CHANGES IN THE PASTORAL/CROPPING ZONE

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ABSTRACT

A history of cropping at the margins between arable and pastoral lands is examined. Assessment is made of the climatic factors that caused an abandonment of cropping. These criteria are then used to assess the likelihood of future cropping persisting along the pastoral margins in different states of Australia. A minimum requirement is that the ratio of water use to evaporation in the growing season should exceed 0.3.

An analysis of past climatic data should also be made to identify sequence of years when rainfall was both above and below average. Periods of above average rainfall can lead to undue optimism for future cropping.

Simple climatic models are required so that farmers can use them to predict the rainfall in the growing season and thereby make appropriate management decisions.

Farming is a complex technical and financial business and farmers will need skills in monitoring, measuring and recording factors that influence this likelihood.

INTRODUCTION

Changes are occurring in many of our agricultural systems as a result of economic, political and social pressures. On livestock farms in low rainfall country, many landholders are in financial difficulty due to low returns from wool and meat, higher fuel and transport costs, and variable climate. In some areas, the problem has been increased due to land degradation, woody weeds, inadequate water supply and large numbers of native and feral animals. As a result , many farmers are now looking for alternative ways of generating a cash flow and maintaining their livelihood.

One of the options being considered is to grow crops in a mixed farming system with livestock. However, in spite of a lot of scientific research at the boundary of the pastoral-cropping zone, landholders have difficulty in deciding which technology is most likely to increase productivity in their climate and soils.

What then are the possibilities of integrating cropping and grazing within the biology and resources of the marginal lands and thereby maintaining an ecological and economic system? What can we learn from the past?

HISTORY OF CROPPING AT THE MARGINS

A good example of pressures and changes at the margins can be obtained from a review of the factors associated with the establishment of Goyder's Line in the Upper North of South Australia (Meinig 1962).

Following the settlement of the colony in 1836, agriculture extended northwards to provide the food resources. However, during the early 1860's, a four-year drought decimated the wheat crops. In 1865 Goyder, the Surveyor General, travelled the countryside and established a line beyond which arable cropping should not be permitted.

But farmers continued to grow wheat beyond the line and wheat yields increased, over the next 25 years. We now know with hindsight that the rainfall in most years was above the long-term average. A common belief at the time was that "the rain follows the plough".

In the 1890's however, the rainfall declined and yields collapsed and the first retreat from farming began in 1896. Cropping however continued in areas closer to Goyder's Line due mainly to a favourable run of seasons from 1902 to 1926. However, rainfall then fell below average for many years and in 1936 the second retreat from the margins of wheat growing commenced. This led to the abandonment of many farms.

The trends in the rainfall patterns from the 1860's to the present can be seen in Figure 1 which shows the cumulative sum of the difference between each year's rainfall and the long term average rainfall. It serves to emphasise that 25 years of rainfall data are inadequate to assess the potential for providing a sustainable farming system over the long term.

While today there are some small areas north of the line which have a favourable climate and soils for worthwhile cropping in general, Goyder's Line is still relevant for defining the limits of cropping in most of the cereal districts in South Australia.

CRITERIA FOR CROPPING

From this farming history, we can assess some of the climatic factors that limit cropping in the marginal areas. A comparison of the average rainfall and evaporation for three sites along the margin are given in **Table 1**. (See page 64).

At Minnipa in the winter season, crops are grown in a dryland farming system in conjunction with sown pastures for livestock. Cereal yields in the district range over the years from an average of 0.3-1.7 t/ha. At Hawker, the land is mostly used for grazing with some cropping in a few favoured areas in the district, while at Yunta, the only land use now is grazing. At all three sites, the rainfall is insufficient to grow any summer crops.

The rainfall/evaporation ratio for winter along most of Goyder's Line is 0.22. The data in **Table 1** indicates that cropping is unlikely to be economic unless the rainfall (or water use, where moisture can be stored in the subsoil prior to sowing) is equal to at least 0.3 of the evaporation in the growing season.

MEASURE OF RAINFALL VARIABILITY

While average climatic values give a preliminary assessment of the likely yields of crops in a region, it is vital to have a record of the past variability of these factors from year to year. While temperature and evaporation vary somewhat, the biggest impact on crop yields is the variation in growing season rainfall. This can be defined by the rainfall decile values.

Table 2 shows the decile values for individual months of the year, the whole year and for combinations of months during the growing season for Minnipa in South Australia. (See Page 65).

Decile 1 means that one year in 10 the rainfall will be less than the amount shown in the column. Decile 5, which is an approximation of the average rainfall, means that five years in 10 the rainfall will be less than the amount shown. Decile 9 means that nine years in 10, the rainfall will be less than the amount shown, or conversely, one year in 10, the rainfall will be higher than the amount shown.

The lower part of the table enables an estimate to be made of the way the season is developing. To the accumulated rainfall for different months, the decile 9, 5 and 1 rainfall data for the remaining months in the growing season are added separately and the values plotted to produce a trend of probability.

COMPARISON OF CLIMATIC VALUES IN OTHER STATES

The assessment of the probability of cropping along the marginal lands boundary in South Australia can be used to examine the situation in other States. Appendix I, (See Page 72), lists the average monthly values for rainfall, evaporation and average daily temperatures in each month for a number of sites in other States. A summary of the winter and summer growing season rainfall and evaporation is given in **Table 3.** (See Page 64).

Evidence of climatic changes at these sites can be gained by calculating the cumulative sum of the annual differences, as was done for the graph in Figure 1. For both Roma and Walgett, the data show a below-average trend from 1900 to the 1940's and then an above-average trend until today. For Southern Cross in Western Australia, the data show a below-average trend from 1896-1914, then above-average to 1935, then below-average 1957 and above-average since then. The prospects of growing different crops and pastures economically at the various sites can be assessed by relating their climatic factors to the values for high and low yields listed in **Table 4.** (See Page 67).

ASSESSMENT OF YIELD

Winter Crops

Data from the previous tables show that the ideal ratio of water use/ evaporation for a high wheat yield should be about 0.8 from sowing to anthesis (flowering) and 0.3 from anthesis to harvest. This gives a total growing season ratio of about 0.5 which can produce about 10 kg/ha of grain per millimetre of total water use. By contrast, a growing season ratio of 0.3 produces about 1 tonne per hectare of grain equivalent to 4.5 kg/ha per millimetre of water use. These figures emphasise the importance of the amount of growing season rainfall to produce economic crops or failing that, the need to store additional water in the subsoil prior to sowing crops in marginal land.

Data in **Table 4** also shows the water use/evaporation ratios for producing high and low yields of lupins and annual legume pastures. In the past, short-term optimism following several years of about average rainfall has led to cropping in the marginal areas. However, it is important to show the limits to cropping from different locations across the countryside. A study from Dalby, through Roma to Charleville (Hammer *et al.* 1984) has shown the decreasing yields and increasing variability as one proceeds further west (**Table 5**). (See Page 68).

In a similar assessment, Fawcett (1967) defined the limit for wheat cropping in country west of Narrabri to be 230mm of rainfall from May to October.

Cropping has also been carried out in recent years in the country between Wentworth and Pooncarie in southern New South Wales (Noble *et al.* 1984). The average ratio of rainfall to evaporation for Pooncarie during the winter months is a low 0.19. Hence cropping is largely opportunistic and is only likely to be profitable in those years where pre-sowing rains stores 50mm or more in the subsoil.

Summer Crops

The possibility of growing crops in the summer time can be assessed in a similar way; but the chances of success are only likely in the northern marginal lands where the water use, evaporation ratio reaches 0.4 to 0.5 in the growing season. Higher values are usually required in the first half of the growing season.

Calculations therefore have to made of the probability of getting sufficient rainfall to reach these ratios,and also to what extent moisture stored in the soil before sowing or alternatively irrigation, will be needed to produce economic yields. These procedures are particularly necessary to ensure satisfactory yields of maize and grain sorghum, both of which are drought prone.

An option open to a few companies and landholders is to sow crops on ancient lakebeds which can either be irrigated throughout the year or on lakes which receive an occasional flooding from a high river.

In these areas, rainfall is usually low and evaporation high and the amount of water needed on the irrigated lakebeds reaches as high as 800mm for a summer crop such as sorghum or cotton, and up to 250mm for a winter cereal. In those lake beds which receive only an occasional flooding, various crops can be sown around the edges as the water level retreats. This can provide opportunities for both winter and summer crops and pastures.

Crops and Pasture Phenology

Crop phenology provides a calendar which identifies the climatic factors influencing the phasic development of plants from seedling through to harvest. Various scientific measurements have identified the factors that dominate the rate of development. They include photoperiod, maximum temperatures, sometimes minus a threshold temperature and mean temperature. Accumulated day-degrees from sowing and the date of onset of a specific temperature can influence vernalisation, flower initiation, anthesis and physiological maturity (Angus *et al.* 1980/81). Delays in time of sowing can alter the rate of crop development and the amount of growth and yield.

An approximate guide to the development of crops is given in **Table 6** and these data can be used to assess the optimum time of sowing, flowering, length of growing season and yield as different sites, as for example those listed in the Appendix. (See Page 68).

Climatic Models

Over the last 30 years or so, many computer-based scientific models have been developed to help understand the effect of climatic factors on the biological processes and plant growth, and thereby devise a formula for making better decisions in agricultural systems.

A brief sample of the many published papers on this subject is as follows:- Greacen and Hignett (1976); Fischer (1979); O'Leary *et al.* (1985); Nix (1985); Hamblin *et al.* (1987); Rimmington *et al.* (1987); Saxton *et al.* (1992). The inputs into the models vary somewhat but usually include some of the critical factors such as rainfall, evaporation, temperature, hours of sunshine, net radiation, wind speed and humidity.

These models provide a good understanding of the science of plant growth and are often used to assess the historical trends in agriculture. However they do have limitations for on-farm predictions because of the technical equipment and the frequency of the measurements needed, sometimes daily or weekly, to run the modelling. There is a need for these models to be tested at field experimental sites with basic farm data, so that the results can be readily simplified and converted to farmer's decision making programs.

Soils

The other basic factor in assessing the potential productivity of a land system is the nature and quality of the soil. The important properties are those which enhance root development and growth. They include the organic matter content and structure of the topsoil, the soil depth to which roots can grow, the water holding capacity, nutrient status, pH, degree of salinity and the presence of toxic elements such as boron and aluminium.

The importance of soils that can store water prior to seeding has already been mentioned and in particular, soils with high amounts of available water are needed to assure the successful growth of sorghum and sunflower (Russell 1988). The water holding capacity of different soils is given in **Table 7**. (See Page 68).

Variations in soil types and hence water holding capacity occur on most farms. In low rainfall areas, sandy soils and heavy clay soils are not favoured for cropping because of the low water holdign capacity of sands and the large amount of water needed to overcome the wilting point in the clays.

Hence, it is important to have a farm plan carried out on the property identifying the areas of high water holding capacity and the potential for root growth. Other areas should be set aside from cropping.

Agronomic Practices

An efficient management program aims to integrate many factors in order to enhance the growth of crops and pastures. In general, arable systems are more demanding than livestock systems. Basically the aim in cropping is to use the rain where it falls, thereby preventing runoff and erosion, reduce the loss of rain by evaporation and increase the production per millimetre of water transpired by the plant.

The following factors are critical and need to be given special consideration.

(i) Tillage methods: the old basic fallow methods of cultivation are destructive and need to be replaced by minimum tillage and direct drilling. Stubble mulching can also reduce erosion problems but may affect seeding and cause disease problems in some cases.

(ii) Time of sowing: best yields occur when the crop develops and completes flowering before the date of the critical temperature given in **Table 6**. Early seeding gives early leaves and these help to reduce the normal 40% loss of rainfall by evaporation (Hamblin *et al.* 1987).

(iii) Nutrient supply: the most efficient growth occurs when all nutrients are present and in the right balance for the particular plant. The production of any food causes an outflow of nutrients from the paddock and these have to be replaced eventually. In many soils in the marginal areas, the nutrient supply is limited and only occurs in the topsoil. The amount of nutrients removed in every tonne of grain from several crops and in a tonne of medic hay is given in **Table 8**. (See Page 69).

The figures given in this table show the amounts removed in the grain. Extra amounts of each nutrient are needed in the stubble associated with each tonne of grain. Thus for wheat, the nitrogen and phosphorus in the grain represents about 70% of the total amount needed, sulphur and zinc 45%, magnesium, copper and manganese 35%, potassium 20% and calcium 10%. Burning the stubble therefore will also cause a loss of nutrients, particularly nitrogen and sulphur.

(iv) Control of weeds and root diseases: a variety of exotic weeds such as heliotrope, onion weed, horehound and nitre bush are common in marginal areas and can severely reduce crop yields (Noble *et al.* 1984). As well, some grasses can carry root diseases from pasture paddocks into the following crop, reducing yield.

(v) Control of native and feral animals and birds: cropping near pastoral areas can attract a whole range of predators. Included are kangaroos, emus, goats, rabbits and feral pigs (in New South Wales) and wild donkeys and camels (in Western Australia). A variety of birds including galahs, cockatiels and crows also cause problems.

In addition to the above issues cropping will require an investment in a range of machinery to undertake land preparation, seeding, spraying for control of weeds and diseases and for harvesting.

INTERACTION OF CROPPING WITH LIVESTOCK

With the allocation of land for cropping, changes will be necessary in the livestock management. Cropping competes in area with livestock.

As a consequence, overgrazing will occur in dry years, and stock numbers may have to be reduced by up to 40% to manage the reduction in available forage and the probability of accelerating erosion.

Problems can also occur around watering points due to competition from native and feral animals seeking grain from the crops. Extra fencing may be necessary to protect both watering points and crop.

In general, livestock grazing requires less input into land management. The main problem is to relate food demands of the animals over the whole year to the reduced months of pasture growth. Long periods of feed shortage can lead to extensive land degradation.

If the cropping program is successful then some of the land should be sown to grain and forage crops which can be harvested and stored in silos on land which could be used as feedlot.

MANAGEMENT PLAN FOR MARGINAL FARMING IN THE FUTURE

The concept of having multiple uses of rangeland presents a big challenge if we are to preserve the landscape for future generations. The approach will require a new vision and perspective based on past climatic trends, possible climate changes due to the greenhouse effect and detailed surveys of land inventories to select the best soils for cropping and to monitor changes in soil properties that could lead to land degradation.

Simple Growth Simulation Models

In the first place, scientific crop simulation models and land surveys can provide government authorities and landholders with a general perception of the suitability of an area for cropping. The climatic models should also evaluate the possible effect arising from global warming. In some areas, the effect could compound existing problems. The current predictions suggest a 2°C warming with 30% or more rain in the summer and 20% less rain in winter. These changes could affect the time of sowing, the length of the growing season, the incidence of weeds and diseases and the yield.

To help farmers monitor climatic effects and production on their properties, simpler models are needed relative to current growing season so that the models' predictions can be more readily used for making better decisions on crop and pasture growth. Two examples are given in **Fig. 2.** (See Page 71).

In part (a), a rainfall decile trend graph, which is updated every month, shows the cumulative monthly rainfall and the prospects for the season, based on plotting deciles 9,5 and 1 for the rest of the growing season. Usually by mid-season, an estimate can be made of whether the growing season will be above- or below-average. This enables decisions to be made on late sowing, additional fertilizer applications, pasture growth and adjustments to stock numbers.

In part (b), a picture is also obtained of the monthly growth patterns from the relationship between evaporation and rainfall. The evaporation is a measure of the sunlight energy and the stress imposed on the water supply. The line "0.2 x evaporation" is an estimate of the amount of rainfall that is lost by evaporation and therefore not available to the plant. For germination to occur, the water supply should exceed 0.3 by evaporation; where the rainfall exceeds the evaporation in any month waterlogging can occur; and growth ceases at 0.2 x evaporation.

Monitoring Programs

In addition to the assessment of the climate, regular monitoring programs will be required for each paddock to record time of seeding, crop development stages, particularly the time of flowering and the date and maximum temperature, the incidence of weeds and pests, the yield, the nutrients removed in the farm products and the incidence of land degradation. Other factors that need to be recorded include fuel and machinery costs, the effectiveness of herbicides and pesticides and the gross margins for each paddock and the cropping and livestock enterprises.

Re-establishing Pastoral Vegetation

Consideration should also be given as to what procedures will be necessary to re-establish pastoral vegetation on areas that do not produce an economic return from cropping.

Significant areas of degraded land have been re-established with perennial native bushes in 220-280 mm annual rainfall country in the northeast of South Australia beyond Goyder's Line. The seed was collected from existing bushes and sown into contour furrows (French and Potter 1975). The most successful establishment of bladder saltbush (*Atriplex vesicaria*) and black bluebush (*Maireana pyramidata*) occurred when more than 25 mm of rain fell in each of the months (June-August) when daily maximum temperatures were about 15°C and daily evaporation less than 4 mm per day.

More recently, oldman saltbush (*Atriplex nummularia*) has been successfully established by deep ripping rows 3 meters apart and planting seedlings several months later (Condon and Sippel 1992). Their results show that grazing these bushes provided a better gross margin per hectare than most pasture forage or grain crops for equivalent rainfall.

New Technologies

A key factor in assessing land management is the need to present an overview of the effects of cropping or grazing. A very positive way of doing this is by using aerial photography. Some farmers are already taking either colour or infra-red photos from light aircraft and reviewing the impact of their management on plant growth and soil stability. Photos are also available from satellite programs.

Looking ahead, one has to question whether more drought resistant productive crops and pastures cannot be developed through genetic engineering. In most plants, however, there is a complex of genes involved in the metabolic processes. If a new gene is introduced into the existing complex, it is uncertain as to whether it will settle within the chromosome. It may also affect the efficiency of another growth process.

There is therefore no quick fix and while successes have been achieved in the past and will continue to do so, several years of testing of a new plant are still required under field conditions to prove its worth.

Recording the Success of Operations

When assessing the effectiveness of new varieties, cropping systems and livestock management, there is a need for a set of indicators to measure the degree of success. These indicators should include the expression of the crop yield as a percentage of the potential yield for the rainfall, the soil types and the levels of organic matter and nutrients necessary to sustain production, and the economic returns per hectare for each farming system and paddock.

To do this successfully will require a comprehensive recording system showing the inputs, costs, prices and yields for each season. It is also necessary to have some simple climatic growth model which can help predict the best decisions for the current season.

Overall, the imediate future is going to become a decade of numeracy. This will mean that many landholders may have to undergo an educational training program in the use of computers. Farming today is a complex climatic, biological, technical and financial business. It will involve monitoring, measuring and recording data to help make the best management decisions.

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TABLE 1: Comparison of the average rainfall and evaporation during winter and summer for three sites near the margins of wheat growing in South Australia.

SITE	WINTER (April-Oct)			SUMMER (Nov-March)		
	Rain (mm)	Evap^n (mm)	Ratio	Rain (mm)	Evap^n (mm)	Ratio
Minnipa	260	860	0.30	88	1480	0.06
Hawker	210	970	0.22	96	1630	0.06
Yunta	136	930	0.15	93	1660	0.06

TABLE 3. Summary of the average rainfall and evaporation during winter and summer at sites near the cropping and pastoral zone in different States.

	Winter		**(April- October)**	**Summer**	**(Nov-**	**March)**
	Rain (mm)	*Evap^n (mm)*	*Ratio*	*Rain (mm)*	*Evap^n (mm)*	*Ratio*
Western Australia						
Merredin	238	810	0.29	74	1660	0.04
Southern Cross	199	955	0.21	81	1645	0.05
New South Wales						
Pooncarie	160	860	0.19	101	1505	0.07
	Winter		**(May-Oct)**	**Summer**	**(Nov-**	**April)**
Trangie	215	585	0.36	278	1415	0.20
Cobar	182	720	0.25	229	1700	0.13
Moree	236	655	0.36	336	1400	0.24
Walgett	204	700	0.29	276	1500	0.18
Queensland						
Dalby	244	650	0.38	430	1130	0.38
Roma	222	670	0.33	380	1240	0.31
Charleville	163	795	0.21	335	1555	0.22

TABLE 2: The rainfall decile values for Minnipa, South Australia,

MINNIPA

RAINFALL DECILES (millimetres)

CALCULATED FOR 1914-1985

		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Highest on record		65	167	86	78	128	141	111	120	132	105	103	88	603
Decile	9	36	59	49	46	72	94	83	79	63	60	45	43	475
	8	24	30	33	34	59	71	64	67	54	44	37	27	444
	7	18	21	19	25	52	55	62	62	45	34	30	19	413
	6	12	15	12	22	42	47	53	56	37	29	22	16	383
	5	7	8	8	17	35	39	44	44	31	25	17	13	336
	4	4	4	5	13	29	34	40	39	24	19	13	10	303
	3	3	2	2	9	22	26	34	30	21	13	10	7	279
	2	1	0	1	5	18	17	28	24	14	8	5	3	263
	1	0	0	0	2	12	11	21	14	9	3	1	1	241
Lowest on record		0	0	0	0	6	4	4	5	0	1	0	0	182
Average		*13*	*20*	*16*	*20*	*39*	*46*	*48*	*47*	*35*	*28*	*22*	*18*	*352*

Table 2 (cont)

COMBINATIONS OF GROUPS OF MONTHS	APR	MAY -OCT	APR -MAY	JUN -OCT	A-M -J	JUL -OCT	A-M -J-J	AUG OCT	AMJ JA	SEP -OCT	AMJ JAS	OCT	APR -OCT
Highest on record	78	473	168	395	248	290	335	216	378	159	427	105	520
Decile 9	46	376	109	306	180	232	229	170	295	109	350	60	394
8	34		85		143		210		269		304		329
7	25		76		124		175		227		274		292
6	22		65		106		155		202		248		264
5	17	232	52	198	94	150	139	111	191	55	221	25	251
4	13		42		87		129		177		202		230
3	9		37		81		124		167		188		220
2	5		30		67		112		145		167		195
1	2	158	23	119	55	93	83	58	111	22	151	3	167
Lowest on record	0	98	14	76	21	42	63	31	78	8	99	1	99
Average	*20*	*244*	*59*	*204*	*106*	*158*	*155*	*110*	*201*	*63*	*236*	*28*	*264*

Table 4: A comparison of the relationship between climatic factors and the yields of wheat, lupins and sown annual legume pasture.	Rain (mm)	Water Use (mm)	Evap^n (mm)	Ratio- $\frac{W.U.}{Evap^n}$	Dry matter kg/ha	Grain
Wheat						
(a) High yield						
Sowing-tillering	111	93	128	0.72	770	
Tillering-anthesis	117	185	229	0.81	7990	
Anthesis-soft dough	30	81	160	0.51	2730	
Soft dough-harvest	34	32	223	0.14	-330	
	292	391	740	0.53	11160	3900
(b) Low yield						
Sowing-tillering	83	73	183	0.40	520	
Tillering-anthesis	42	93	232	0.40	2330	
Anthesis-soft dough	21	49	178	0.28	1350	
Soft dough-harvest	7	21	195	0.11	-300	
	153	236	788	0.30	3900	1060
Lupins						
(a) High Yield						
Sowing-anthesis	251	230	270	0.85	4210	
Anthesis-harvest	119	250	360	0.69	6950	
	370	480	630	0.76	11160	3260
(b) Low yield						
Sowing-anthesis	140	210	250	0.75	2570	
Anthesis-harvest	16	76	385	0.20	1800	
	156	286	635	0.45	4370	1580
Annual Legume Pasture						
(a) High Yield	220	214	288	0.74	6160	
(b) Low Yield	110	91	354	0.26	1560	

Table 5: The variability of rainfall and wheat yield across southern Queensland.

Site	Ratio - Rainfall/Evap^n	Av. Yield 1961-81 t/ha	Coefficient of Variation	Probability of growing 1.5t/ha (%)
Dalby	0.38	1.93	41	60
Roma	0.33	1.39	56	35
Charleville	0.21	0.89	65	25

After Hammer *et al.* (1984)

Table 6: Accumulated daily maximum air temperatures during the development of different crops, and the optimum temperature for the flowering stage

	Accumulated day-degrees of maximum temp. (°C) Sowing to		Optimum average weekly max. temp. for flowering
	Start (of Flowering)	End (of Flowering)	
Lupins	1600	2400	20
Barley	1800	2000	23
Wheat	1900	2200	23
Safflower	3200	3700	23
Sunflower	1600	2400	28
Soybeans (indeterminate)	1600	2600	32
Annual legume pasture (early variety)	1600	2700	20

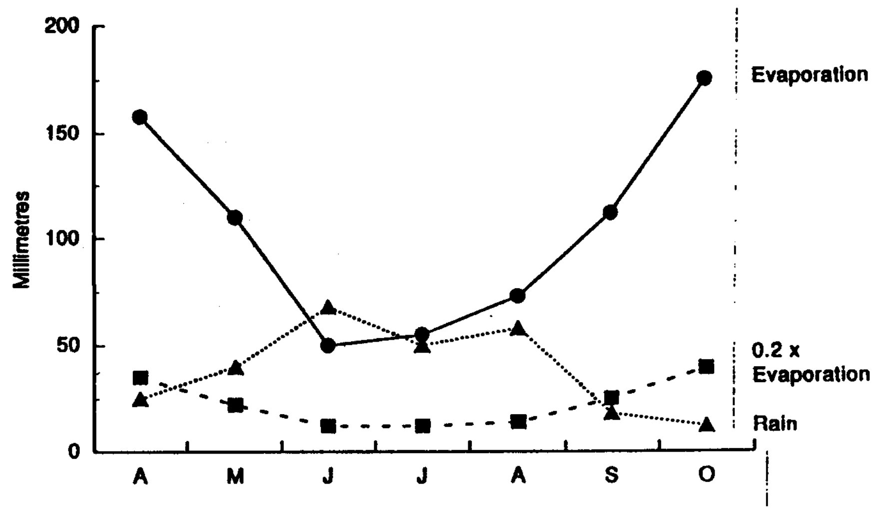
Table 7: The water holding capacities in a range of soils measured as moisture (mm) per 30 cm soil.

Soil	Field Capacity	Wilting Point	Available to Plants
Sand	25	15	10
Loam	75	40	35
Clay Loam	110	55	55
Cracking Clay	140	80	60

Table 8: The average amount of nutrients removed at harvest in a tonne of grain from different crops and from a tonne of hay

	NUTRIENTS								
	N	P	K	S	Ca	Mg	Cu	Zn	Mn
				(kg)				*(g)*	
Wheat	23	3.0	5	2	0.4	1.3	7	16	40
Lupins	57	4.5	10	4	2.5	2.7	8	32	16
Sunflower	26	4.1	8	4	2.0	2.5	10	25	15
Medic Hay	30	3.0	25	2	9.0	3.7	8	20	15

Figure 1:
The cumulative sum of the difference between each year's rainfall and the long term average annual rainfall in a region beyond Goyder's Line in South Australia from 1858-1990.



Dry matter kg/ha								
Wheat	-	300	800	2100	2800	2400	700	9100
Medic pasture	-	1000	1700	1500	2100	1000	-	7300

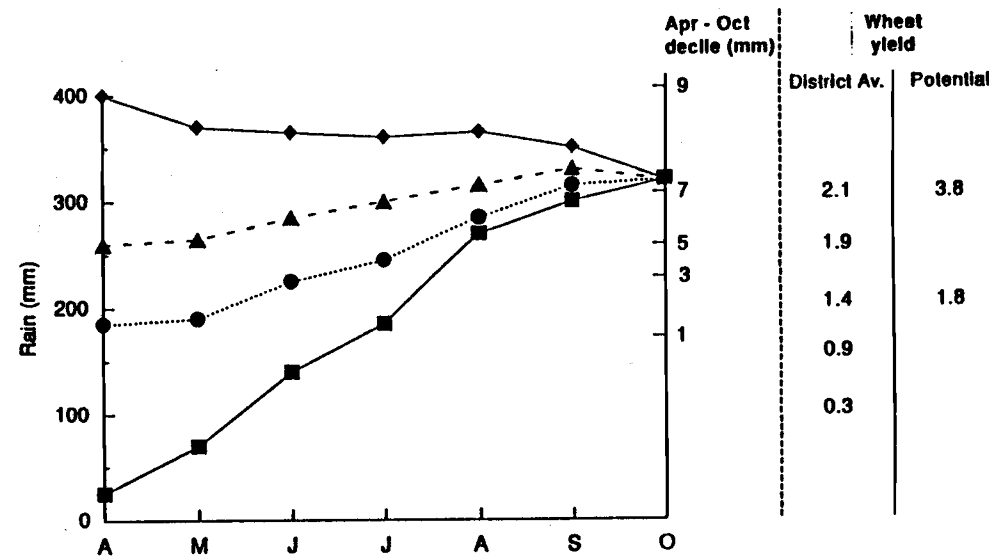


Figure 2: Examples of simplified climatic models to assist farmers in making decisions during the growing season:

(a) graph of the decile rainfall trend derived from cumulative rainfall to each month, plus decile 9 (*), decile 5(D) and decile 1(O) rainfall for the remaining months of the growing season; and

(b) graph showing the relationship between monthly evaporation, 0.2 x evaporation, rainfall and dry matter production for both wheat and medic pasture.

APPENDIX

Average monthly rainfall, evaporation and maximum and minimum daily temperatures for a range of sites near the cropping/pastoral zone in different states.

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Sth Aust.													
Minnipa													
Rain (mm)	13	20	16	20	39	46	48	47	35	28	22	18	352
Evap^n (mm)	350	300	240	160	110	70	75	105	140	200	270	330	2340
Max. Temp ^oC	31	32	28	24	20	16	16	17	20	24	27	30	24
Min. Temp ^oC	15	16	14	12	9	7	6	7	8	10	12	14	11
Hawker													
Rain (mm)	19	20	15	21	32	40	34	33	27	23	23	19	306
Evap^n (mm)	380	300	280	185	120	70	75	105	160	260	310	360	2700
Max. Temp ^oC	34	33	30	25	20	17	16	18	21	25	29	32	25
Min. Temp ^oC	18	18	15	11	7	4	4	4	6	10	13	15	10
Yunta													
Rain (mm)	20	21	14	17	22	22	16	19	18	22	20	19	233
Evap^n (mm)	380	340	260	180	120	55	65	100	170	240	320	360	2600
Max. Temp ^oC	33	33	29	24	19	16	15	18	21	25	29	31	24
Min. Temp ^oC	15	15	13	9	6	4	3	4	6	9	11	14	9
West. Aust.													
Merredin													
Rain (mm)	12	14	23	21	38	52	49	37	23	18	13	12	312
Evap^n (mm)	380	330	300	170	100	70	70	80	120	200	280	370	2470
Max. Temp ^oC	34	33	30	25	20	17	16	17	21	24	29	32	25
Min. Temp ^oC	17	17	15	12	8	6	5	5	6	8	12	15	11

S/Cross Rain (mm)	14	20	21	21	34	41	38	30	19	16	15	11	280
$Evap^n$ (mm)	400	330	280	210	125	80	70	100	140	230	270	360	2600
Max. Temp °C	35	34	31	26	21	17	16	18	21	26	29	33	26
Min. Temp °C	18	17	15	12	8	6	5	5	6	10	13	16	11

	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**YEAR**
N.S.W **Pooncarie** Rain (mm)	20	21	19	17	27	23	22	23	23	25	21	20	261
$Evap^n$ (mm)	365	295	240	160	100	60	75	100	150	215	270	335	2360
Max. Temp °C	34	33	30	25	20	17	16	18	22	25	29	31	25
Min. Temp °C	19	18	15	11	8	5	5	6	8	12	13	16	11
Trangie Rain (mm)	58	54	50	35	37	35	34	32	31	46	45	36	493
$Evap^n$ (mm)	280	235	220	125	80	55	70	90	125	165	240	315	2000
Max. Temp °C	33	32	29	25	20	16	15	17	20	25	28	32	24
Min. Temp °C	18	19	15	11	8	4	3	4	6	10	13	16	11
Cobar Rain (mm)	55	41	38	25	36	24	28	33	25	36	34	36	411
$Evap^n$ (mm)	340	270	260	140	105	65	75	110	150	200	280	360	2350
Max. Temp °C	34	33	30	25	20	16	16	18	21	26	29	32	25
Min. Temp °C	20	20	17	13	9	6	5	6	9	12	16	19	13
Moree Rain (mm)	76	65	51	31	42	25	45	37	35	52	51	62	572
$Evap^n$ (mm)	270	220	210	150	100	60	75	90	130	200	250	300	2050
Max. Temp °C	33	33	31	27	21	19	18	19	23	27	30	33	26
Min. Temp °C	20	20	17	12	8	5	4	5	8	13	15	18	12

Walgett Rain (mm)	65	57	42	32	39	37	32	29	28	39	40	40	480
Evap^n (mm)	320	250	220	160	110	70	80	95	150	195	270	330	2250
Max. Temp ^oC	35	34	32	28	22	19	18	20	24	28	32	34	27
Min. Temp ^oC	21	20	17	13	9	6	4	6	9	13	16	19	13
Qld **Dalby** Rain (mm)	84	76	67	36	35	41	42	30	39	57	74	93	674
Evap^n (mm)	210	190	170	130	110	70	75	105	120	170	190	240	1780
Max. Temp ^oC	32	31	30	27	23	19	19	20	24	27	30	31	26
Min. Temp ^oC	19	18	17	13	9	6	4	6	9	13	16	18	12

	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**YEAR**
Roma Rain (mm)	83	75	65	33	37	36	39	27	33	50	55	69	602
Evap^n (mm)	245	185	170	140	90	70	70	110	140	190	220	280	1910
Max. Temp ^oC	34	34	32	28	24	21	20	22	26	30	33	34	28
Min. Temp ^oC	21	20	18	14	9	6	4	6	10	14	17	19	13
Charleville Rain (mm)	74	68	67	32	34	20	27	21	21	40	40	54	498
Evap^n (mm)	300	270	230	175	110	80	85	130	165	225	270	350	2390
Max. Temp ^oC	35	34	32	28	23	20	19	22	26	29	33	35	28
Min. Temp ^oC	21	21	19	14	9	5	4	6	10	14	18	20	13

SOURCE: Bureau of Meteorology - Climatic Averages and Climatic Atlas of Australia (1988)