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By: M.D.A. Bolland, R.D. Fletcher and D.A. Collins
Editor: D.A.W. Johnston

Summary

Various cultural practices aimed at improving the use of rain for grain production of wheat and barley were studied in experiments for five consecutive years (1979-1983) on Kumarl red-brown clay loam soils near Salmon Gums, Western Australia. The water-holding capacity of these soils, and their location in a low rainfall area (< 325 mm/a), combine to make them marginal for producing grain. In contrast to sowing wheat on ley pasture, mechanically fallowing the year before planting (July to September, depending on rainfall) markedly improved grain yields by 1.3 to 4 times. This was because the long fallow allowed for more water to be stored at depth in the soil and this water was available to crops in the following year. For both long fallowed and non-fallowed Kumarl soil, furrow seeding of wheat, five methods of sowing wheat or barley in an attempt to plant as early as possible after the start of the winter-growing season, and the use of various seeding densities of wheat, did not significantly improve yields above the normal "conventional" sowing procedures. The earlier seeded crops always showed the greatest potential for producing grain. However, in all years these crops rapidly dried-off because of a water shortage before all the grain was produced and also because of poor weed control. The yield potential was never realised. For each day the sowing of wheat was delayed on both long fallowed and non-fallowed soil, a yield depression of between 1 and 4% resulted.

We conclude that, in comparison to the "conventional" method of sowing wheat or barley on Kumarl soil at Salmon Gums, seeding rates of about 70 kg/ha on soil fallowed the previous year using mechanical cultivation for weed control, should increase yield from cereal grain production between 1.3 and 4 times. Using this technique, relatively greater yield increases occurred in the drier years and years with below average September rainfall and this should result in substantial increases of farm income from wheat in poorer seasons than might otherwise have been obtained.

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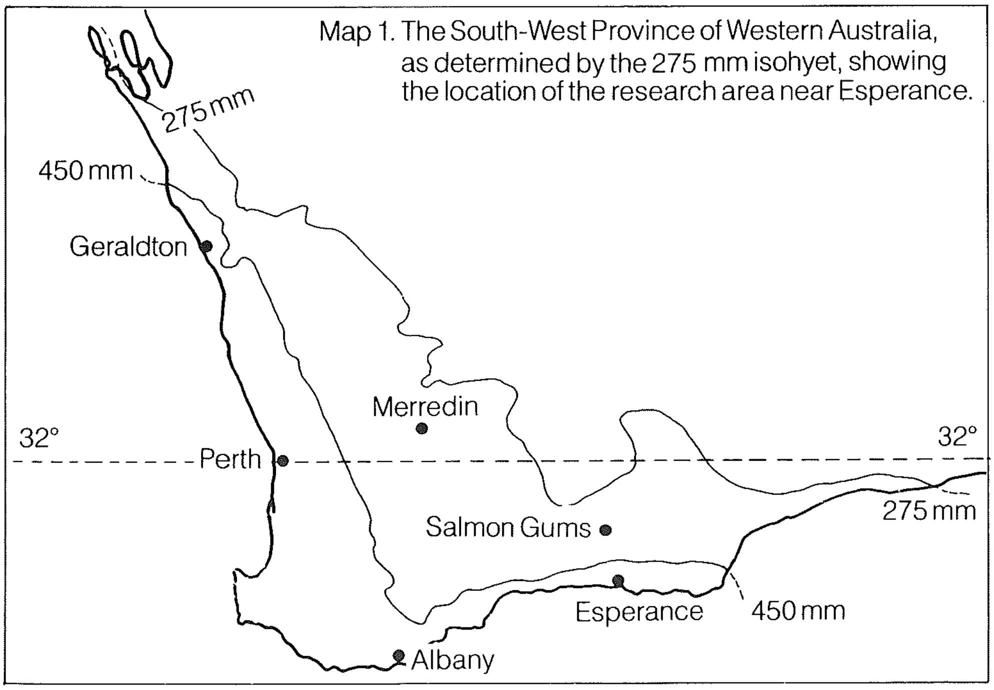
Introduction

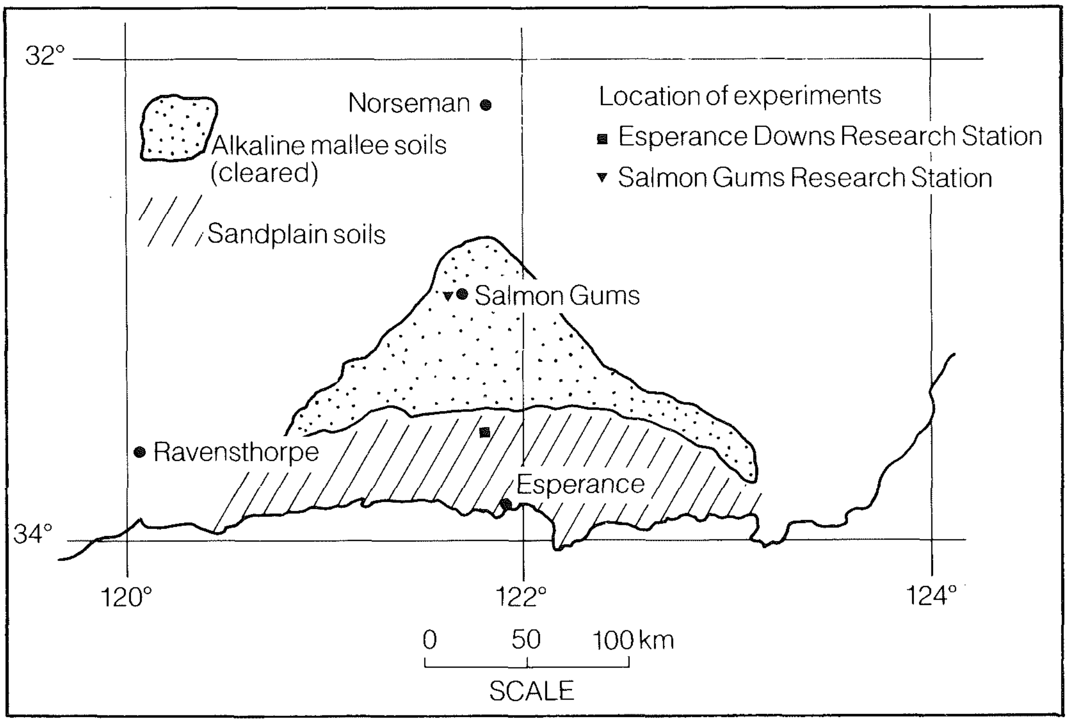
The Kumarl clay loam soils (Burvill 1936, 1986/87) near Salmon Gums, 100 km north of Esperance in south-western Australia (map 1), are relatively fertile soils in the virgin state and were cleared and developed for farming in the 1920s. The area (figure 1) has an average annual rainfall of 330 mm, with about 200 mm (60% of the annual average) falling in the winter growing season of about four months (early-May to early-September). In contrast to the sandy soils of the Circle Valley series (Burvill 1936), the Kumarl soils contain 20-30% clay and have much higher water-holding capacities. However, when compared with the sandier soils, the Kumarl soils adsorb water more strongly and a relatively larger proportion of the soil water content is unavailable to the plant. Low rainfall and soil type combine to make these soils of marginal use for agriculture.

The main agricultural enterprises of the area are wheat, barley and wool. Farmers generally sow cereals on these soils in a one year crop:two-three year pasture ley rotation, using methods largely developed from experiments in the 1920s and 1930s on newly cleared soils on Salmon Gums Research Station (Thomas and Seinor 1929, 1932 and 1933). The pastures are ploughed about 7 d after the break to the season, and 10-14 d later the seed is sown at 40 kg/ha with a tyned combine seeder. This method is called "conventional" seeding. Some farmers fallow these soils in July to September, depending on rainfall after sowing their current year cereal crops and this is called the "long" fallow. Alternatively, other farmers fallow after harvest when suitable rains have occurred from November to March and this is called the "opportunity" or "short" fallow. Before the commencement of this research in 1979, the effect of these times of fallow on grain yields was not known.

The development of herbicides and minimum tillage methods of seeding crops provide alternative ways of fallowing the Kumarl soils and of seeding cereal crops. Herbicide use and minimum tillage methods of sowing crops may enable crops to be sown earlier, which may or may not increase yields of grain. Fallow experiments on similar soils at Merredin (Tennant 1980) showed that grain yields about doubled in dry seasons as a result of a long mechanical fallow compared with crops planted on non-fallowed soils. However, these results cannot be confidently applied to Salmon Gums because of the varying rainfall distribution at both locations. There is more summer rainfall at Salmon Gums, about 40% of the



Map 1. The South-West Province of Western Australia, as determined by the 275 mm isohyet, showing the location of the research area near Esperance.



Map 2. Location of experiments, 1979 to 1983.

total annual average, compared with 29% at Merredin. The Kumarl soils at Salmon Gums have received large dressings of superphosphate since the 1920s and 1930s. Moisture is considered to be the major factor limiting yields of cereal grain. There do not appear to be any nutrient, disease or insect problems. The Kumarl soils have uniform properties (table 1), but vary in micro-relief. Depressions or "crab" holes are common. These depressions trap moisture and, particularly in dry years, produce impressive looking cereal crops and good grain yields (at least 1 t/ha).

The aim of the research was to determine whether significantly improved yields of wheat or barley grain could be obtained from different cultural practises aimed at making the maximum use of rain on the Kumarl soils at Salmon Gums.

Table 1. Some properties of the top 10 cm of the Kumarl soil and the Circle Valley sand

Soil property	Kumarl soil*							Circle Valley sand
pH:								
a) 1 : 5 soil : water (w/v)	8.2	8.3	8.6	8.4	8.2	8.6	8.4	7.1
b) 1 : 5 soil : 0.01M $CaCl_2$ (w/v)	7.7	7.6	8.0	7.8	7.7	7.9	7.6	6.5
	2 mm fraction							
Mechanical analysis:								
Sand (%)	59.3	55.1	67.6	50.9	53.1	56.8	63.3	9.0
Silt (%)	7.0	10.0	14.0	14.0	12.0	10.0	11.0	3.0
Clay (%)	32.0	33.0	17.0	33.0	37.0	31.0	24.0	7.0
Organic carbon (%)**	1.35	1.43	2.04	1.41	1.11	1.39	1.31	0.92
Total nitrogen (%)	0.10	0.10	0.11	0.11	0.08	0.11	0.10	0.06
Cation exchange capacity (m.e./100g)+	27.4	28.0	17.8	28.4	25.8	28.3	25.0	4.3
Exchangeable cations (m.e./100g)+								
Calcium	15.9	13.2	7.0	16.9	12.9	14.2	13.2	NM#
Magnesium	9.2	10.3	6.7	8.6	8.6	9.2	7.2	NM
Potassium	1.4	1.7	1.3	1.8	1.3	1.6	1.5	NM
Sodium	2.3	2.9	2.8	2.3	1.5	2.6	1.8	NM

* The Kumarl soils vary visually. The table lists properties of a range of these soils upon which the experiments were situated for the five years to indicate that they are essentially similar.

** Walkley and Black (1934)

+ Extracted in 1 M NH_4Cl at pH 8.5

Not measured

Materials and methods

The soils are brown calcareous earths of the Kumarl series, principally Gc 1.12 and Gc 1.22 (Northcote 1979). Some properties of the top 10 cm of soil collected from some of the experiments are listed in table 1.

The 'methods of sowing' experiments were sited each year on both the Kumarl clay loam and Circle Valley sand (Burvill 1936). The latter soil is a shallow sand over a hard-setting loamy soil over a mottled yellow clay subsoil (Dy 5.43, Northcote 1979). Some properties are listed in table 1.

The long term average monthly rainfall and actual rainfall recorded at Salmon Gums Research Station is shown in figure 1. The average rainfall during the "winter" growing season is about 200 mm/a. Daily rainfall and average monthly temperatures during the five year period of the experiments are shown in figure 2. The winter distribution of the rainfall and monthly rainfall are shown in table 2. In comparison to the mean rainfall, the experiments were conducted in relatively dry years in 1980 and 1981, and the September rainfall was very low in 1980, 1981 and 1982, a crucial period when grain is being developed.

There were five experiments on a new site each year from 1979 and 1983. A randomized block design with four or five replications was used.

Apart from experiment 1 (fallow), the other four were on a non-fallowed or a long-fallowed site each year. For the latter, the experimental areas were fallowed in July-September (depending on rainfall) of the year previous to sowing. The pasture was killed by ploughing,

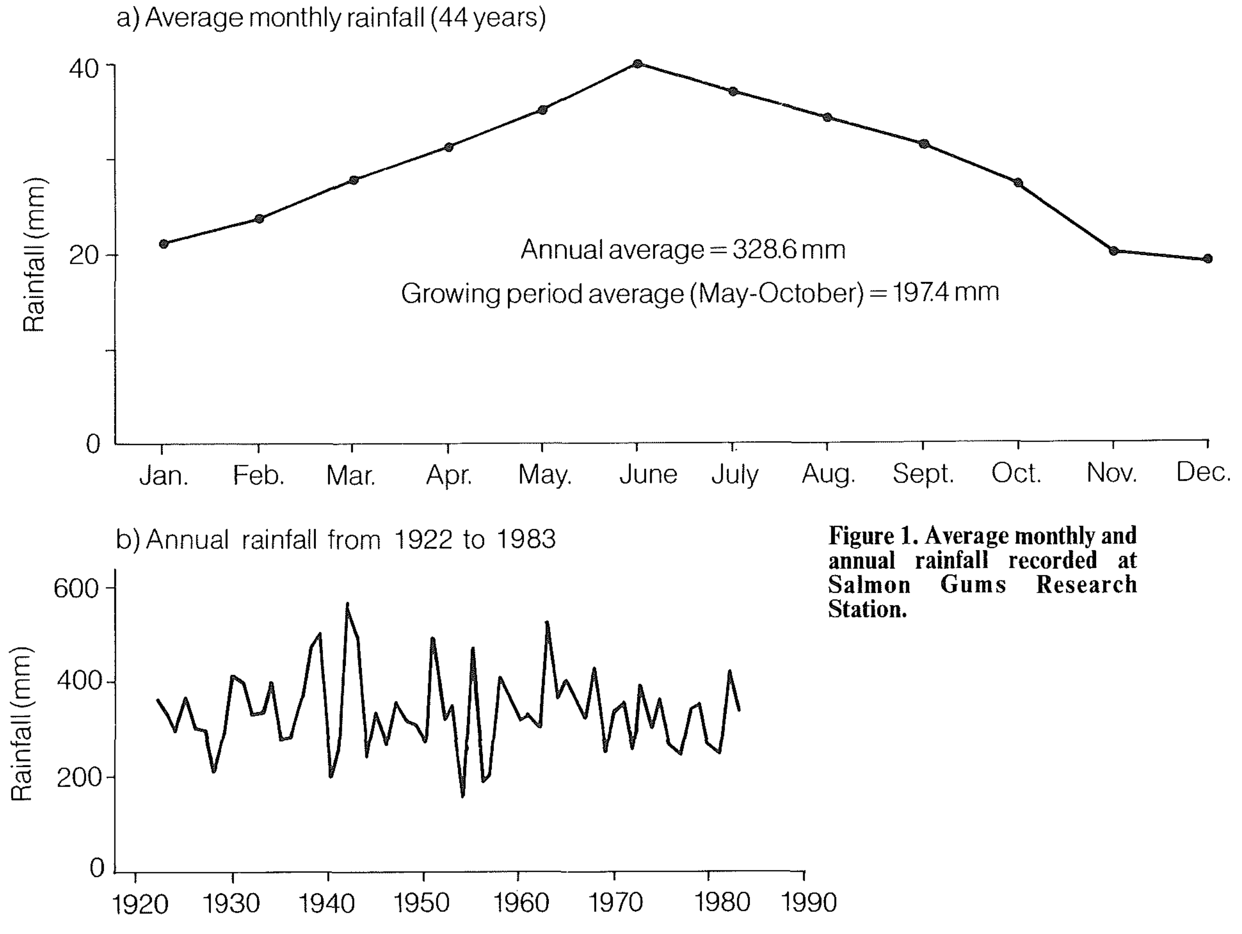


Figure 1. Average monthly and annual rainfall recorded at Salmon Gums Research Station.

Figure 2. Daily rainfalls and monthly mean temperature measured on Salmon Gums Research Station for each of the five years of the experiments.

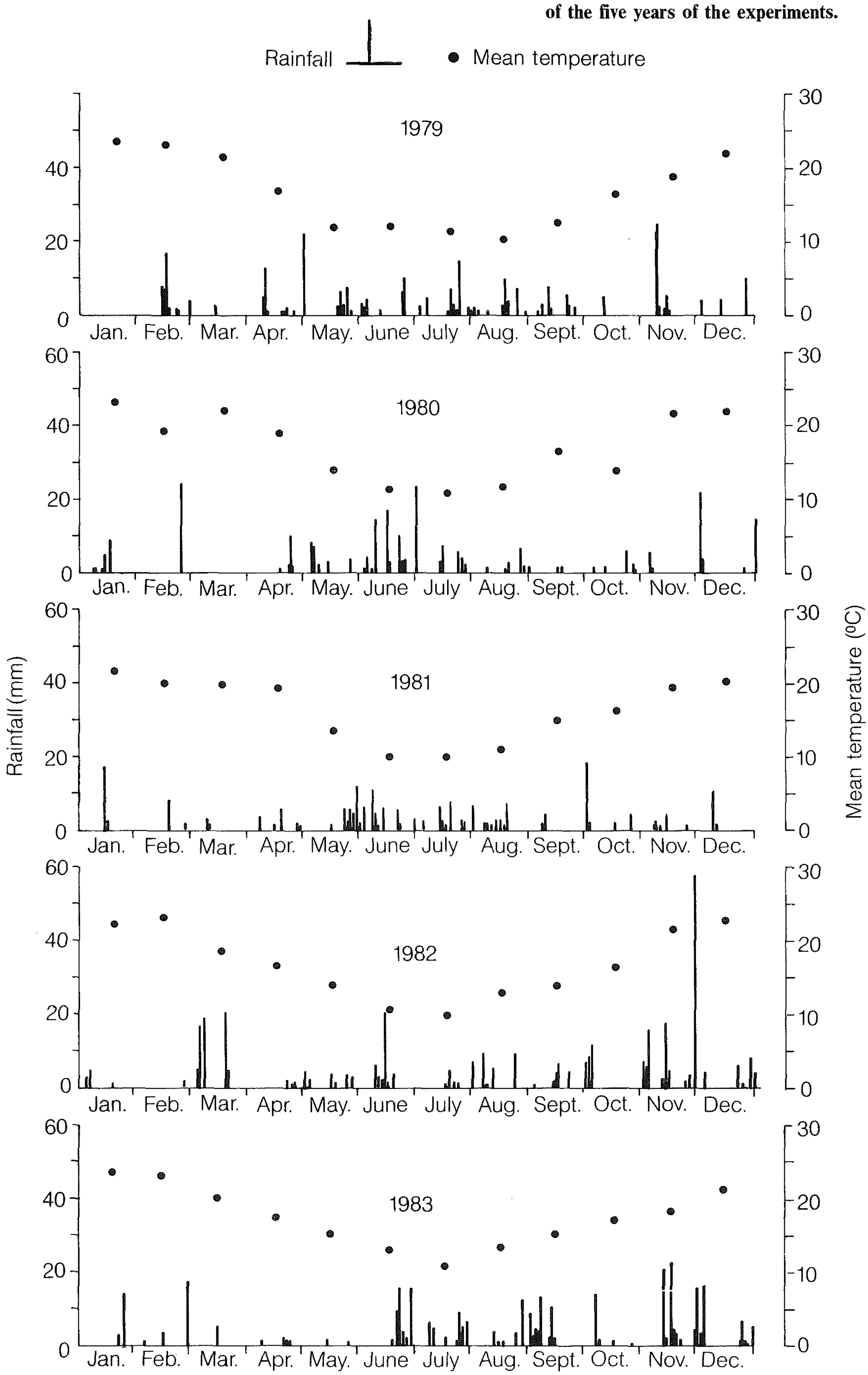


Table 2. Rainfall for 1979 to 1983.

Month	Year					Long term average
	1979	1980	1981	1982	1983	
January	0.0	17.6	21.0	9.0	16.6	21
February	43.9	24.9	10.9	2.6	21.6	24
March	3.8	0.4	5.6	66.6	7.4	24
April	22.1	15.2	14.0	5.3	7.0	25
May	(47.8	25.3	34.2	20.4	3.0	34
June	(40.0	83.4	43.0	38.3	51.6	42
July	*(38.8	24.2	27.2	3.7	39.6	36
August	(31.3	15.4	28.4	35.9	23.0	34
September	(25.8	3.4	7.0	19.8	47.8	30
October	6.2	13.0	25.5	27.4	17.2	28
November	57.4	6.4	10.6	116.8	55.8	22
December	18.4	42.1	12.0	25.1	54.8	18
Total	335.5	271.3	239.4	370.9	345.4	337
May to September* Rainfall	183.7	151.7	139.8	118.1	165.0	176
Per cent of total	54.8	55.9	58.4	31.8	47.7	52.2

followed by scarification (using a tyned implement) to kill subsequent germinations of pasture. Experiment 4 was on Kumarl soil and on non-fallowed Circle Valley sand. The latter soil has a light surface texture and, if fallowed, is susceptible to severe wind-erosion.

Weed control was achieved by cultivation except for experiment 4. This involved ploughing about 7 d after the break to the season to kill the germinating pasture, followed 10 d later by a further cultivation using a tyned implement.

Experiments 1, 2, 3 and 5 were sown to wheat (*Triticum aestivum* cv. Madden), and experiment 4 to both wheat (cv. Madden) and barley (*Hordeum vulgare* cv. Clipper). The plots were sown using a 12-row tyned combine. About 110 kg/ha superphosphate (9.1% total P, 11% S) was drilled with the seed. The sowing depth was 2-3 cm and the amount of seed sown was about 50 kg/ha. Annual ryegrass (*Lolium rigidum*), barley grass (*Hordeum* sp.), wild turnip (*Brassica tournefortii*), wild mustard (*Sinapis arvensis*), capeweed (*Arctotheca calendula*), annual medics (*Medicago* sp.), which germinated after the crop was sown, were killed by spraying with herbicides.

Grain was harvested from all plots after the plants had dried-off and grain moisture content was <12%. Small plot harvesting machines were used to harvest the plots. From each 12 row plot with rows 17.5 cm apart the middle 8 rows were harvested. In the 4.2 m wide plots, 24 rows were seeded 17.5 cm apart. The middle 20 rows were harvested leaving the 2 buffer rows on either edge of the plot. Harvesting details for the 'furrow seeding' experiment (experiment 2) are described separately.

Experiments

1: Fallowing (wheat)

Subsoil moisture was conserved by killing the pasture for different periods of time before sowing wheat. The grain harvested from these fallow treatments were compared with yields from "conventional" and minimum tillage seeding methods on ley pasture. There were seven treatments comprising five methods of fallow preparation compared with conventional and minimum tillage seeding techniques on a pasture ley. The treatments were replicated five times (table 3). Plot dimensions were 4.2 m wide and 60 m long with 0.8 m buffers between each plot. Pastures were killed either by cultivation using a tyned implement (mechanical fallow), or by a herbicide spray of 2-3 L/ha Spray.Seed® (chemical fallow) (table 3). The plots were subsequently cultivated or sprayed respectively as required to ensure 100% weed control.

2: Furrow sowing (wheat)

To measure the effect of furrow sowing the seed was either deposited at the base of the furrow (furrow seeding), or in the mound of soil between the furrows (conventional seeding, figure 3). Rainwater lay above the seed in the furrow seeded treatments and it was thought that this may improve yields in dry years. There were ten treatments and four replications in 1979, 12 treatments and four replications in 1980 and 1981, and eight treatments and four replications in each of the years 1982 and 1983 (tables 4 and 5). Plots were 2.1 m wide and 60 m long, with 0.8 m wide buffers between each plot. A 12-row tyned drill was used for all treatments. For furrow seeding, the rear cultivating tynes were

Table 3. Grain yields of wheat for experiment 1 (fallow) on Kumarl soil

Treatment	Year 1980##	1981	1982	1983
	Yield (kg/ha)			
Pasture key				
a) crop sown conventionally*	463	364	109	1 123
b) crop sown by "minimum tillage"**	278	166	—	—
Long mechanical fallow+	710	748	426	1 447
Short mechanical fallow+	433	689	266	1 221
Long chemical fallow#	562	266	145	1 139
Short chemical fallow#	428	352	224	1 112
Long fallow (mechanical and chemical)**	—	—	96	1 510
LSD ($P<0.05$)	152	179	173	236

* Plots scarified (using a tyned implement) twice before sowing using a tyned seeder, with 10.2 cm wide points on the seeding and rear cultivating tynes.

** Plots sprayed with 1 to 2 L/ha Spray.Seed® to kill weeds, and sown with a tyned seeder with 4 cm wide points on the seeding tynes and no front or rear cultivating tynes.

\+ Pasture killed using a tyned implement the previous July-September, depending on rainfall, for the long fallow, or during the previous summer (short fallow), and subsequent germinations killed using a tyned implement. Plots sown using a tyned seeder, with 10.2 cm wide points on the seeding and cultivating tynes.

\# As for mechanical fallow, but pasture initially killed, and any subsequent germinating weeds killed by using 1 to 2 L/ha Spray.Seed® .

*** As for long mechanical fallow, but subsequent germination, after initial mechanical cultivations, was killed using 1 to 2 L/ha. Spray.Seed® .

\## Fallowed 1979, plots sown 1980.

removed from the drill so that the seed deposited by the seeding tynes remained in the furrow made by the seeding tynes (figure 3). Two row spacings were used; 17.5 cm between rows (12 rows seeded per plot) and 35 cm between rows (six rows per plot). In one treatment for each row spacing, the furrows were compressed by trailing V-shaped pieces of angle iron behind each seeding tyne and placing a weight on these pieces of metal. The aim was to compact the soil on the sides of the furrows so that rainwater shed into the middle of the furrow over the seed (figure 3). There were two sowing rates, 25 and 50 kg/ha for both 17.5 and 35 cm row spacings.

For plots sown with 17.5 cm row spacings the middle eight rows were harvested, leaving two buffer rows on either edge of the plot. In plots sown with 35 cm row spacings, the middle four rows were harvested, leaving one buffer row on each edge of the plot.

3: Seeding rates (wheat)

To determine the optimum sowing density for wheat ten seeding rates were compared. These were 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 kg/ha with four replications. The plots were 2.1 m wide and 60 m long.

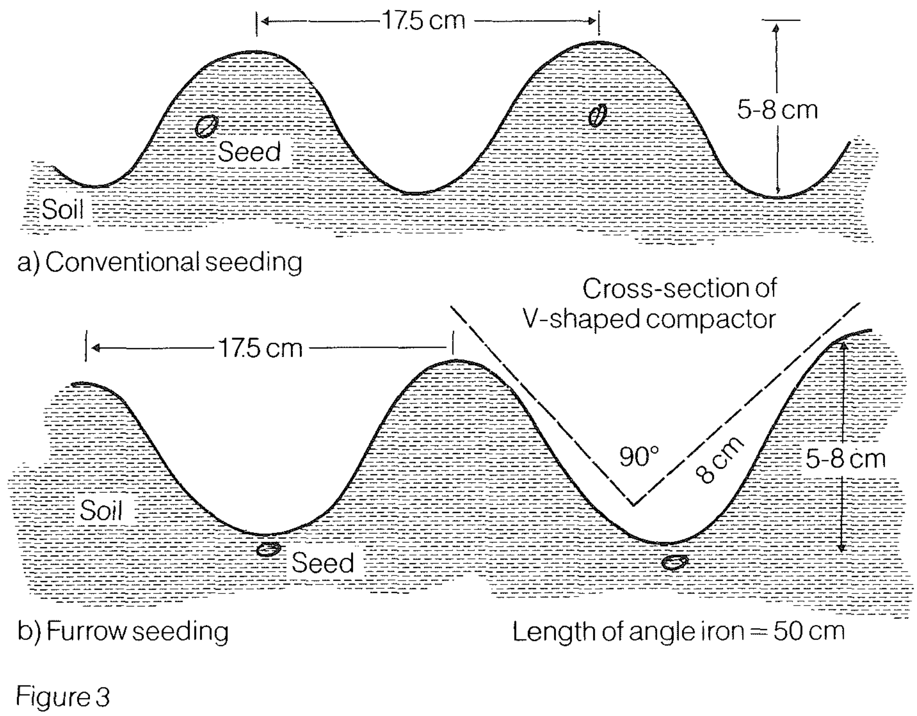


Figure 3. Cross-section of plots to show location of seed sown conventionally (a), and by furrow seeding (b).

4: Methods of sowing (wheat and barley)

To test if methods which sow wheat or barley earlier than "conventional" seeding techniques improve yields because of the slightly longer growing season, five methods of crop establishment were compared. In one treatment, the crop was sown when the germinating pasture plants were at the cotyledon stage. In this case, seeding and weed kill were attempted as soon as possible in one operation. Other treatments involved using Spray.Seed® at 1 to 2 L/ha to kill the germinating pasture. The crop was then planted in one of three ways:

* With normal 10.2 cm wide points on the seeding and cultivating tynes;
* With narrow seeding points, 4 cm wide on the seeding tynes and no front and rear cultivating tynes and
* With a triple-disc drill.

Control plots were 4.2 m wide and were sown conventionally (see Introduction). All other treatment plots were 2.1 m wide. The length of all plots was 60 m.

Table 4. Grain yields of wheat for experiment 2 (furrow sowing) on non-fallowed Kumarl soil for seeding rates of 25 and 50 kg/ha

Treatment	Year 1979		1980		1981		1982		1983	
	Seeding rate (kg/ha)									
	25	50	25	50	25	50	25	50	25	50
	(Yield kg/ha)									
Conventional seeding* with harrows	402	350	242	267	131	96	748	791	848	856
Conventional seeding* without harrows	—	—	252	354	63	103	552	690	846	799
Furrow seeding#:										
17.5 cm space between rows uncompressed	352	323	215	315	77	77	—	—	—	—
17.5 cm space between rows compressed	404	341	233	237	143	150	—	—	—	—
35 cm space between rows uncompressed	225	356	237	277	108	98	546	577	852	904
35 cm space between rows compressed	350	248	219	288	145	119	604	571	723	796
LSD ($P<0.05$)	188		125		63		193		343	

* Sown with a tyned drill with rear cultivating tynes. Row space = 17.5 cm.

\+ Sown with a tyned drill, but without rear cultivating tynes or harrows behind the drill so that seed deposited in the soil in the middle of the furrows (figure 1). Furrows were either uncompressed or compressed using a V-shaped piece of angle iron trailing behind the seeding tynes. A 360 kg weight was placed over all the compressors.

\# Seeding rate adjusted to give required rate/ha

Table 5. Grain yields of wheat for experiment 2 (furrow sowing) on long fallowed Kumarl soil at seeding rates of 25 and 50 kg/ha

Treatment	Year 1979		1980		1981		1982		1983	
	Seeding rate (kg/ha)									
	25	50	25	50	25	50	25	50	25	50
	Yield (kg/ha)									
Conventional seeding* with harrows	294	244	417	483	517	466	717	731	1 058	1 216
Conventional seeding* without harrows	—	—	413	354	468	337	733	745	1 083	1 063
Furrow seeding+ #:										
17.5 cm space between rows uncompressed	317	240	438	344	435	253	—	—	—	—
17.5 cm space between rows compressed	356	281	390	384	386	466	—	—	—	—
35 cm space between rows uncompressed	331	396	352	436	403	445	704	646	958	1 290
35 cm space between rows compressed	358	271	498	469	330	515	658	760	848	1 233
LSD ($P<0.05$)	129		164		306		289		235	

* and + See footnote to table 4
\# See table 4

5: Time of sowing (wheat)

Yield losses resulting from delays in seeding were measured. There were 11 times of seeding and four replications. Seeding commenced shortly after the first rains of the winter growing season and the other treatments were seeded at about weekly intervals thereafter, depending on rainfall (tables 10 and 11). Plots were 2.1 m wide and 60 m long.

Results and discussion

Fallow experiments

The long mechanical fallow i.e. fallowing the soil the year (July-September) before sowing, markedly increased yields on the Kumarl soil, by between 1.3 to 4.0 times, with the largest increases occurring in the dry crop years of 1980 and 1981 and again in 1982 when the September rainfall was low (table 3). Using chemicals to kill the pasture for the long fallow was not as successful as mechanical weed control. The reasons for this are not known. Perhaps cultivation of the soil facilitates penetration of the rain to lower soil profiles, minimising losses by evaporation. Short (i.e. summer) chemical or mechanical fallows did not significantly ($P > 0.05$) improve yields over the pasture ley treatment.

Furrow seeding

Compared with the conventionally sown treatments, furrow seeding did not significantly ($P > 0.05$) improve yields of wheat in any of the years for both non-fallowed (table 4) and long fallowed (table 5) soil. There was probably no advantage to be gained from furrow seeding because the rain may have wet all the top soil, including the soil in the ridges between the furrows.

Seeding rates

Farmers at Salmon Gums usually sow their crops on Kumarl soils at seeding rates of about 40 kg/ha. Maximum grain yields for the experiments on non-fallowed Kumarl soil (table 6) were produced from seeding rates of between 50 and 90 kg/ha in 1980 and between 60 and 100 kg/ha in 1983. However, there was no significant difference ($P > 0.05$) for seeding densities in excess of 20 kg/ha in 1982, or for any of the seeding rates in 1979. For the experiments on long fallowed Kumarl soil, significantly greater yields ($P < 0.05$) were measured in 1983 for seed sown at rates of between 50 and 90 kg/ha. In other years however, there was no significant ($P > 0.05$) difference in yields measured for any of the seeding rates (table 7).

Methods of sowing

The treatment planted shortly after the break to the season was seeded 7-14 d before the other five treatments (tables 8 and 9) and the conventionally sown plots were usually sown last, up to 5 d later than any of the other treatments. For the experiments on non-fallowed soil, yields of grain were similar, irrespective of whether the crop was wheat or barley, or how the crops were sown (table 8). The exceptions were the treatments sown using Spray.Seed® herbicide and the triple disc drill in 1983, which produced only about one-third the yields of the other treatments and the 1980 barley yields, which were only 60% of the wheat yields. For the experiments

Table 6. Grain yields of wheat for experiment 3 (seeding rates) on non-fallowed Kumarl soil

Seeding rate (kg/ha)	Year 1979	1980	1982	1983
	Yield (kg/ha)			
10	179	121	158	510
20	152	161	294	723
30	223	161	308	650
40	204	250	333	815
50	198	298	288	800
60	140	309	346	1 015
70	106	304	317	996
80	104	373	317	1 156
90	148	377	341	1 019
100	117	336	350	1 067
LSD ($P<0.05$)	83	81	75	113

Table 7. Grain yields of wheat for experiment 3 (seeding rates) on long fallowed Kumarl soil

Seeding rate (kg/ha)	Year 1979	1980	1982	1983
	Yield (kg/ha)			
10	271	619	404	1 040
20	179	750	396	967
30	146	704	392	1 098
40	152	819	429	1 233
50	194	756	467	1 452
60	129	721	435	1 302
70	202	717	525	1 667
80	133	752	377	1 630
90	123	752	404	1 646
100	96	690	408	1 433
LSD ($P<0.05$)	99	142	74	332

Table 8. Grain yields of wheat and barley for experiment 4 (methods of sowing) on non-fallowed Kumarl soil

Treatment	Year 1980		1981		1982		1983	
	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley
	Yield (kg/ha)							
Seeding on the break using a combine*	563	358	632	665	217	292	1 302	1 217
Pasture killed with Spray.Seed® **								
Sown with a combine*	436	223	807	775	285	198	1 317	1 243
Sown with a modified combine+	377	250	866	620	200	206	929	765
Sown with a triple-disc drill	381	321	545	653	277	106	244	533
Conventional seeding#	503	295	633	455	225	221	1 321	1 283
LSD ($p<0.05$)	101		275		138		477	

* 12 row combine with 10.2 cm wide points on the seeding and cultivating tynes.

** 1 to 2 L/ha Spray.Seed®

+ No front or rear cultivating tynes and narrow 4 cm wide points on the seeding tynes.

Plots scarified, using a tyned implement, to kill the germinating pasture and again cultivated 10 days later when the crop sown using a combine drill. These plots were 4.2 cm wide, all other plots were 2.1 m wide

Table 9. Grain yields of wheat and barley for experiment 4 (methods of sowing) on long fallowed Kumarl soil

Treatment	Year 1980		Year 1981		Year 1982	
	Wheat	Barley	Wheat	Barley	Wheat	Barley
	Yield (kg/ha)					
Seeding on the break using a combine*	1 152	998	889	747	260	240
Pasture killed with Spray.Seed® **						
Sown with a combine*	998	1 017	754	548	250	150
Sown with a modified combine+	927	1 058	609	590	208	144
Sown with a triple-disc drill	971	950	751	623	88	115
Conventional seeding#	1 024	872	688	435	440	294
LSD $(p<0.05)$	175		179		100	

*, **, +, #: See footnote to table 8.

Table 10. Grain yields of wheat and barley for experiment 4 (methods of sowing) on Circle Valley sand

Treatment	Year 1979		Year 1980		Year 1981		Year 1982		Year 1983	
	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley
	Yield (kg/ha)									
Seeding on the break using a combine*	417	493	990	1 104	323	156	281	250	1 021	831
Pasture killed with Spray.Seed® **:										
Sown with a combine*	409	852	904	938	242	135	617	644	1 006	858
Sown with a modified combine+	445	740	915	700	208	152	469	450	848	717
Sown with a triple-disc drill	319	317	971	1 010	238	100	325	260	740	569
Conventional seeding#	985	1 431	978	833	219	88	394	469	940	858
LSD $(p<0.05)$	289		162		71		82		113	

*, **, +, #: See footnote to table 8.

on long fallowed soil, yields of grain were similar, irrespective of the crop sown (wheat or barley), or how they were sown (table 9). The exception was in 1982, when the best wheat yields were harvested from the conventionally sown treatments, the treatments sown using Spray.Seed® and the triple disc drill yielding only about 20% of this treatment and all other treatments yielding about 50%.

For the experiments on Circle Valley sand (table 10), yields were again similar for both cereals and for all sowing procedures, with the following exceptions. In 1979, the best yields were from the conventionally sown plots which gave about double the yields of the other treatments. In 1983, yields were reduced by about 30% for the treatments using Spray.Seed® and sown with triple disc drill. Barley yields in 1981 were about half those obtained for wheat. The reasons for the above exceptions are not known.

For all three methods of sowing experiments, the plots which were seeded as early as possible near the break of the season always looked the most impressive — the plants were always at a more advanced growth stage and were taller. The consistently worst looking plots were those sown using the triple disc drill, particularly on the Kumarl soil. Penetration of the triple-disc drill into the Kumarl soil was not a problem as the treatments were sown when the soil was moist, with the exception of 1982, when the soil was very dry when sown and penetration of the soil surface by the discs was poor. However, by harvest time, yields were similar for all treatments, with the exceptions as mentioned above. For the early sown treatments in all years, potential yields of grain were generally never realised because of insufficient water for seed production (haying off). Another reason which may have reduced yield potential of grain was the presence of weeds. Barley grass (*Hordeum* sp.) invariably germinated on the earliest sown plots after the crop was sown. At present, there is no herbicide which will kill barley grass without also adversely affecting the crop. Barley grass was rarely seen in the other treatments, presumably because later cultivations or herbicide sprays before sowing successfully killed germinating barley grass seedlings.

Time of sowing

The decreases in grain yield for each day sowing was delayed for non-fallowed soil was 1.1 to 4.1% and for long fallowed soil 1.1 to 3.4% (tables 11, 12 and 13). In 1979, frost affected yields of grain. The best yields were measured for crops sown 42 d after the first sown plots, the earlier sown plots probably suffering frost damage and so yields of grain were reduced.

Table 13. Linear regression* of grain yield on days from first sowings, for experiment 5 (time of sowing) showing proportional yield losses caused by delays in sowing wheat after the break of the season.

Year	r^2	a	b	Yield loss** (%/d)
Non-fallowed Kumarl soil				
1980	0.74	544	− 5.87	1.1
1981	0.85	435	− 7.03	1.6
1982	0.86	390	−13.11	3.4
1983	0.89	978	−40.41	4.1
Long fallowed Kumarl soil				
1980	0.80	607	− 6.63	1.1
1981	0.91	1 322	−21.58	1.6
1982	0.72	537	− 8.73	1.6
1983	0.98	1 627	−55.89	3.4

* Equation fitted: y = a+ b x, where y is the yield (kg/ha) and x is the number of days from the first sowing.

** Yield loss = 100 (b/a).

Table 11. Grain yields of wheat experiment 5 (time of sowing) on non-fallowed Kumarl soil

1979		1980		1981		1982		1983	
Days sown after first sowing April 26	Yield (kg/ha)	Days sown after first sowing May 9	Yield (kg/ha)	Days sown after first sowing May 28	Yield (kg/ha)	Days sown after first sowing June 15	Yield (kg/ha)	Days sown after first sowing July 7	Yield (kg/ha)
0	247*	0	750	0	153	Apr. 2**	194	May 26 +	1 053
7	356	7	458	9	304	May 25**	111	June 27 +	1 283
14	350	14	428	16	412	June 0**	403	July 0 +	914
21	325	21	289	23	262	7	308	4	944
31	306	28	269	33	156	16	108	8	589
35	272	35	389	40	84	22	151	15	372
42	314	42	336	47	75				
49	336	49	203	54	38				
56	222	56	220	61	47				
63	0	70	161	68	0				
70	0	84	92	68	0				
LSD (P<0.05)	177		172		177		145		281

* Seed sown at 135 kg/ha on April 26, 1979.

** April 2 and May 25 were "false" breaks to the season, the season actually commenced on June 15.

\+ The season did not break until June 30, 1983, May 26 being a "false" break, and June 27 treatments were seeded dry.

Table 12. Grain yields of wheat experiment 5 (time of sowing) on long fallowed Kumarl soil

1979		1980		1981		1982		1983	
Days sown after first sowing April 26	Yield (kg/ha)	Days sown after first sowing May 9	Yield (kg/ha)	Days sown after first sowing May 28	Yield (kg/ha)	Days sown after first sowing June 15	Yield (kg/ha)	Days sown after first sowing July 7	Yield (kg/ha)
0	172	0	720	0	1 270	Apr. 2**	289	May 26 +	1 106
7	286	7	564	9	1 164	May 25**	469	June 27 +	2 086
14	186	14	397	16	915	June 0**	514	July 0 +	1 681
21	142	21	464	23	1 125	7	481	4	1 364
31	286	28	314	33	674	16	467	8	1 125
35	256	35	425	40	203	22	292	15	828
42	475	42	483	47	134				
49	400	49	195	54	134				
56	217	56	206	61	31				
63	0	70	133	68	0				
70	0	84	89	68	0				
LSD (P<0.05)	180		175		262		124		345

*, **, +; See footnote to table 11.

Conclusions

The main finding from the experiments was that grain yields of wheat were increased by between 1.3 to 4 times, by using a long mechanical fallow. Compared with crops planted conventionally without fallow, the long mechanical fallow markedly improved grain yields in the two dry years of 1980 and 1981, when the September rainfall was very low (table 2). This effect also occurred in 1982 when the September rainfall was below average, but the annual rainfall was above average. The long mechanical fallow did not significantly improve yields in 1983, an average rainfall season, but with above average September rainfall. The relative increase in income from wheat is very significant, particularly in the poorer seasons (table 14).

Increasing seeding rates of wheat from 40 kg/ha to between 50 and 100 kg/ha resulted in a doubling of grain yields in some years. We conclude that farmers should increase their seeding rates to about 70 kg/ha, thereby reaping the benefits of better grain yields in the dry years. A doubling of income from wheat grain would more than offset the cost for extra seed, particularly when the farmers on these soils generally grow their own seed.

Farmers and agricultural advisers have often speculated whether furrow seeding would markedly improve grain yields of cereals on the Kumarl soils near Salmon Gums, particularly in dry years. Our results showed no advantage for using this technique on these soils when compared with current methods.

Most farmers sow their cereals on the Kumarl soils using "conventional" practice. Those who have attempted to seed earlier have invariably failed to increase grain yields because of "haying off" of a promising crop and poor weed control. We obtained similar results in the methods of sowing experiments.

For each day delayed in seeding both fallowed and non-fallowed Kumarl soil, reductions in wheat yields of between 1 to 4% were measured. Before these experiments, such information was unknown.

Table 14. Costs, returns and profits, calculated using 1983 prices† for wheat sown by 'conventional' methods on Kumarl soil at Salmon Gums Research Station, with and without a long mechanical fallow for the years 1980 to 1983

	Non-fallow ($/ha)	Long fallow ($/ha)
Costs — estimated		
Superphosphate*	32	32
Ploughing	11	22
Sowing	11	11
Harvesting	18	18
Total	72	83
Returns (+ profit, − loss)		
1980	58 (−14)	89 (−6)
1981	45 (−27)	94 (+11)
1982	14 (−58)	54 (−29)
1983	140 (+68)	187 (+104)

* Drilled with the seed
† Prices from the 1983 Farm Budget Guide, published jointly by the Western Australian Department of Agriculture and by the Western Farmer and Grazier.

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