 (D6)	8 (D10)
2017	116 (D9)	235 (D1)	256 (D1)	12	0.50 (D1)	14.9 (D10)	23 (D9)	7 (D9)	10 (D10)
2018	99 (D8)	306 (D4)	319 (D4)	44	0.67 (D4)	15.0 (D10)	31 (D10)	10 (D10)	12 (D10)
2019	39 (D1)	307 (D4)	309 (D4)	40	0.66 (D4)	14.9 (D10)	28 (D10)	15 (D10)	9 (D10)
2020	53 (D3)	333 (D5)	333 (D5)	50	0.81 (D7)	14.5 (D8)	21 (D8)	5 (D8)	12 (D10)
2021	73 (D5)	318 (D4)	323 (D4)	45	0.70 (D4)	13.7 (D2)	28 (D10)	5 (D8)	4 (D8)
	Number of years in last 20 years (2002 to 2021) higher than decile 5 (decile 6 and above).								
	10	5	6		7	15	19	17	17

Mean T / Max T	Rain / Rain:E / Tmin
D1	1
D2	2
D3	3
D4	4
D5	5
D6	6
D7	7
D8	8
D9	9
D10	10

MINNIPA PIRSA	NGS Rain (mm)	GS Rain (mm)	Summer Rain + GS Rain (mm)	RANK	GS (Rain/E) (mm)	GST (°C)	Tmax>25°C (days)	Tmax>30°C (days)	Tmin<2°C (days)
1991	91 (D7)	292 (D8)	312 (D9)	98	0.51 (D8)	15.0 (D10)	42 (D9)	15 (D9)	1 (D3)
1992	95 (D7)	355 (D10)	374 (D10)	112	0.71 (D10)	13.7 (D2)	26 (D3)	7 (D4)	5 (D8)
1993	269 (D10)	223 (D4)	286 (D7)	84	0.40 (D5)	14.5 (D8)	42 (D9)	16 (D9)	5 (D8)
1994	61 (D4)	125 (D1)	130 (D1)	4	0.21 (D1)	14.7 (D9)	41 (D8)	12 (D8)	7 (D9)
1995	45 (D3)	255 (D6)	257 (D6)	62	0.46 (D6)	14.3 (D6)	35 (D7)	11 (D7)	2 (D5)
1996	35 (D2)	286 (D8)	286 (D7)	83	0.51 (D8)	14.1 (D5)	29 (D4)	12 (D8)	2 (D5)
1997	63 (D4)	190 (D3)	191 (D2)	24	0.35 (D3)	14.0 (D3)	32 (D5)	11 (D7)	9 (D10)
1998	105 (D8)	214 (D4)	227 (D4)	41	0.38 (D4)	14.1 (D4)	34 (D6)	9 (D6)	3 (D6)
1999	54 (D4)	178 (D2)	180 (D2)	17	0.30 (D2)	14.8 (D10)	37 (D7)	14 (D8)	1 (D3)
2000	51 (D3)	292 (D8)	292 (D8)	89	0.54 (D8)	14.4 (D7)	35 (D7)	7 (D4)	1 (D3)
2001	79 (D6)	261 (D7)	264 (D6)	65	0.48 (D7)	14.2 (D6)	33 (D5)	10 (D6)	1 (D3)
2002	50 (D3)	203 (D3)	207 (D3)	32	0.34 (D2)	15.0 (D10)	53 (D10)	17 (D10)	6 (D9)
2003	89 (D7)	182 (D2)	188 (D2)	22	0.34 (D2)	14.0 (D4)	28 (D3)	4 (D3)	2 (D5)
2004	41 (D2)	201 (D3)	201 (D3)	28	0.36 (D3)	14.7 (D9)	43 (D9)	21 (D10)	3 (D6)
2005	50 (D3)	235 (D5)	237 (D5)	50	0.41 (D5)	15.1 (D10)	49 (D10)	19 (D10)	1 (D3)
2006	140 (D9)	103 (D1)	122 (D1)	2	0.17 (D1)	14.4 (D7)	42 (D9)	12 (D8)	3 (D6)
2007	108 (D8)	112 (D1)	135 (D1)	7	0.18 (D1)	15.0 (D10)	53 (D10)	19 (D10)	4 (D8)
2008	95 (D7)	124 (D1)	135 (D1)	6	0.20 (D1)	14.7 (D9)	45 (D9)	11 (D7)	5 (D8)
2009	144 (D10)	304 (D9)	339 (D9)	106	0.55 (D8)	14.4 (D7)	33 (D5)	11 (D7)	0 (D1)
2010	59 (D4)	305 (D9)	305 (D8)	95	0.60 (D9)	13.7 (D2)	35 (D7)	10 (D6)	6 (D9)
2011	146 (D10)	250 (D6)	287 (D7)	85	0.46 (D6)	14.5 (D8)	34 (D6)	8 (D5)	0 (D1)
2012	88 (D7)	168 (D2)	170 (D1)	12	0.28 (D2)	14.4 (D7)	48 (D10)	24 (D10)	0 (D1)
2013	67 (D5)	222 (D4)	230 (D4)	45	0.37 (D3)	15.6 (D10)	57 (D10)	25 (D10)	2 (D5)
2014	105 (D8)	285 (D8)	294 (D8)	91	0.47 (D6)	15.2 (D10)	50 (D10)	20 (D10)	8 (D9)
2015	28 (D1)	244 (D6)	244 (D5)	56	0.44 (D6)	14.1 (D4)	38 (D8)	19 (D10)	3 (D6)
2016	116 (D9)	260 (D7)	276 (D7)	77	0.49 (D7)	14.1 (D4)	34 (D6)	9 (D6)	4 (D8)
2017	140 (D10)	141 (D1)	166 (D1)	11	0.23 (D1)	14.9 (D10)	40 (D8)	15 (D9)	0 (D1)
2018	62 (D4)	186 (D2)	187 (D2)	19	0.30 (D2)	15.0 (D10)	47 (D10)	15 (D9)	1 (D3)
2019	41 (D2)	216 (D4)	220 (D4)	40	0.35 (D3)	14.9 (D10)	50 (D10)	24 (D10)	3 (D6)
2020	92 (D7)	224 (D5)	232 (D4)	47	0.40 (D5)	14.5 (D8)	42 (D9)	15 (D9)	1 (D3)
2021	67 (D5)	210 (D3)	211 (D3)	36	0.36 (D3)	14.5 (D8)	41 (D8)	13 (D8)	1 (D3)
	Number of years in last 20 years (2002 to 2021) higher than decile 5 (decile 6 and above).								
	11	6	5		6	16	18	18	10

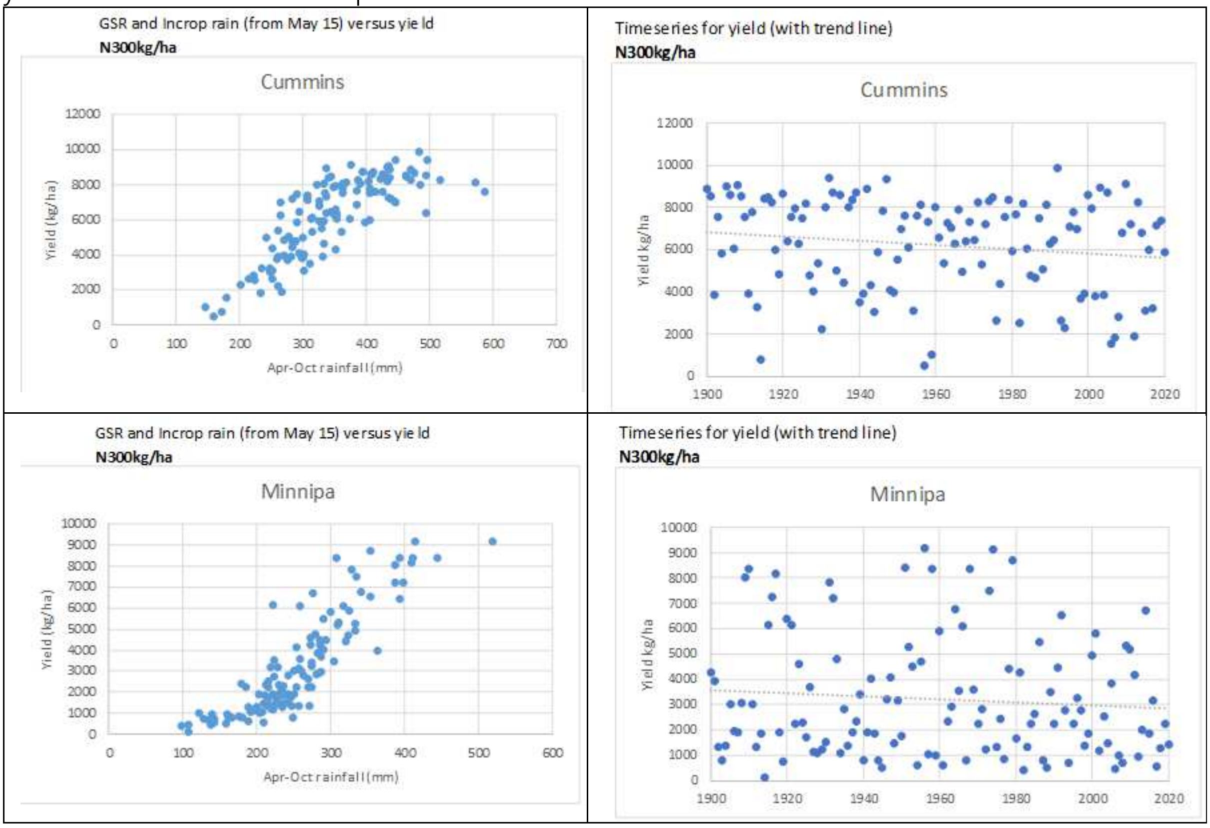
Mean T / Max T	Rain / Rain:E / Tmin
D1	1
D2	2
D3	3
D4	4
D5	5
D6	6
D7	7
D8	8
D9	9
D10	10

Figure 1. Timeseries of rainfall at Cummins and Minnipa



APSIM is a useful indice as it is an integrator of climate, soil and management. It is not simply a measure of rainfall. This can be observed by comparing simulated wheat yield as a function of growing season rain which highlights the importance of rainfall on wheat productivity and also shows that other factors influence productivity (Figure 2); and also by comparing the timeseries of simulated wheat yield with the timeseries of rainfall (Figure 1).
It should be noted that simulated wheat yield is a close match to observed wheat yield. This is because simulation models require some calibration to the field conditions. This is the process undertaken by other teams. Nevertheless APSIM simulations are considered a valuable management tool.

Figure 2. Relationship of simulated wheat yield to rainfall and timeseries of simulated wheat yield at Cummins and Minnipa.



Framework for economic analysis
February 2022

APSIM simulated wheat production was used to assist with Activity 4. Investigate the value of information from seasonal climate forecasts and soil moisture monitoring for decision making at least three sites, and specifically with developing V1 of the Economic analysis. This data was provided to the CSIRO team and included in their delivery of Nitrogen report (APSIM x soil water probe visualisation x N decision tool) in collaboration with SARDI Climate Applications and EP Ag Research which is available as an appendix to the CSIRO milestone report. That report details the SARDI milestone of V1 of the Economic analysis and places it in a broader and more useful context for Eyre Peninsula primary producers.

This is an excerpt from the report provided to the CSIRO team.

Using APSIM to analyse nitrogen response in wheat: SSW & N matrix

Bronya Cooper and Peter Hayman, SARDI, Jan 2022

We are using the sophisticated daily timestep model APSIM for analysis of climate and risk for nitrogen decisions, particularly the response of wheat yield to N topdressing.

We are interested in the relative contribution of both N rate and starting soil water (SSW) to the overall yields/profit. This can give an idea of the value of information on these parameters at the start of the season. Our plan is to use the APSIM output for economic analysis.

To investigate, we are using APSIM with various SSW and N rates. This work aligns with the Smart Farming project on Resilient and Profitable Farming on the Eyre Peninsula, and as such we are integrating some of the APSIM components (particularly soils) developed by CSIRO as part of the same project. Our initial focus has been on APSIM output at Cummins (reported here) and Minnipa.

Cummins APSIM setup

Nitrogen

- APSIM runs varying the amount of Nitrogen (as NO3) added at sowing (From 0 – 300kg/ha in increments of 10kg, and 400kg/ha).
- In all cases there is 50kg/ha N in soil (as NO3) reset 14 May (day prior to sowing), which is spread throughout the top 3 layers (0-50cm depth).

Starting soil water

- Matrix uses a range of ssw from 0mm - 60mm (by 10mm), 80mm and 100mm.

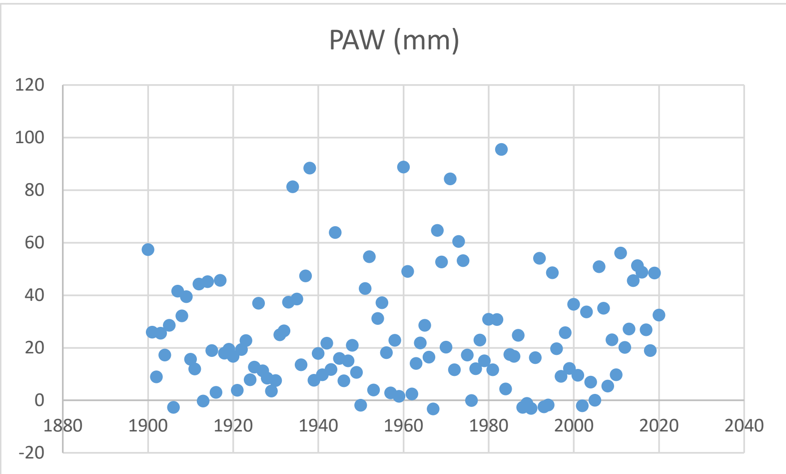
- Ssw is filled from top, amount relative to wheat.
- The ssw is also reset 14 May, the day prior to sowing. In an earlier analysis we reset the ssw (Plant Available Water) to 0mm on Jan 1 each year and reported the PAW on 14 May (see Figure 1). This gave a median PAW of 20mm, but with a large range between about 0-100mm.

Soil

- Wilksch Yeelana soil provided by CSIRO ("Wilksch_Yeelana_FrSW"). See Figure 2.
- PAWC 211.2mm
- I also included the updated ini file recommended by CSIRO for better N mineralisation in heavier soils.

Other APSIM setup notes

- Cummins SILO met file from 1900-2020 was used (decided not to use the different mat file from Therese that apparently is better for radiation, as it only from 1990 (AWAP).
- Fixed sowing on May 15, cv. V2_P3



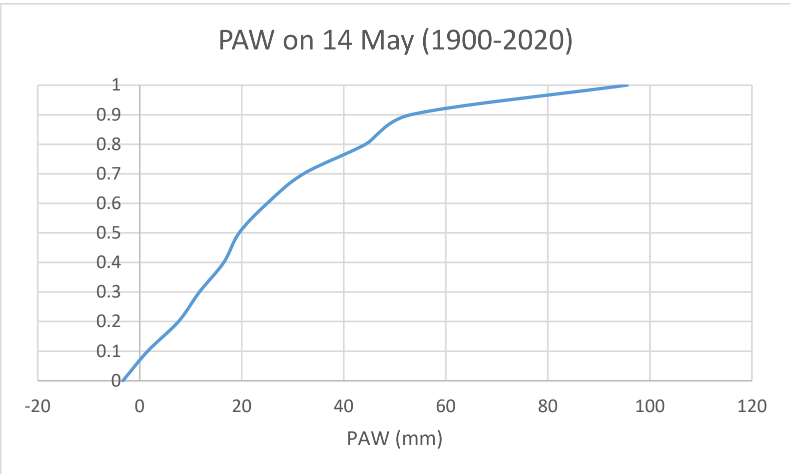
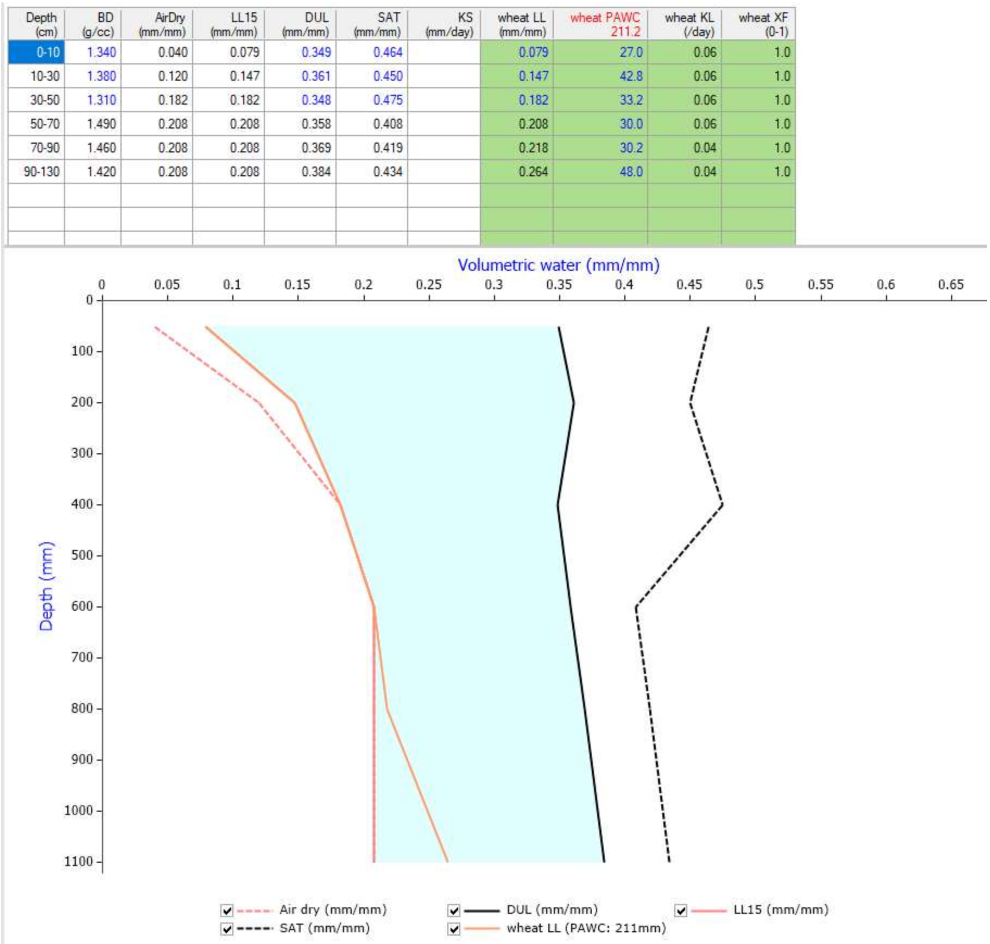


Figure 1: Plant Available Water amount on 14th May, when PAW was reset to 0mm on Jan 1, using APSIM setup for Cummins 1900-2020.



Depth (cm)	BD (g/cc)	AirDry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	KS (mm/day)	wheat LL (mm/mm)	wheat PAWC 211.2	wheat KL (/day)	wheat XF (0-1)
0-10	1.340	0.040	0.079	0.349	0.464		0.079	27.0	0.06	1.0
10-30	1.380	0.120	0.147	0.361	0.450		0.147	42.8	0.06	1.0
30-50	1.310	0.182	0.182	0.348	0.475		0.182	33.2	0.06	1.0
50-70	1.490	0.208	0.208	0.358	0.408		0.208	30.0	0.06	1.0
70-90	1.460	0.208	0.208	0.369	0.419		0.218	30.2	0.04	1.0
90-130	1.420	0.208	0.208	0.384	0.434		0.264	48.0	0.04	1.0

Figure 2: "Wilksch_Yeelana_FrSW" soil (PAWC 211.2) provided by CSIRO.

Results

Figure 3 shows the increase in average yields across N rates (from about 3t/ha for N0, to 6-8t/ha for N400. It also shows that average yields increase with higher starting soil water.

The colour formatted tables (Tables 1 & 2) show the nitrogen efficiency for yield (kg increase in yield per kg nitrogen added). They are arranged with N amount along the top (columns) and Years down the left side (rows), where the years are sorted from lowest (top) to highest yield (using yield when 400kg N was added).

The darkest orange highlights negative values. This is where there is a reduction in yield/biomass, even though more N was added. We can see that there are more of these negative values in the lower SSW categories, and also more negatives in yield compared to biomass.

We were interested to see the N response when averaged across deciles of the maximum yield (generally the yields when 400kg/ha N was added). Figure 4a shows the average yields across deciles, and Figure 4b shows the corresponding N efficiency averaged across deciles. It's interesting to note in 4b that the higher decile yields start with an efficiency of around 40kg yield per unit N added.

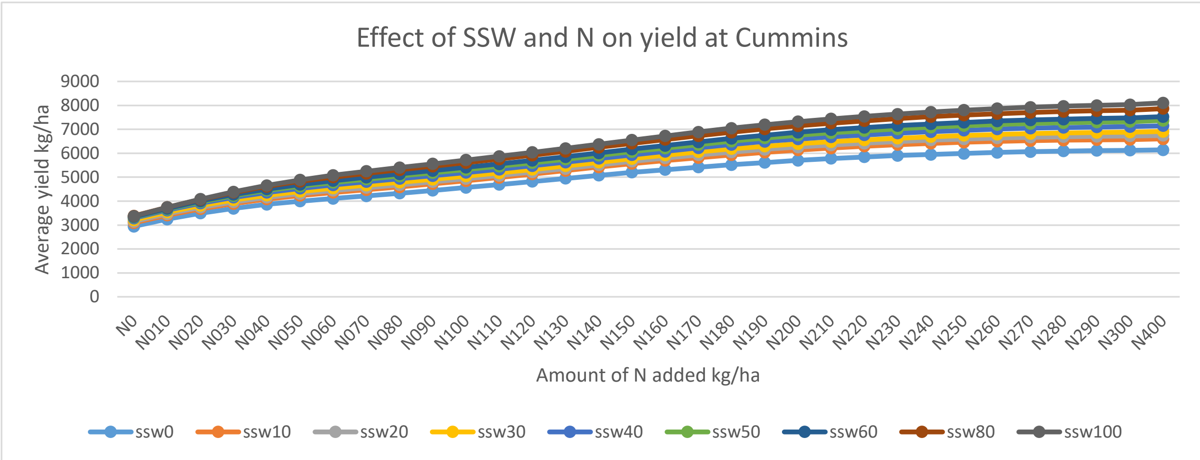
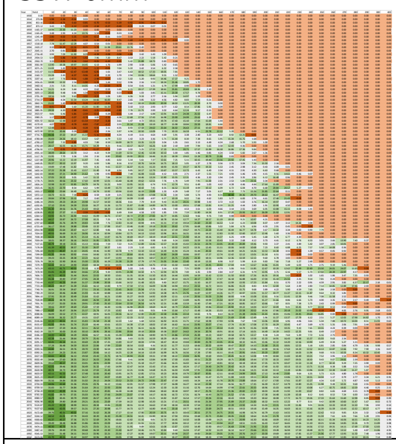
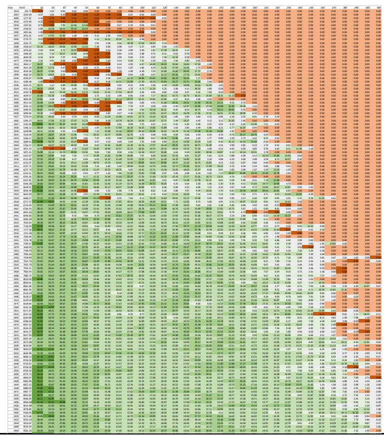
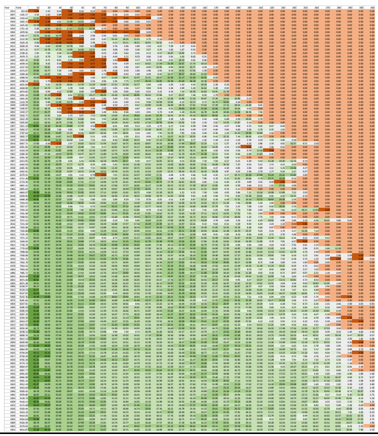
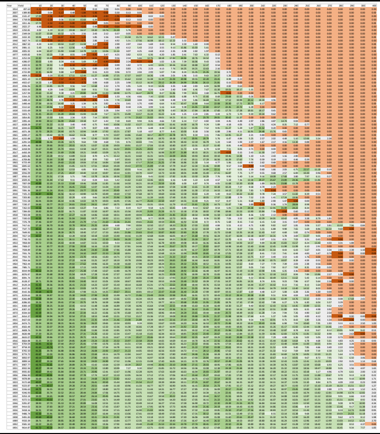
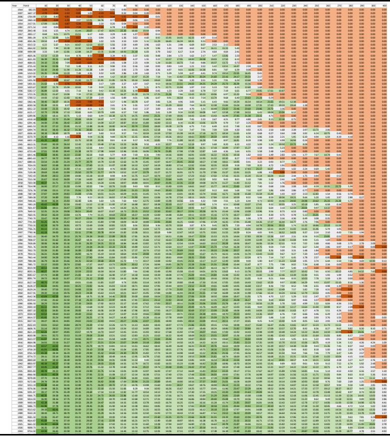
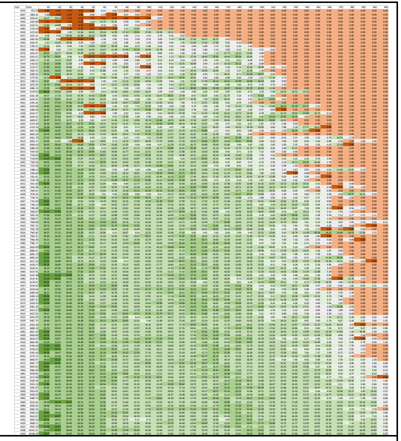


Figure 3: APSIM simulated average wheat yields at Cummins (1900-2020). Various nitrogen rates at sowing and starting soil water (SSW) at sowing were used.

<u>Yield</u>

SSW 0mm	SSW 10mm	SSW 20mm
		
SSW 30mm	SSW 40mm	SSW 50mm

SSW 60mm | SSW 80mm | SSW 100mm

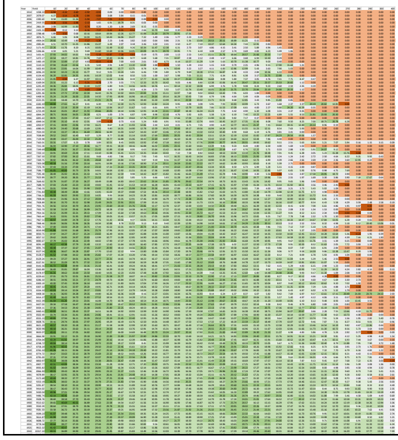
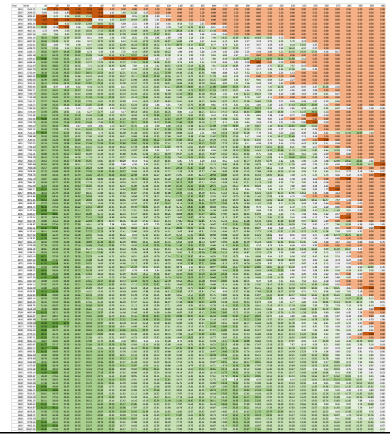
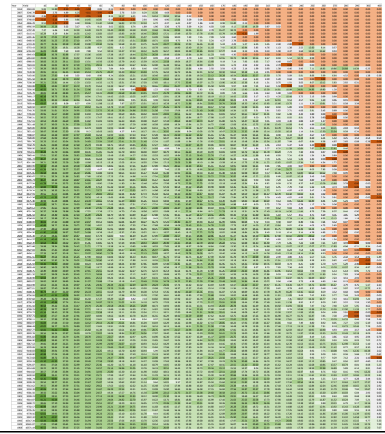
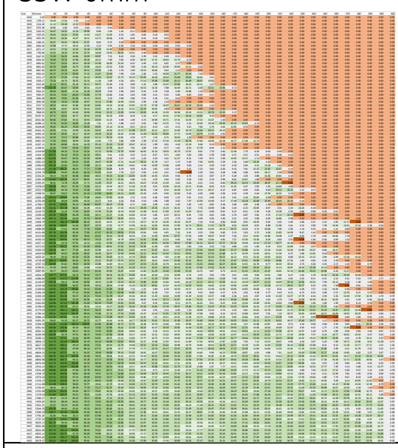
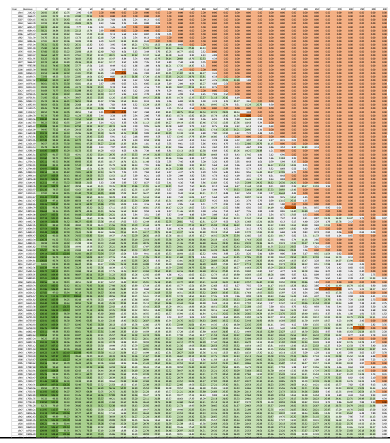
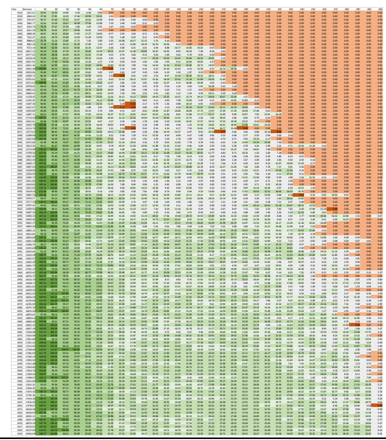




Table 1: APSIM simulations of nitrogen efficiency for yield (kg increase in yield per kg N added) across different starting soil water (SSW) amounts at Cummins. Rows are years between 1900-2020, ordered from lowest (top) to highest yield when 400kg N is added (to represent N unlimited yields). Columns are the different N amounts added at sowing, between 0-300kg/ha in increments of 10kgN/ha, and far right with 400kg N/ha added.

Biomass

SSW 0mm | SSW 10mm | SSW 20mm

SSW 30mm | SSW 40mm | SSW 50mm

Table 2: APSIM simulations of nitrogen efficiency for biomass (kg increase in biomass per kg N added) across different starting soil water (SSW) amounts at Cummins. Rows are years between 1900-2020, ordered from lowest (top) to highest biomass when 400kg N is added (to represent N unlimited yields). Columns are the different N amounts added at sowing, between 0-300kg/ha in increments of 10kgN/ha, and far right with 400kg N/ha added.

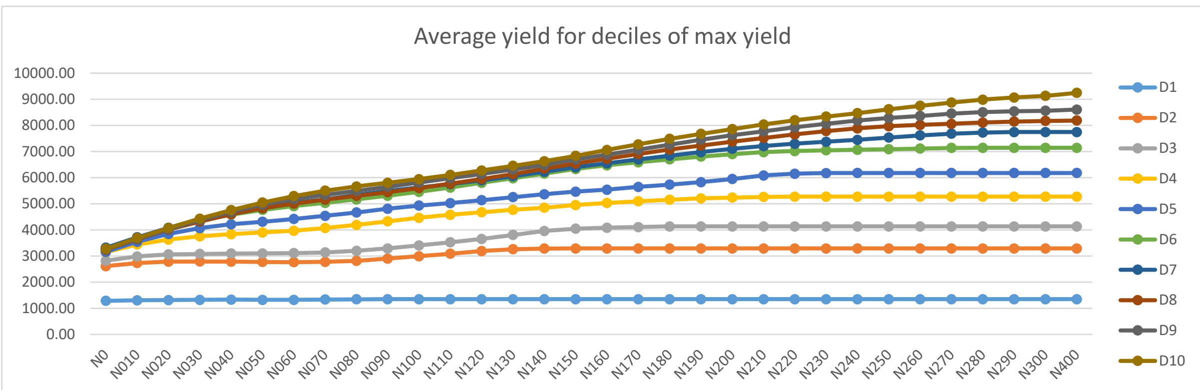


Figure 4a: Yield response to N averaged over deciles of the maximum yield. For example, "D1" shows the yields across various N rates averaged over the 10% of years that have the lowest maximum yields.

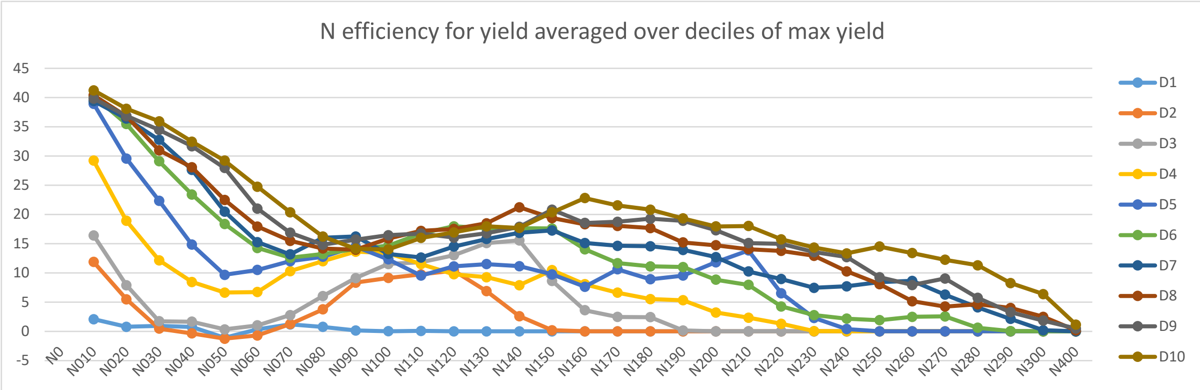


Figure 4b: N efficiency (increase in yield per unit N added), averaged over deciles of maximum yield.

Implications

We'd planned to use the APSIM output for economic analysis. However, for this to lead to sensible conclusions the APSIM yield response needs to follow a diminishing marginal return pattern, where the change in yield per unit nitrogen added could be expected to be larger at a low N rate, and diminish as the N rate increases to the point of the system being N unlimiting. This is not what we are finding in the APSIM data shown here. The worst cases have been highlighted (in dark orange in Tables 1 & 2) where we are seeing a reduction in yield/biomass, even though more N was added. However, even in cases that only have increased yield with N rates, we are finding most don't follow a diminishing marginal return. Our initial response has been to look at fitting a curve to the APSIM output to force a diminishing return. This is explored further in the summary document "N response using a quadratic".