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DEPARTMENT OF AGRICULTURE - WESTERN AUSTRALIA

Toward better minimum tillage for south-coastal sandplain soils

W.L. Crabtree

August 1990

TECHNICAL REPORT 111

DIVISION OF RESOURCE MANAGEMENT

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WESTERN AUSTRALIAN DEPARTMENT OF AGRICULTURE

DIVISION OF RESOURCE MANAGEMENT

TECHNICAL REPORT NO. 111

TOWARD BETTER MINIMUM TILLAGE FOR SOUTH-COASTAL SANDPLAIN SOILS

W.L. Crabtree

Division of Resource Management
Department of Agriculture
Baron-Hay Court
SOUTH PERTH 6151

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C O N T E N T S

1	Acknowledgments	i
2	Abstract	1
3	Introduction	2
4	Materials and Methods	3
	4.1 Experiments conducted and why	3
	4.2 General experimental procedure & measurements	4
	4.3 Experimental tillage details	5
	4.4 Soils and climate	5
5	Results and Discussion	7
	5.1 Farmer tillage comparison experiments	7
	5.2a Agronomy experiments in 1985	8
	5.2b Agronomy experiments in 1986	9
	5.3 Late minimum tillage	10
	5.4 Effect of a short fallow on minimum tillage	11
	5.5 Deep ripping	12
	5.6 Cultivation depth while sowing	14
	5.7 Cultivation tine position	14
	5.8 Harrows	15
6	General Discussion	16
7	Recommendations	18
8	References	19
9	Publications and extension activities for project	20
	9.1 Publications	20
	9.2 Reports and proceedings	20
	9.3 Extension activities	20
10	List of experiments	21

2. Abstract

The objective of the project was to promote successful minimum tillage crop establishment practices on sandy, wind erodible soils. Some 83 experiments were conducted during the two seasons of the project's duration (1985-86). Most of the experiments were monitored for emergence, dry matter production at anthesis, grain yield and rainfall. The lack of detailed crop monitoring was a weakness in the work. However, many useful results were obtained and are summarized in this report.

In 1985, 17 farmers compared their conventional cropping practices with some form of minimum tillage cropping. Only 4 of these farmers had tried minimum tillage cropping for 2 years or more. The minimum tilled crops yielded 21% less grain than the conventionally sown crops. The reasons for these decreased yields were in most cases related to inexperienced management, with the farmers not being aware of the factors that affected minimum tillage crop yields. However, some of the farmers that were more experienced with minimum tillage had less yield reductions with minimum tillage.

The minimum tilled treatments usually had very poor weed kill strategies which often resulted in large weeds at sowing, very cloddy seed-beds, numerous insects in the young crops and in-crop weeds that could not be controlled. Generally the weeds were not controlled soon enough after germinating and were usually quite large by the time herbicides were applied. Sowing was then usually done too soon after spraying and often resulted in very cloddy seed-beds. Intact weed roots usually held the soil together during cultivation, consequently, poor "root release" was often associated with these seed-beds.

Subsequent experiments showed that minimum tillage can be improved to give grain yields similar to conventional cropping while not making the soil vulnerable to wind erosion. These good yields were achieved by:

1. ensuring the paddock was free of grass weeds in the year prior to cropping,
2. spraying weeds when small, which in some cases required an extra spray in autumn, and ensuring sufficient "root release" occurred prior to sowing,
3. applying label-rates of knockdown herbicides,
4. cultivating the soil to 10-16 cm depth before or at sowing,
5. putting the sowing tines in line with the working tines and
6. controlling insects quickly when detected (though not a problem if 1. above is adhered to).

During the project 876 farmers were contacted personally, 40 newspaper and agmemo articles were written, 8 radio talks were given, 2 video segments were contributed to, 60 groups were spoken to and 3 publications made. The above strategies for improving minimum tillage grain yields were explained to farmers through the mentioned mediums. The rate of adoption of minimum tillage for sandy soils increased during this time as can be demonstrated in part by the amount of herbicides sold in the Jerramungup district. From 1985 to 1988 knockdown herbicides sales increased from 13 000 to 37 000 L, which could translate to an increase from 21 000 to 64 000 ha cropped using some form of minimum tillage. However, it is difficult to determine how much of this increase could be attributed to the impact of this work.

3. Introduction

Severe wind erosion in the Jerramungup area over the years prompted the local Soil Conservation District Advisory Committee to seek funding for the project titled, "Conservation tillage for wind erodible soils". The project was undertaken at the Jerramungup Department of Agriculture from January, 1985 to April, 1987. The project's aim was to extend conservation tillage to farmers on wind erosion prone soils from Fitzgerald (60 km east of Jerramungup) to the South Stirlings (90 km south west of Jerramungup).

The area was first cleared for agriculture in the late 1950's. Conventional cereal cropping for the district involved planting a cereal crop after two years of clover dominant pastures. Conventional cropping being; plough twice with a single disk plough, then sow with a combine. Root rakes, rippers, scarifiers and harrows were commonly used to remove root material and rocks from the paddocks and ensure good weed control.

In the late 1970's cereal prices increased which was followed by a 50% increase in area cropped. Such an increase in cropping area was not always paralleled with larger machinery purchases. So for farmers to sow more land with existing machinery they often cultivated the soil dry and had longer fallow periods and later sowings. Together with the use of harrows and rippers and dry, windy breaks to the seasons a lot of severe wind erosion occurred throughout the district in 1980-82 (Goddard *et al.*, 1982). It was not until about 1980 that chemicals were used by some farmers in the district to control weeds.

After these bad wind erosion years many farmers attempted direct drilling (spray then seed). However, because direct drilling was a new technique and required practice to achieve good result, most farmers experienced yield reductions of up to 50% when compared to conventional cropping. Some farmers persisted with direct drilling with improved results. Many adopted a combination of spray and cultivate before sowing (minimum tillage) and some reverted back to a modified conventional program, being more conscious of the factors affecting wind erosion (Crabtree, 1986). Most farmers in the district have environmental and safety concerns about herbicide use (Goss and Fry, 1985). These concerns have had a significant affect at decreasing the rate of adoption of minimum tillage.

Since 1983, serious wind erosion has not occurred. However, farmers of the region are aware that if dry windy conditions occur again, many farmers could experience wind erosion unless excessive soil cultivation practices cease. In 1984, the Jerramungup Soil Conservation District Advisory Committee acquired funding for a three year project to:

(i) assess the performance of minimum tillage compared to conventional cropping on a farm scale on the various soil types in the Jerramungup and South Stirlings area,
(ii) identify constraints to adoption of minimum tillage,
(iii) facilitate research work or extension aimed at overcoming any constraints, and
(iv) promote minimum tillage on wind erodible soils in the area.

This report summarizes the research findings of 1985-86 into improved minimum tillage practices and suggests modifications to farmer tillage practices to ensure good results with minimum tillage.

4. Materials and Methods

4.1 Experiments conducted and why

The research component of the program consisted of 83 experiments (Table 1).

Table 1: Title, number and year of the experiments.

	Experiment	No.	Year
1	Farmer tillage comparison	17	1985
2	Late sowing	1	1986
3	Agronomy	6	1985-86
4	Fallowing	4	1986
5	Deep ripping	31	1985-86
6	Cultivation depths	4	1986
7	Cultivation vigour	4	1986
8	Seed covering implements	16	1985-86

The 17 farmer comparison experiments were conducted to determine possible farmer problems with minimum tillage techniques. These farmers compared conventional with minimum tillage cropping practices. The farmers performed these 2 cropping techniques as they thought best.

Farmers have generally experienced poorer yields from minimum tilled than conventionally sown crops, particularly when sown late in cold conditions. A late sown experiment was conducted to demonstrate the problems commonly associated with late sown minimum tilled crops. Decreased herbicide activity on weeds under these conditions can slow down the rate of weed root kill and therefore slow the release of soil bound by roots, giving large clods at sowing. These clods increase the variability of sowing depth, decrease emergence and expose weakened seedlings to insect attack.

The minimum tillage agronomy experiments were conducted to determine the best combination of sowing date, nitrogen application and degree of cultivation for improving minimum tillage yields.

The fallow experiments were conducted to see if fallowing with minimum tilled cropping could improve grain yields compared to conventional grain yields. It was thought that fallowing could have beneficial effects on minimum tillage grain yields. The known benefits of fallowing are numerous. Fallowing can: decrease insect incidence (Micheal, 1987), allow weeds to breakdown, enhance nitrogen mineralisation (Mason, 1986), decrease soil water loss, ensure a better seed-bed and possibly decrease root diseases in crop. When fallowing is done conventionally on sandy surfaced soils however, it can promote wind erosion.

Deep ripping or cultivation on sandplain soils of medium rainfall areas in Western Australia can increase cereal grain yields (Jarvis *et al.*, 1986). Deeper cultivations loosened the soil which enables plant roots to grow more rapidly in the soil and make more efficient use of fertilizer nitrogen early in the season (Delroy and Bowden, 1986). Cereal grain yield responses to deep ripping duplex soils have not been modelled. It has also been shown that minimum tillage sown plots usually have greater soil firmness with lower grain yields compared to conventional sowings (Hamblin and Tennant, 1979). Therefore a combination of deep cultivations and minimum tillage may overcome grain yield penalties associated with minimum tillage, hence, the deep ripping experiments were conducted.

The shallow duplex soils of the study area are prone to waterlogging and deep ripping will decrease trafficability which could interrupt sowing operations. Therefore a deep cultivation at sowing, using the seeding machine in a one pass operation, was thought a more practicable way of achieving soil loosening. This would ensure sowing was not delayed and resulted in the deeper cultivations at sowing experiment.

The intensity of cultivation at or prior to sowing is thought to improve minimum tillage crop establishment (E. Rowley pers comm). Perhaps this is because of improved soil loosening and a more uniform seed-bed. The tine position experiment was designed to compare the effect of the degree of cultivation on grain yield. The position and number of cultivation tines on a direct drilling machine were compared with emergence and grain yield improvements to determine the importance of degree of cultivation at sowing.

Surface soil compaction over the sown seed has improved cereal emergence on sands (Pathak *et al.*, 1976) and scratching the surface with harrows breaks down clods and kills weeds. However, harrow use has often been associated with the occurrence of wind erosion. Flexicoil land-packers, finger harrows and heavy conventional harrows are commonly used throughout the area. Flexicoil land-packers also have potential for reducing the risk of wind erosion (D. Cater unpublished data). The harrow experiments were designed to determine their effects on emergence and perhaps grain yield.

4.2 General experimental procedure and measurements

All small plot experiments (exps 2-7 in Table 1) were of complete randomised block designs and were replicated 3 or 4 times. The farmer implemented experiments of minimum tillage versus conventional sowing and the seed covering experiments had 6 replicates for all measurements, as the paired T-test was used. All experiments were sampled for; emergence 2-3 weeks after sowing, dry matter cuts at anthesis and grain yield with a machine harvester. Pesticides were applied as deemed appropriate. All the experiments were sown to either Aroona wheat (*Triticum aestivum*) or Stirling barley (*Hordeum vulgare*) at 48-70 kg/ha.

The 1985 and 1986 small plot experiments were sown with a standard 4 row combine and a modified combine respectively unless otherwise stated. The modified combine cultivated to 10 cm depth with 3 rows of tines at 18 cm spacings with 3 rear rows of shallow sowing tines also at 18 cm row spacings (it is equivalent to a Chamberlain 700 series combine). Conventional sowing refers to cultivations 21 and 7 days before sowing at 10 cm depth with a tined implement. At some sites 1.0 L/ha of Spray.Seed was sprayed before the first cultivation to ensure no transplants occurred in the plots. The minimum tillage treatments in 1986 were sprayed with 2.0 L/ha of Spray.Seed 3 weeks before sowing, the same time as the first cultivation of the conventional cultivation treatments.

For more detailed information on each experiment, including quantity of pesticide and fertilizer and the tillage dates, consult the Division of Resource Management's 1985-86 research summaries.

4.3 Experimental tillage details

The 17 farmer comparison experiments involved cropping half of a paddock with minimum tillage and the other half with conventional sowing techniques. The farmers sowed each treatment on the same day with equal amounts of fertilizer and seed and managed each section to the best of their ability. The sites were inspected several times throughout the growing season.

The late sown experiment was sown on 25 July 1986 after being sprayed with either 1.5 or 2.0 L/ha of glyphosate or Spray.Seed and 0.5 L/ha of Dicamba 0, 8, 16 or 31 days before sowing. A conventional tillage treatment (cultivated twice before sowing) and least tillage (Spray.Seed and Dicamba 31 days before sowing with seeding tines only) treatment were included. All but one of these treatments were sown with the modified combine which had heavy conventional harrows and a flexicoil trailing.

The 6 agronomy experiments (2 in 1985 and 4 in 1986) used a factorial experimental design and compared minimum tillage and conventional sowings with different sowing dates (1 vs 21 June in 1985 and June versus July in 1986) nitrogen applications (top-dressed urea at 100 kg/ha or nil) and degree of cultivation (deep ripping in 1985 or no ripping in 1986). Both of the 1985 experiments were located at Fitzgerald on J Spencers' farm, one of which did not have the nitrogen treatment included. The sites were both very water repellent (3.2 MED, King 1981) and dry when cultivated.

The fallowing experiments compared conventional fallowing with chemical (2.0 L/ha of Spray.Seed) fallowing at four, two or no weeks prior to sowing on the same day.

The 1985 deep ripping experiments compared ripping depths of 0 with 30 cm using an Agrowplow. In 1986, five depths (0, 10, 20, 30 and 40 cm) and four implements (scarifier, chisel plough, Panbreaker and Agrowplow) were compared. The experiments were located on 22 different properties and a prerequisite for site selection was that the site had been copped at least 8 times. The sites were ripped when dry in April and when wet in May-June in 1985 and 1986 respectively. They were sown perpendicularly to the ripping treatments by the respective farmers with their seed and fertilizer preferences.

The modified combine enabled a variable cultivation depth with the front 3 rows of tines while maintaining a shallow sowing depth. Six cultivation depths (0, 4, 8, 12, 16 and 20 cm) were compared with conventional sowing.

The degree of cultivation experiments compared 4 different tine configurations on the front 3 cultivating tines while using 18 cm wide points. They were: in line or off line with the sowing tines (at 18 cm spacings), 12 cm spacings of random position relative to the sowing tines or removed completely. These tillage treatments were compared with conventional sowing.

The seed covering implements were pulled behind farmer sowing equipment at or immediately after sowing and weed counts were also made.

4.4 Soils and climate

All experiments were conducted on the sandy surfaced duplex soils (Dy 4.42 and Dy 4.82; Northcote, 1979; Carder and Grasby, 1986) with the sandy A horizon usually being 10-20 cm thick. The surface soils typically have clay contents of between 1 and 6% (Crabtree 1984, R. Harper pers comm). These low clay levels are a contributing factor in enhancing these soils' susceptibility to wind erosion.

The Jerramungup climate is Mediterranean with an average annual rainfall of 405 mm (Table 2), 70% of which falls in the May to October growing season. Strong winds from April to August are often associated with cold fronts passing through the south west corner of the state. Jerramungup wind-speeds are among the highest in the state and have a high frequency of very erosive winds (P. Hanson, unpublished data).

Table 2: Jerramungup monthly rainfall (mm) for 1980-86 and long term average (1895-1987)

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1980	32	44	5	42	18	48	28	40	13	52	60	88	470
1981	19	23	3	15	69	47	19	41	23	13	23	9	304
1982	121	17	37	5	18	36	23	79	41	10	23	12	422
1983	5	47	10	19	10	97	48	43	62	38	72	126	576
1984	0	11	25	26	58	31	47	75	91	29	30	3	424
1985	16	19	24	26	35	14	91	66	61	45	38	5	441
1986	0	72	14	4	51	58	83	58	60	23	16	22	459
long term	16	20	26	32	48	49	51	44	42	35	25	18	406

Experiments 3, 4, 6 and 7 (Table 1) were conducted adjacent to each other at 4 sites in 1986. The sites were: Crabtree's, Baily's F, Baily's A and Parsons. The first 2 sites gave the best grain yields, least statistical variance and should be interpreted with more confidence than the latter 2 sites which generally gave grain yields of < 1.0 t/ha. Cereal root diseases and water repellence problems were evident at these latter sites. Poor N and K nutrition and Mn deficiency were evident at Parsons and Baily A sites. Each site was soil tested and characterized in April 1986. The results are shown as below (Table 3).

Table 3: Soil fertility for topsoil (top 10 cm) and subsoil (20-30 cm depth), soil type, site history and weed population for the experiments 3, 4, 6 and 7 at the 4 sites.

	S I T E							
	Crabtree		Baily F		Baily A		Parsons	
Particulars	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsol
Texture	1.5	1.5	1.0	1.0	1.5	1.0	1.0	1.0
%gravel	17	27	20	32	17	42	0	0
Phosphorus	9	3	25	8	18	2	19	10
N nitrate	12	7	12	3	18	6	6	3
N ammonium	5	5	8	3	6	3	4	3
Potassium	110	79	190	31	310	74	37	26
Organic C	1.11	.64	2.17	.37	1.75	.34	.77	.3
Reactive Ion	285	463	520	674	570	313	101	217
Chloride	44	15	38	12	55	13	72	26
pH	6.0	6.2	5.9	6.4	6.4	7.2	6.1	6.1
MED[A]	0.4 (low)		1.8 (moderate)		2.8 (severe)		2.4 (severe)	
Soil Type	All sites were sand over gravel over clay at varying depths							
Clay depth	21cm		39cm		48cm		42cm	
Cleared[B]	1978		1962		1962		1968	
1983	Past		Past 9 k/h P		Past 8 k/h P		Past	
1984	Barley 8 k/h P		Past 9 k/h P		Barley 8 k/h P		Past	
1985	Past		Past 9 k/h P		Lupins 9 k/h P		Past	
Weeds prior to crop in 1986	85% clover 5% capeweed 5% thistle 1% dock		40% geranium 30% capeweed 10% clover 10% grs+dock		50% clover 25% brome grs 20% ryegrass 1% sorrel		50% capeweed 25% geranium 10% brome grs 10% clover	

[A]Molarity of ethanol drop test (King, 1981)
[B]Past = Pasture; k/h = kg/ha; grs = grass

5. Results and Discussion

5.1 Farmer comparison experiments

The farmer comparison experiments demonstrated that many farmers had problems with minimum tillage crop establishment techniques. On average the minimum tilled crops gave 21% less grain yield than the conventionally grown crops (Table 4). Conventional crops generally had better emergence and grew more vigorously than the minimum tilled crops. Reasons for this varied from site to site. However, farmers that had good pre-sowing weed control and small clod size in their seed-beds had minimum tillage grain yields close to conventional yields. The 9 farmers with good minimum tillage techniques averaged only 9% less in grain yield with their minimum tillage techniques. However most crops were sown in mid-June, a month after the optimum time, and consequently yielded much less than their potential.

Table 4: Farmer grain yield results for minimum tillage versus conventional sowing and level of significance.

Site	Farmer	Crop[A] Type	Grain yield (t/ha)[B] MT	CC	MT/CC response (%)	signi - icance level[C]
1	Lynch	B	3.09	3.16	98	
2	Spencer	B	2.54	2.45	104	
3	Bryan	W	1.96	2.27	86	***
4	Shearer	B	1.70	2.03	84	**
5	Gilmore	B	1.65	2.19	75	***
6	Hick	B	1.63	1.69	96	
7	Spencer	B	1.62	1.22	133	
8	Griffiths	B	1.21	2.68	45	***
9	Deegan	W	1.11	1.23	90	
10	Edmondson	W	1.08	1.77	61	***
11	Jackmann	B	1.08	1.66	65	***
12	Dougherty	W	.92	1.12	82	*
13	Ross	B#	.85	1.04	82	**
14	Reeves	W	.83	1.67	50	***
15	Martin	W	.62	.76	82	
16	Gooch	B	.55	.72	76	
17	Keding	B#	.51	1.20	43	***

[A]wheat(W) or barley(B) and barley grain yields derived from DM(#)
[B]minimum tillage(MT) and conventional cultivation(CC)
[C]level of significance at the 5, 1 and 0.1 % level (*, ** & ***).

The most common problem experienced with minimum tillage cropping was related to poor weed control the year before and just prior to sowing. Farmers generally sprayed with knockdown herbicides when the weeds were large and then sowed too soon after (generally within a week). These large weeds had extensive root systems which were still intact at sowing. This resulted in the sowing operation leaving large clods on the soil surface (up to 30 cm in diameter). Seeds were often placed below these clods. On germination, the seedlings had to penetrate clods before reaching the soil surface.

This expense of seedling energy reserves resulted in a high seedling mortality and the surviving plants were weakened and more susceptible to insect attack. The lack of fallow on the minimum tilled treatments enabled cutworm, webworm, desiantha and red legged earth mite to survive until crop emergence. These weakened and insect damaged seedlings were less able to compete with emerged weeds. The minimum tilled treatments also had more firm soil compared to the conventionally sown treatments, which probably also slowed root growth.

Poor early vigour on the minimum tilled treatments could also have been due to the release of various phytotoxic acids (Cochran *et al.*, 1977) from the decaying organic material inhibiting plant growth on the minimum tilled treatments. This is more likely to occur if a thick mat of weeds are sprayed under cold conditions and sown soon after ($<$ 3 weeks). The insufficient plant breakdown time can decrease crop emergence and seedling death may result. This probably occurred on most sites but was clearly evident at site 10 (Table 4).

More weeds were evident in the minimum tilled crops. Most broad leaf weeds were controlled pre-sowing but no in-crop herbicides were yet available for the control of brome grass (*Bromus diandrus*), silver grass (*Vulpine myuros*) and barley grass (*Hordeum leporinum*) which often germinated in the crop. Conventional cultivation will kill 3 germinations of weeds prior to sowing which will decrease the likelihood of weeds emerging in the crop. Spray topping the pasture the year before cropping would decrease this problem.

Another possible reason for the better grain yields on the conventionally sown treatments is increased nitrogen availability for plant growth. The fallowing from early cultivations will enable mineralisation of nitrogen to occur prior to sowing which is available for crop growth (Russell, 1973). Cereals grown on south coastal sandplain soils generally respond well to nitrogen application (Mason, 1986). Since leaching rains did not occur in the early stages of crop growth during these experiments (1985) nitrogen from conventional fallowing would have been available for early crop growth. The farmers in the study applied less than the recommended amounts of nitrogen to their crops, hence nitrogen deficiency would have occurred on most of these sites, particularly in the non-fallowed (minimum tilled) treatments.

Poor crop establishment occurred at several sites due to the dry start to the season (14 mm for June, Table 2) being compounded by water repellence on some soils. Dry cultivation on water repellent soils shattered the soil structure making a "fluffy" seed-bed that was more resistant to wetting. The minimum tilled treatments wet up more evenly prior to sowing enabling better cereal emergence and in some cases better grain yield than the conventionally grown crops.

Gravelly soils in these experiments were more suited to minimum tillage than soils without gravel. Sandy soils without gravel had larger clods after a cultivation than those with gravel. The gravel stones aided the breaking up of soil clods, ensuring a better seed-bed. At gravelly sites there was little difference in grain yield between minimum tilled and conventionally grown crops.

<u>5.2a Agronomy experiments 1985</u>

Very little weed growth occurred prior to the application of knockdown herbicides and one pass of a tined implement was sufficient to prepare a "fine" seed-bed making the soil susceptible to wind erosion. The conventional treatment at both sites had lower emergence and grain yield than the direct drilled plots. The lower grain yield was related to the poor establishment caused by the dry start and water repellent soil.

Time of sowing did not affect grain yield with either tillage treatment at either site. This was probably due to the first sowing being done when the soil was more dry than at the second sowing. The knockdown herbicides (Roundup and Spray.Seed) had no effect on establishment or grain yield at either site, which was expected given that only a few small weeds were present prior to spraying.

Top-dressed nitrogen at the one site tested increased dry matter production at anthesis by 28% and grain yield at harvest by 21%. The minimum tilled plots responded better to nitrogen application than the conventionally sown plots.

Deep ripping also decreased establishment and grain yield although not significantly. Again the water repellence was the reason given for this as rain that fell channelled its way through the topsoil via ripped lines into the wearable subsoil. The soil wet up from below leaving the cultivated soil dry until the July rains.

5.2b Agronomy experiments 1986

Perhaps the most important aspect of crop agronomy is time of sowing. Unfortunately, the potential grain yields of the varieties used in these experiments were missed due to sowing one month later than is recommended (W. Smith pers comm). In these experiments, June sowing averaged 17% more grain yield than July sowing (Figure 1). At the highest yielding sites (Crabtree and Baily F) the June sowing averaged 53% more grain yield than the July sowing. Better weed control in the July sowing at the other two sites resulted in the July sowings yielding similar to the June sowings.

Top-dressed nitrogen increased grain yield on average by 32% (390 kg/ha). The average June sowings responded better with grain yield to nitrogen than the July sowings (37 versus 26 %) but were twice as responsive on the two high yielding sites (39 versus 17 %), with the earlier sowings.

Minimum tillage grain yields with the modified combine averaged 2% less than conventionally sown plots. At Crabtree's the minimum tilled plots gave 5% more grain yield than conventionally sown plots. This was in part attributed to less nitrogen leaching from the root zone on the minimum tilled plots prior to sowing as the soil was very wet from June to August.

At the Baily F site, the fungus; Rhizoctonia bare patch (*Rhizoctonia solani*), was present but was less evident in the cultivated treatments. The conventionally sown plots responded two-fold to nitrogen at the June sowing compared with the minimum tilled plots. This was probably due to the conventionally sown plants having more healthy root systems, which were more able to extract nitrogen than the Rhizoctonia damaged plant roots from the minimum tilled plots.

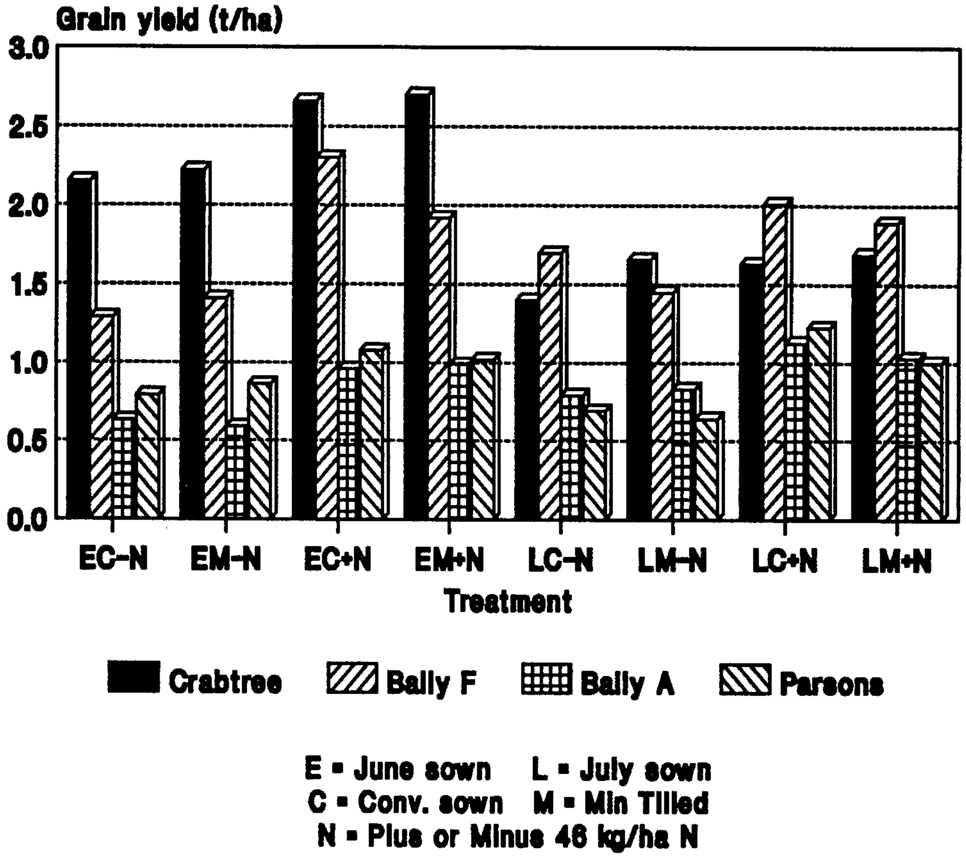

Figure 1: Effect of time of sowing (June vs July), applied nitrogen (4 weeks after sowing) and tillage on cereal grain yield. With LSD's at 5% being 0.10, 0.15, 0.06 and 0.09 t/ha respectively.

5.3 Late minimum tillage

Late sowing with minimum tillage induced a 34 to 56% grain yield penalty when compared to conventional sowing (Table 5). Poor grain yields were related to poor plant establishment ($P<0.001$) by the equation;

$$GY = 32.7 + 0.77 \times (PC) \qquad R^2 = 72 \qquad \text{eqn 1.}$$

where GY is grain yield (% of conventional treatment) and PC is plant count (plants/m^2). Poor barley emergence was empirically related to increasing size and number of soil clods. Again the soil clods inhibited barley emergence.

All treatments experienced a high seedling mortality, which mainly occurred in the first two weeks after emergence. Seedling counts were decreased by between 5 and 24% from 19 to 26 days after sowing. At 140 days after sowing even fewer plants were counted. The least number of plants were counted on the Roundup sprayed plot where a 49% reduction in plant counts was observed.

Table 5: Barley and grass plant counts and barley grain yield after various crop establishment techniques at Baily's.

Sowing Method[A]	Sprayback time[B] (days)	Plant counts (pl/m^2) barley, days after sowing: 19	26	140	grass 140	Barley grain yield (t/ha)	Response to CC[C] sowing (%)
CC	31	111	98	85	51	1.62	100
RU	31	105	83	76	106	1.36	84
RU	16	86	65	59	71	1.15	71
RU	8	75	60	46	49	1.08	67
RU	0	77	60	48	30	1.08	67
SS	31	96	80	70	101	1.07	66
SS	16	80	76	59	76	1.02	63
SS	8	76	67	57	60	1.15	71
SS	0	76	63	47	46	.79	49
SS	31	68	55	48	147	.72	44
LSD (P=0.05)		12	7	9	15		11

[A]conventional sowing (CC); Roundup and Spray.Seed (RU and SS) knockdown used.
[B]time between spraying and sowing.
[C]percent of conventional grain yield.

The Roundup sprayed plots had increasing grain yields with the increasing period between spraying and sowing. The Spray.Seed treatments had similar grain yields except for the treatment that was sown the same day as spraying. The ryegrass growth and vigour was greatest on the Spray.Seed treated plots. There was less ryegrass competition in the Roundup plots sprayed 0 and 8 days before sowing than all the Spray.Seed treated plots. This resulted in better grain yields from the Roundup sprayed plots than the Spray.Seed plots that were sown the same day as sprayed.

5.4 Effect of a short fallow on minimum tillage

Longer fallow periods generally gave better grain yields (Figure 2) and the chemical fallows gave grain yields similar to conventional fallows. A 4 week chemical fallow with a cultivation immediately before sowing yielded on averaged only 2% less than the conventional fallowing over the 4 sites. Similarly spraying 4 weeks before direct drilling with the modified combine yielded 4% less than the conventional treatment (not significant). A 2 week chemical or mechanical fallow gave grain yields similar to a 0 week fallow, being 9-13% less than the conventional treatment. This happened despite having a "good" seed-bed and plant counts similar to the longer fallowed treatments. This difference might have been due to the presence of "soil diseases" or less nitrogen available to the plants from mineralisation or a combination/interaction of these factors.

On a grass free, clover dominant pasture a chemical fallow gave 3-9% more grain yield than any of the 4, 2 or 0 week conventional fallows. Any cultivation at this site was deleterious to grain yield. The decreased grain yield was attributed to better soil nitrogen status on the minimum tilled plots, as cultivation followed by rain probably enhanced mineralisation and leaching of nitrogen prior to sowing.

The soils of the chemical fallow treatments were generally more moist at sowing on the dry sites and were more trafficable at sowing on the wet sites. The mechanical fallows often shattered the soil, increasing wind erosion potential on some sites. Where grasses and diseases were more evident, the conventional fallow gave best grain yields.

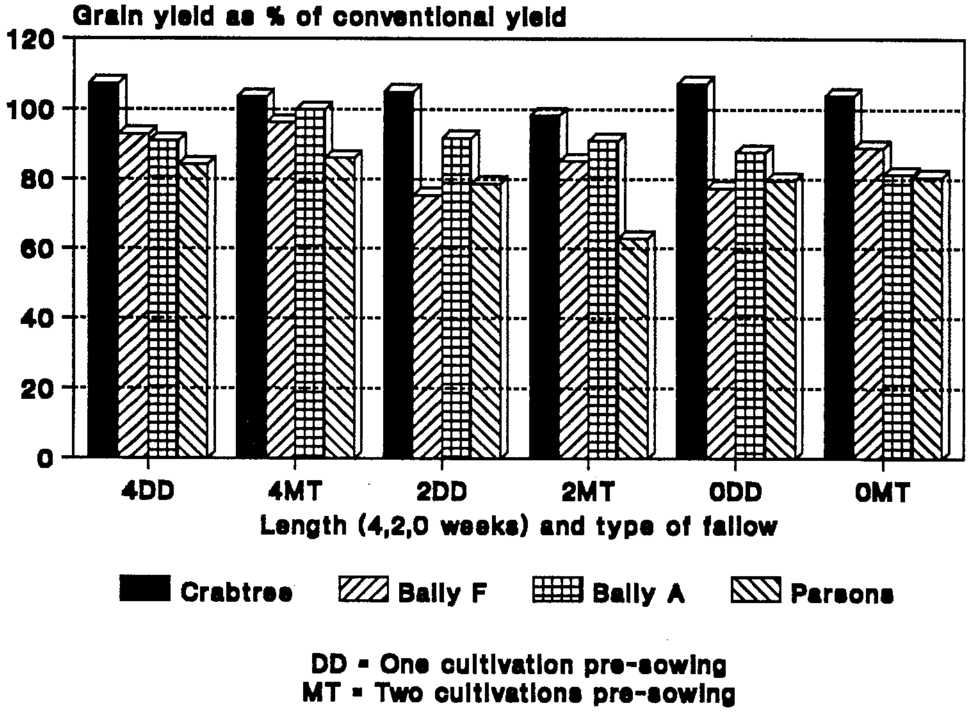

Figure 2: Effect of fallow on cereal grain yield compared to conventional sowings. With LSD's at 5% being 6, 11, 20 and 23 % respectively.

5.5 Deep ripping

There was a firm relationship between depth to clay and response to 30 cm ripping (Figure 3). The grain yield response to 30 cm ripping improved with increasing thickness of the sandy A horizon ($P<0.001$), the equation being:

$$GY = 88.13 + 0.866(d) \quad \text{where} \quad R^2 = 63 \qquad \text{eqn 2.}$$

where GY is grain yield response (%) to 30 cm ripping and d being depth to clay (cm). An economic response to ripping these soils to 30 cm was found likely (at 1986 economic values) if the sandy A horizon was more than 32 cm thick.

Responses to 30 cm ripping were similar on the 10 gravelly soils to responses on the sandy soils without gravel. The only exception was where the gravel stones were large in size up to 10 cm in diameter. Under these conditions there was no response to 30 cm ripping.

Fifteen experimental results, with 20 and 30 cm depth of ripping, were sub-divided into 2 groups; soils where the B horizon was 39-65 cm from the surface (deep) and soils where the B horizon was 15-23 cm from the surface (shallow). At the deep sites the average response to depth of ripping was linear (Figure 4). While at the shallow sites the average response to 20 cm ripping was greater than the average response to 30 cm ripping. Ripping into the clay soil was of no benefit on these soils.

The Agrowplow required more horsepower to pull than the Panbreaker, chisel plough or the scarifier but was most successful at soil loosening and resulted in better grain yields.

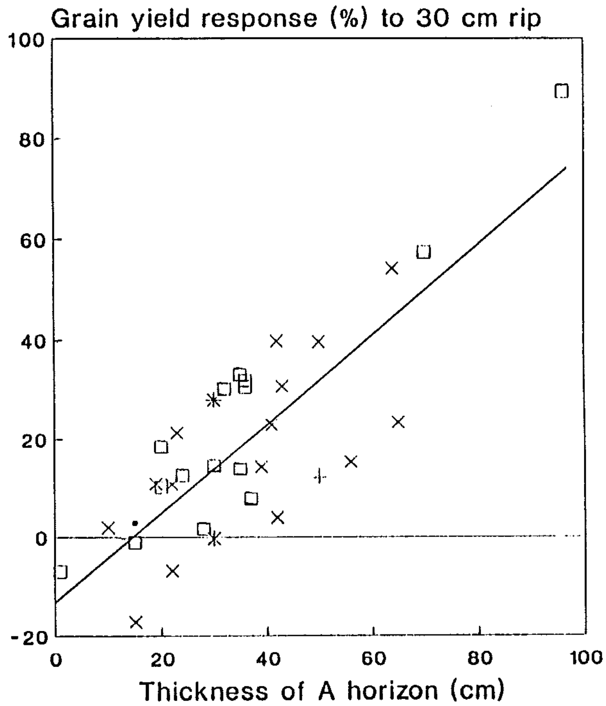

Figure 3: Grain yield response to 30 cm ripping on duplex soils with varying depth to the clay B horizon.

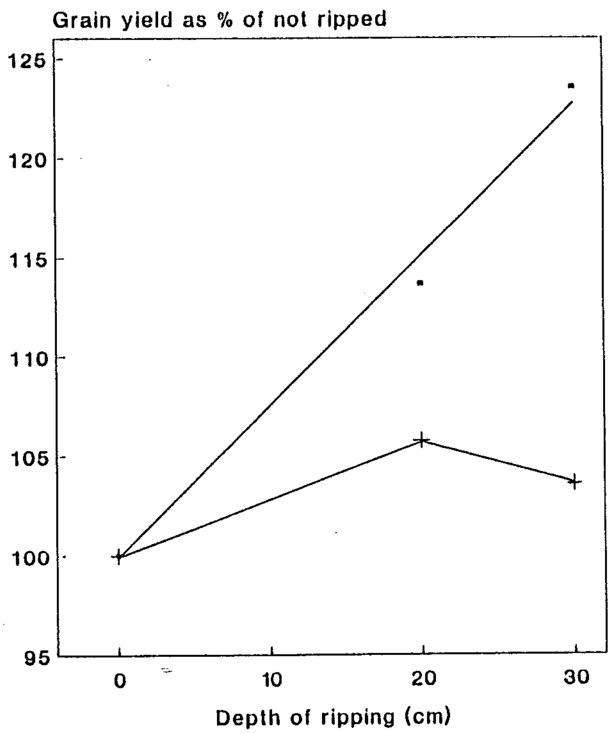

Figure 4: Effect of ripping depth on cereal grain yield on shallow (<25 cm to clay); + and deep (>39 cm to clay); ▪ duplex soils.

5.6 Cultivation Depth at Sowing

Deeper cultivations gave better grain yields (Figure 5), similar to the deep ripping results. The average grain yield over the 4 sites showed that direct drilled plots gave grain yields equal to conventional sown plots, if the cultivation tines on the one pass combine were cultivating at or greater than 12.8 cm depth. The equation being:

Conventional GY (%) = 87.6 + 0.97(depth of cultivation (cm)).

Increasing cultivation depth in direct drilled plots from 4 to 16 cm resulted in grain yield improvements from 130 to 400 kg/ha (10-36%). At 3 of the 4 sites, the 12 and 16 cm cultivation depth on the direct drilled plots gave equal to or better than the grain yields from the conventionally sown plots. Direct drilling with only the sowing tines gave superior grain yields to the treatment with the cultivating tines at 4 cm depth. This result is not understood but may be due to the seed being placed onto firm moist soil or due to fungal pathogens being shifted from the sowing position or some nitrogen effect.

Depth to clay may also affect a sites responsiveness to deep cultivations. Generally the further the clay was from the surface the greater the site responded to deeper cultivations.

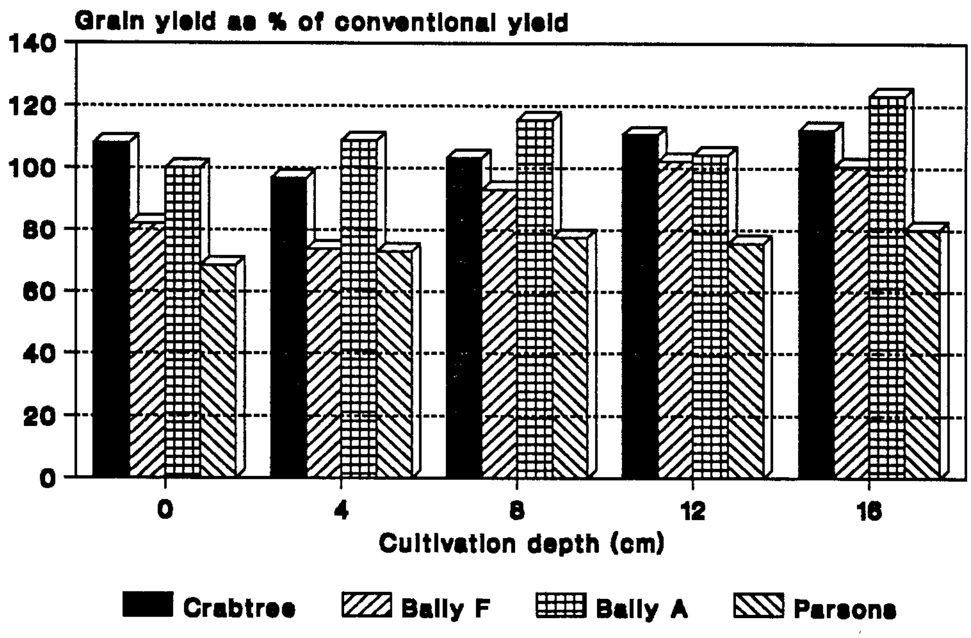

Figure 5: Effect of cultivation depth on cereal grain yield. With LSD's at 5% being 10, 13, 17 and 12 % respectively.

5.7 Cultivation Tine Position

Having the cultivating tines in line with the sowing tines gave similar grain yields to conventional sowing techniques and was generally higher yielding than other cultivating tine positions (Figure 6).

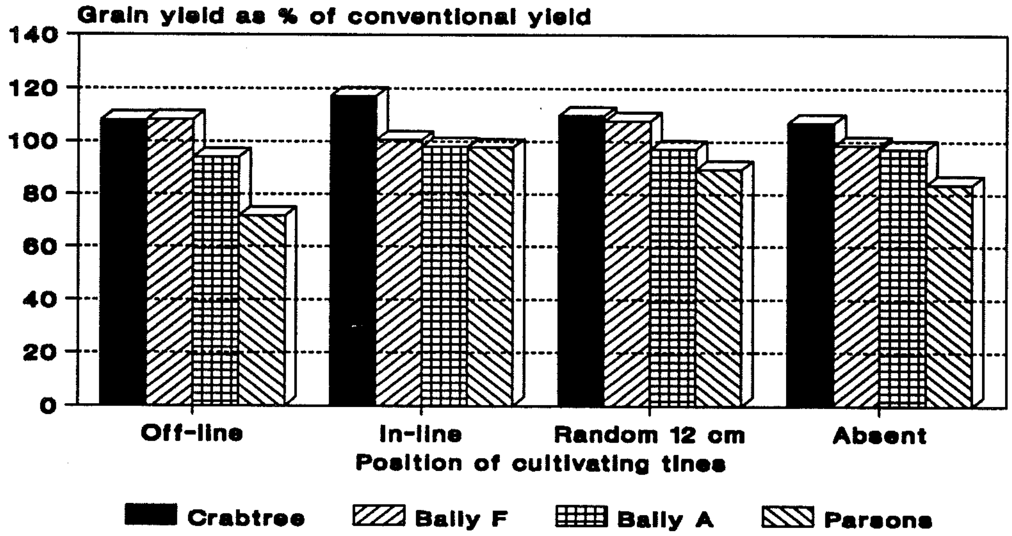

Figure 6: Effect of cultivating tine position compared to conventional sowing on cereal grain yield. With LSD's at 5% being 8, 11, 20 and 23 % respectively.

5.8 Harrows

Flexicoils increased emergence by 20, 8 and 2% in a moist seed-bed (1985) when direct drilled, minimum tilled and conventionally sown. On a direct drilled crop the flexicoil increased grain yield ($P<0.10$) by 20%. At this site the flexicoil treated soil had barley that stood more erect than the no compaction plots.

Flexicoils, heavy conventional and finger harrows used in the wet sowing conditions of 1986 did not improve cereal emergence significantly (Figure 7). However, weeds germinated better in both years and in some cases warranted control.

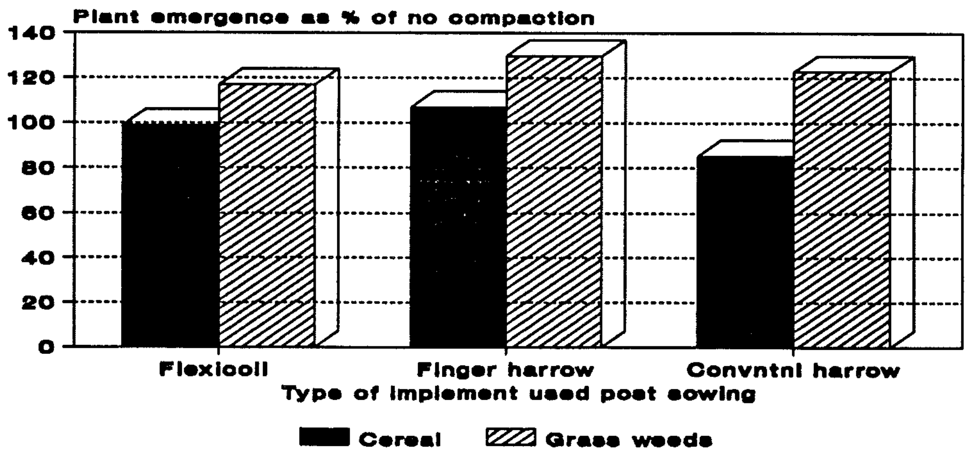

Figure 7: Effect of type of harrow on cereal and grass emergence in 1986 at 5 sites. LSD at 5% being 17%.

6. General Discussion:

Conventional cropping as practiced by farmers in the Jerramungup area (June to July sowings) has given higher grain yields than minimum tillage as practiced by the same farmers. Cropping cereals every third year, with two years of grassy pasture in between, has been the general farming practice in the district. These grassy pastures are the main reason for the poor minimum tillage yields and farmers generally have not manipulated pastures for legume dominance prior to cropping.

Introduction of grass free legume crops or pastures would vastly improve both minimum tillage and conventional grain yields as demonstrated in this work. Such a cropping strategy would enable farmers to sow at the break of the season enabling the crop to make full use of the growing seasons' rainfall. Sowing with long season, high yielding cultivars will improve grain yields and use more water, thereby helping to slow the rise in the water-table. Obviously conventional sowing requires a 3 week fallow period prior to sowing and is not appropriate for early sowings. To achieve the benefits of early planting farmers need to use some form of minimum tillage.

Early sowing also decreases the risk of paddocks getting too wet to sow, which is common with June and July conventional sowings (the loss due to re-sowing is large and common in the area). Minimum tillage sown paddocks in the area are also more trafficable which improves the probability of post sowing operations.

A problem with grass free pastures in the area is that sheep will quickly utilize and break up dried clover in the paddocks which will then erode easily in the strong local winds. Consequently, farmers would have to graze these paddocks more carefully over the summer and be contented with less pasture utilization. To overcome the decreased pasture availability over the summer farmers could feted sheep.

No doubt cropping will still continue on grassy paddocks in the near future. Therefore the less preferred option of cropping these paddocks is to improve the minimum tillage grain yields by spray-topping these pastures. However, this does not give all the benefits of grass free cropping such as decreased incidence of "take-all" (*Gaeumannomyces graminis*) and few in-crop weeds. In these conditions farmers may need to make some modifications to their minimum tillage practice to achieve reasonable yields.

A summer spray may be necessary to control weeds growing on summer rains. A two to four week spray fallow early in the season may also be required to ensure adequate root release has occurred prior to cultivating. This will decrease clod size, perhaps fungal activity, insect incidence and severity, allow nitrogen mineralisation to occur and conserve soil moisture. This should result in better seed-bed and grain yields on these paddocks.

A cultivation prior to sowing should ensure better yields on these sandy soils. If a combine could be set up to work deep (10-16 cm) and/or seed in line with the working tines then better minimum tillage grain yields might be achieved. Some farmers in the area are achieving this by putting a scarifier in front of their combine and cultivating while sowing. If Rhizoctonia bare patch is present then an extra cultivation prior to or at sowing becomes more important (Jarvis and Brennan, 1986).

Deep ripping on duplex soils throughout the area resulted in increased grain yields. Depending on costs and returns, ripping could be economical. Cereals responded linearly to depth of ripping on deeper sands. Where clay is less than 30 cm from the surface, 30 cm ripping may not be economic but 20 cm ripping may be. The Agrowplow gave best grain yields. Gravely soils are likely to respond to ripping similarly to sandy soils if the gravels are small.

Flexicoil use in these experiments increased cereal emergence particularly when the soil was slightly dry at sowing. However, weed emergence also increased with flexicoil use, and needed to be controlled. The flexicoil was beneficial for reducing clod size and obtaining a more uniform sowing depth.

Viable and sustainable cropping techniques are needed for these wind erodible sandplain soils of the south coast. Minimum tillage if done correctly will give both economical returns and improve soil stability. Cultivations on these sandy soils need to be kept to a minimum to decrease wind erosion risk. One cultivation prior to sowing in most cases is sufficient to both maintain soil stability and achieve grain yields equal to and better than conventional yields. Potential grain yields will only be reached if sowing is done at the break of the season and conventional sowing is not suitable for this purpose.

7. Recommendations

Farmers on the south coast of Western Australia have the technology to successfully establish crops using some form of minimum tillage. There are large economic incentives for farmers to sow crops at the break of the season on manipulated paddocks. If sowing is done later then weeds need to be killed before they get too large. If this is done then minimum tillage will perform similarly to conventional cropping. Conventional cropping has the potential to enhance the risk of wind erosion and has a yield penalty due to the need to delay sowing after the break. Hence farmers should adopt minimum tillage as a viable crop establishment technique especially on sandy soils prone to wind erosion.

8. References

Carder, J., and Grasby, J., (1986). A framework for regional soil conservation treatments in the medium and low rainfall agricultural districts. Research Report No. 1/86 Agdex No. 577.

Cochran, V.L., Elliot, L.F., and Papendick, R.I., (1977). The production of phytotoxins from surface crop residues. *Soil Science Society America Journal* **41**:903-8.

Crabtree, W.L., (1984). The Effect of Cultivation on soil fertility. Thesis University of Western Australia.

Crabtree, W.L., (1986). The Role of Minimum Tillage on the Southcoast Sandplain Soil. Western Australian Dept. of Agric. D.R.M. Technical Report 45.

Delroy, N.D. and Bowden, J.W. (1986). Effect of deep ripping, the previous crop, and applied nitrogen on the growth and yield of a wheat crop. *Australian Journal of Experimental Agriculture.* **26**:469-79.

Fry, P. and Goss, K.F. (1985). Communication networks and the adoption of three farm practices. Western Australian Dept. of Agric. Technical Report.

Goddard, B.J., Humphry, M.G. and Carter, D.J. (1982). Wind erosion in the Jerramungup area 1980-1981. Western Australian Dept. of Agric. D.R.M. Technical Report 3.

Hamblin, A.P., and Tennant, D., (1979). Interactions between soil type and tillage level in a dryland situation. *Australian Journal of Soil Research.* **17**:177-89.

Jarvis, R.J., Riethmuller, G.P., Henderson, C.W.L., and Hamblin, J., (1986). Deep Ripping. Western Australian Dept. of Agric. Farmnote No 50/85.

Jarvis, R.J., (1986). Research summaries. Plant Research Division W.A. Dept. of Agric.

Jarvis, R.J., and Brennan, R.B., (1986). Timing and intensity of surface cultivation and depth of cultivation affect Rhizoctonia bare patch and wheat yield. *Australian Journal of Experimental Agriculture.* **26**:703-8.

King P.M., (1981). Comparisons of methods for measuring severity of water repellence on sandy soils and assessment of some factors that affect its measurement. *Australian Journal of Soil Research.* **19**:275-85.

Mason, M., (1986). Research summaries. Plant Research Division W.A. Dept. of Agric.

Micheal, P., (1987). Insects and minimum tillage W.A. Dept. of Agric. Farmnote 50/85.

Northcote, K.H. (1979). 'A Factual Key for the Recognition of Australian Soils'. 3rd Edn. (Rellim Technical Publications: Glenside, S. Aust.)

Pathak, B.S., Gupta, P.K., and Mahajan, V., (1976). Effect of soil compaction on Seedling emergence. Punjab Agric. Univ. Ludhiana. *Journal of Soil Research.* **13**(1):35-47.

Russell, E.W., (1973). Soil conditions and plant growth. Longman Scientific and technical.

9. List of Publications and Extension activities

9.1 Publications

Crabtree W.L. and Jarvis R.J. (1986). Depth to clay affects grain yield response to ripping on duplex soils. *Australian Fieldcrops Newsletter* **21** pp 76-8.

Crabtree W.L. (1986). The role of minimum tillage on the southcoast sandplain soil. Western Australian Dept. of Agric. D.R.M. Technical Report 45

Crabtree W.L., Rees D., and Moore J. (1987). Effect of cultivation technique on crop establishment and yield of barley on a non-wetting soil. *Australian Fieldcrops Newsletter* **22** pp 42-6.

Crabtree W.L. (1989). Cereal grain yield response to deep ripping on duplex soils. *Australian Journal of Experimental Agriculture* **29**:691-4.

9.2 Reports & Proceedings

Crabtree W.L. (1985). Minimum Tillage for Sandplain Soils. W.A. Department of Agriculture, Jerramungup trial report. Crabtree W.L. (1986). Minimum Tillage for Sandplain Soils. W.A. Department of Agriculture, Jerramungup trial report.

Crabtree W.L. (1986) "Successful Minimum Tillage for the Southcoast Sandplain Soil." Proc. of Soil Conservation Workshop, at Wongan Hills August, 1986.

Crabtree W.L. (1987) "Minimum Tillage for the Southcoast Sandplain Soil." Proc. of Conservation Farm Planning - Profit or Pipedream, at Jerramungup, March, 1987.

9.3 Extension Activities

From 1985 to 1987 while working with the Western Australian Department of Agriculture at Jerramungup I was involved in the following extension activities.

Extension Type	YEAR 1987	1986	1985	TOTAL
Talks (Seminars+Groups)	21	18	21	60
Newspaper Articles	3	4	2	9
Video Production	1	0	1	2
Radio Interviews	3	2	3	8
Publications	1	1	1	3
Farmer Contacts	224	332	320	876
Agmemo Articles (Dept of Ag)	14	13	4	31

10. List of Experiments

Experimental Number	Title of sites	No.
86JE45	Minimum Tillage versus Conventional Cultivation	17
85JE42	Minimum Tillage for Sandplain Soils	1
85JE44	Minimum Tillage versus Conventional Cultivation	1
85JE64	Deep Ripping for Duplex Sandplain Soils	16
85JE68	Flexicoils with Minimum Tillage	11
86JE48	Autumn Fallow on the South Coast Sandplain	4
86JE49	Nitrogen by Time of Sowing with Minimum tillage	4
86JE52	Working Depths for Minimum Tillage	4
86JE53	Working Tine Positioning for Minimum Tillage	4
86JE78	Sprayback Times for Late Direct Drilling	1
86JE51	Deep Ripping on Duplex Soils	15
86JE54	Harrows and Flexicoils for Crop Establishment	5
Total		83

TECHNICAL REPORTS

	TITLE	AUTHOR
1.*	LAND DEGRADATION IN THE FITZROY VALLEY	RANGELAND MANAGEMENT BRANCH
2.*	REPORT ON THE CONDITION OF THE GASCOYNE CATCHMENT	D.G. WILCOX, E.A. MCKINNON B.J.GODDARD, M.G. HUMPHREY
3.*	WIND EROSION IN THE JERRAMUNGUP REGION 1980-81	D. CARTER
4.*	AGRICULTURAL DEVELOPMENT IN THE NORTH KIMBERLEY	D.G. WILCOX, J. RIPLEY, R.F. JOHNSON
5.*	VISIT OF WORKING PARTY ON NORTH KIMBERLEY AGRICULTURE DEVELOPMENT 1977	D.G. WILCOX, J. RIPLEY, R.F. JOHNSON
6.*	PROBLEMS & PROSPECTS OF KIMBERLEY PASTORAL INDUSTRY	R.B. HACKER
7.	QUOBBA CHALET DEVELOPMENT, LAND CAPABILITY STUDY & ENVIRONMENTAL CONSIDERATION	J. RICHES
8.*	REVIEW OF CURRENT DRAINAGE INVESTIGATIONS IN W.A.	R.A NULSEN
9.	PRELIMINARY GROUNDWATER INVESTIGATIONS IN RELATION TO SOIL SALINITY AT FITZGERALD	C. HENSCHKE
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14.	BRIEF STUDY OF LAND CAPABILITY IN COASTAL REGION SHIRE OF HARVEY	M. WELLS, P. HESP
17.*	AN ASSESSMENT OF INTERCEPTOR BANKS AT DANGIN	C. HENSCHKE
18.	SOIL FACTORS AFFECTING FLOOD RUNOFF ON AGRICULTURAL CATCHMENTS IN WESTERN AUSTRALIA	D.J. McFARLANE
19.	HYDROLOGICAL STUDIES IN SOIL SALINITY	C. HENSCHKE
21.*	SOILS & GEOLOGY OF THE BERKSHIRE VALLEY EXP. CATCHMENT	M. WELLS & D. MCFARLANE
22.*	SUMMARY OF BROOME & DERBY PINDANA STUDIES	P. DOLLING
24.	VLAMING HEAD - TANTABIDDI WELL - COASTAL RESOURCE SURVEY	P. HESP, J.G. MORRISSEY

TITLE		AUTHOR
25.	RURAL (NON IRRIGATION) WATER SUPPLIES IN W.A. A PERSPECTIVE TO THE YEAR 2000	I. LAING
26.	WATER EROSION ON POTATO LAND DURING THE 1983 GROWING SEASON DONNYBROOK	D. MCFARLANE
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38.	LAND RESOURCE SURVEY, FALL POINT, BROOME WA	P. CURRY, P. HESP
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48.	JANDAKOT GROUNDWATER SCHEME - A STUDY OF LAND RESOURCES AND PLANNING CONSIDERATIONS	M.R. WELLS, N.L.B. RICHARDS A.J. CLARKE
49.*	REPORT ON LAND DEGRADATION INVESTIGATIONS: KENT RIVER SOIL CONSERVATION DISTRICT	R. COLMAN D. MIERS

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51.*	WATER SPREADING AND WATERPONDING IN NEW SOUTH WALES AND THEIR RELEVANCE TO WESTERN AUSTRALIA	J. QUILTY
52.	EVALUATION OF RISK FACTORS LEADING TO SOIL DESTABILISATION ON THE SOUTH COAST SANDPLAIN OF WESTERN AUSTRALIA	R.V.R. GWYNN P.A. FINDLATER J.R. EDWARDS
53.*	THE SOILS OF FALLS FARM CATCHMENT CUBALLING, WESTERN AUSTRALIA	R.A. SUDMEYER
54.	"DRAINS" A METHOD OF FINANCIALLY ASSESSING DRAINS USED TO MITIGATE WATERLOGGING IN SOUTH-WESTERN AUSTRALIA	JOHN S. SALERIAN DON MCFARLANE
55.	"BANKS" A METHOD OF FINANCIALLY ASSESSING BANKS USED TO MITIGATE WATER EROSION IN SOUTH-WESTERN AUSTRALIA	JOHN S. SALERIAN DON MCFARLANE
56.	THE ECONOMICS OF SALTLAND AGRONOMY	JOHN S. SALERIAN CLIVE MALCOLM EDDIE POL
57.	WATER EROSION SURVEY IN THE NORTHAM DISTRICT AFTER STORMS IN JUNE 1987	D.J. McFARLANE A.T. RYDER
58.	INVESTIGATION OF A SALINE VALLEY ON ALLANDALE RESEARCH FARM	D.J. McFARLANE R. ENGEL A.T. RYDER
59.	WATER EROSION IN THE GERALDTON AREA DURING THE JUNE-JULY 1986	K.J. BLIGH
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63.	ASSESSMENT OF LAND CAPABILITY FOR ON-SITE SEPTIC TANK EFFLUENT DISPOSAL	M. WELLS
64.*	STORAGE LIFE OF FARM DAMS	G.J. LUKE C.G. DENBY
65.	EVAPORATION DATA FOR WESTERN AUSTRALIA	G.J. LUKE K.L. BURKE T.M. O'BRIEN
66.	A REVIEW OF MACHINERY FOR CROPPING WITH REDUCED WATER EROSION	K.J. BLIGH
68.	AN ASSESSMENT OF LAND CAPABILITY FOR RESIDENTIAL LAND USES, BABBAGE ISLAND CARNARVON, WESTERN AUSTRALIA	M.R. WELLS V.P.M. OMA

No.	TITLE	AUTHOR
69.	THE LAND RESOURCES AND CARRYING CAPACITY OF THE GASCOYNE LOCATIONS 228 AND 299, NORTH OF CARNARVON, WESTERN AUSTRALIA	M.R. WELLS V.P.M. OMA A.McR. HOLM
70.*	CODE LISTS FOR COMPUTERIZED SOIL AND LAND RESOURCE DATA RECORDING	P.D. KING M. WELLS
71.	THE USE OF PERMEABILITY, CONDUCTIVITY AND RESISTANCE IN THE DESCRIPTION OF WATER MOVEMENT IN SOILS AND PLANTS	H. BORG
72.	THE CONCEPT OF PRIME AGRICULTURAL LAND - A WESTERN AUSTRALIAN PERSPECTIVE	V.T. READ
73.	A METHOD FOR ASSESSING WATER EROSION RISK IN LAND CAPABILITY STUDIES - SWAN COASTAL PLAIN, DARLING RANGE WESTERN AUSTRALIA	M. WELLS
74.	SOILS OF THE KOJANEERUP ANNEX OF THE MOUNT BARKER RESEARCH STATION	P.A. FINDLATER P. MULLER
75.	SOIL CONSERVATION AND MANAGEMENT STRATEGIES FOR LAKE TOOLIBIN CATCHMENT	S. HEARN
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81.	SALINITY IN WESTERN AUSTRALIA - A SITUATION STATEMENT	
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	TITLE	AUTHOR
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