PLANT AND SOIL

TITLE: Furrows, press wheels and wetting agents improve crop emergence and yield on water repellent soils

The following manuscript contains 14 pages of text, 4 tables, 3 figures and a suggested short running title could be "crop establishment on water repellent soils".

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Abstract

The rates of emergence of wheat and lupin were measured in 13 field experiments on water repellent sands. Conventional sowing was compared with furrow sowing either with or without the use of a press wheel and several rates of banded wetting agent. Measurements included, severity of water repellence, plant emergence, rainfall, soil temperature at sowing and, at one site, the area of wet soil after sowing.

All ameliorative techniques improved emergence, with responses being greatest when seeds were sown into dry soil. Compared with conventional sowing, furrow sowing increased wheat and lupin emergence by an overall average of 16 and 41% respectively. The benefits were greater at the drier sites. Increases in emergence due to the use of a press wheel were sometimes small, although they always occured (1-19%). It was visually observed that press wheel use gave more uniform seeding depth, reduced clods and ensured more accurate placement of banded wetting agent.

Banded wetting agent consistently improved wheat and lupin emergence, particularly where early rains were light and press wheels were used. The wetting agent increased the cross-sectional area of wet topsoil (0-10 cm) which was positively related with increased wheat emergence ($R^2 = 0.91$). At 0.5 L ha^{-1} of banded wetting agent, the soil along the furrow was four times wetter than without wetting agent. Wetting agent at 0.5 and 1 L ha^{-1} (with press wheels) increased wheat emergence by 6 and 11% and lupin emergence by 13 and 11%, respectively. The high rates of banded wetting agent gave highest plant densities.

Grain yield was only measured at three sites. Furrow sowing did not increase grain yield, however, press wheels use with furrow sowing increased grain yield by 30%. Banded wetting agent increased grain yield and they were positively correlated. The highest rate increased grain yields by a further 9% above press wheels and furrow sowing.

Introduction

Crop establishment on water repellent soil is affected by non-uniform infiltration and distribution of water in the surface soil layer (Bond 1972, King 1981, Crabtree and Gilkes 1998a). Many seeds sown into water repellent soil remain dry and will not germinate, giving patches of bare soil, between emerged plants (McGhie 1983).

For water repellent sands, emergence and grain yield improvements have been found for barley with furrow sowing, compared with sowing in the ridge (Bond 1972, Crabtree and Gilkes 1998a). Press wheels have also improved emergence, growth and grain yield of barley (Crabtree and Gilkes 1998a). Similarly, banded wetting agent has increased emergence (McGhie 1983) and given an economic increase in barley yield (Crabtree and Gilkes 1998a). Pastures have also shown similar improvements in emergence with these techniques (Crabtree and Gilkes 1998b).

Severity of water repellence and the seasonal conditions may affect the impact of these treatments. The degree to which the soil dries over summer and the soils temperature when rain falls has a great impact on the wettability of repellent soils in mediterranean climates (King 1981). Cold and very dry soils will decrease a soils wettability (Wetherby 1984).

The hypotheses tested here is that furrow sowing, either alone or in combination with press wheels and banded wetting agents, will improve emergence of cereals and lupins on water repellent soils. Benefits from these techniques are difficult to predict as they relate to (i) the amount of early season rainfall, (ii) the severity of soil water repellence, and (iii) the temperature of the soil at sowing.

Materials and methods

Sites

Twelve experiments were conducted in the southern and northern agricultural regions of south Western Australia in 1988-89 (Table 1). Three sites were sown to lupins (*Lupinus angustifolius* - cv Danja) and nine to wheat (*Triticum aestivum* - cv Spear and Aroona [south] and Gutha [north]), with an additional site in 1987 (site 13) being sown to barley (*Hordeum vulgare* - Crabtree and Gilkes 1998a).

The experimental soils were acidic, sandy-surfaced, duplex soils being either Dy 4.82 or Dy 4.42 (Northcote 1979). The surface sands were either grey or red-brown and overlay a heavier textured horizon at 35-95 cm depth. The topsoil (top 10 cm) had a pH of 4.5-5.3 (1:5 0.01 M $CaCl_2$), contained 1-5% clay, had 0.8-1.3 % organic carbon and had water repellence values of 1.5-4.0 MED (molarity of ethanol drop test, as per King 1981, n = 3). Average annual rainfall for the sites is 375-425 mm, most of which falls during the growing season from May to October.

Table 1. Site details for the lupin (1-3) and wheat (4-12) experiments.

Site	Locality in southwestern Australia	Water repellence MED	sd	Date Sown	Applied fertiliser ($kg\ ha^{-1}$) P	N
1	Dalyup	4.0	0.2	11 May '88	13	0
2	Gibson	3.0	0.2	9 June '88	13	0
3	Yerangutup	3.2	0.3	29 May '88	15	0
4	Condingup	3.4	0.3	30 May '88	13	25
5	Isseka	2.0	0.6	31 May '88	20	18
6	Neridup	3.6	0.3	7 June '88	10	22
7	Badgingarra	2.6	0.6	8 June '88	20	18
8	Badgingarra	1.9	0.5	16 June '89	20	18
9	Eneabba	1.5	0.8	15 June '89	20	18
10	Isseka	2.7	0.5	14 June '89	20	18
11	Kojaneerup	3.8	0.2	5 May '89	13	25
12	Moonyoonooka	3.7	0.5	14 June '89	20	18

Experimental design and treatments

The experiments followed either a complete (1988) or incomplete (1989) randomised factorial design. Seven rates of banded wetting agent were applied (0, 0.5, 1, 2, 4, 8 and 16 L ha^{-1}) at sowing. Seeding in the side of a ridge (conventional) was compared with furrow sowing, either with or without press wheels, and banded wetting agent at most sites (1-7 and 11). The treatements of wetting agents without press wheels was not included in the remaining 5 sites. All treatments were replicated 3 times.

The press wheels used were cast iron, in a gang of 8, each weighed 28 kg, was 10.3 cm wide and 38.2 cm in diameter; they were 'V' shaped with an internal apex angle of 120°. They had a total loading of 31 kg (an extra 3 kg for each wheel, for axle, frame and bearings) on each wheel, which applied an average vertical force of 3.0 N mm^{-1}. The apices of the press wheels were placed directly over the seed.

Experimental procedure and measurements

Sites were sprayed with standard rates of herbicides (either glyphosate or a diquat:paraquat mix) before sowing. The lupin sites were sprayed with 2 L ha^{-1} of simazine before cultivating. Pre-sowing cultivation was done at 8 km h^{-1} to a depth of 6-8 cm deep across sites 1, 2, 5, 6, and 9-12 to ensure weed control and to make the site conditions more uniform.

Seeding rates varied from 68-80 kg ha^{-1} for lupins and 50-80 kg ha^{-1} for wheat, with the lower rates being used at the more northern sites. Plots were either 20 or 40 m long, 1.44 m wide and seeds were sown at 2-4 cm depth with 10-20 kg ha^{-1} of applied P in the seed furrow (Table 1). The seeder had 4 rows of tines; the front row for cultivating, the middle 2 rows for sowing and the rear row for seed covering (with conventional seed placement only). The rows of tines were spaced 36 cm apart with 12 cm wide points attached to 3 of the rows of tines and 5 cm wide points attached to the third row of tines. All treatments were sown at 4 km h^{-1}, except for the conventional treatment which was sown at 8 km h^{-1} to ensure ridge sowing.

Wetta Soil® wetting agent was applied accurately to the lowest part of the furrow through solid stream nozzles. The nozzles were mounted on a boom attached behind either a gang of mounted press wheels or the combine frame. The wetting agent was mixed with water at different concentrations to obtain the range of application rates. These water plus wetting agent solutions were applied at a constant 30 L ha^{-1}, spraying was at 150 kPa pressure and in a 3-5 mm wide band. Because of the low volumes of water applied, a water only control treatment was not considered necessary. Insecticide (chlorpyrifos) was applied at 2 L ha^{-1} at site 2 only.

Six plant counts per plot, using a one metre length randomly located along a row, were measured 14 and 21-28 days after sowing (DAS) for lupins and wheat. For comparing emergence between sites, the plant counts were adjusted to percent of the conventional treatment.

Soil was collected from each site in a grid pattern before sowing, in order to measure the severity of water repellence (King 1981). This was done using the molarity of ethanol drop (MED) test on air dried topsoil (10 cm). Daily rainfall was measured at each site and the daily temperature was obtained from the Bureau of Meteorology's recording stations located near the sites.

At one site (11), 6 measurements of topsoil wetness, were taken at random, across a seeded row of topsoil (18 cm wide by 10 cm deep). This was done 8 DAS which was 10 hours after 16 mm of rain.

Curve fitting and analyses of data

Emergence response curves to banded wetting agent, both with and without press wheels, were fitted by eye. The highest plant emergence value achieved at each site, was designated as maximum emergence (or 100%). This value was used to determine the percentage of plants that did not emerge for the less successful treatments at each site.

The percentages of plants that did not emerge with conventional, furrow sowing (with and without press wheels) and 1 L ha^{-1} rate of banded wetting agent (with and without press wheels) were calculated for each site. The 1 L ha^{-1} rate was used as this is a rate farmers might consider economically viable.

Rainfall that might effect plant emergence was deemed to be that rain which fell between 1 April and the date of sowing (subsequently referred to as 'early rains'). The percentage of plants that did not emerge was then compared with the amount of early rains.

Results

All amelioration techniques used (furrow sowing, press wheel use and banded wetting agent) improved the emergence of both lupins and wheat compared to conventional seeding (Tables 2 and 3). Furrow sowing increased lupin and cereal emergence by an average of 41% and 16% across all sites respectively.

Table 2: Lupin emergence for conventional and furrow sown with and without press wheels and with rates of banded wetting agent (means, n=3).

Site	Conv.[A] (pl/m^2)	Percent plant counts at 14 DAS, with press wheels at the following rate of banded wetting agent (L/ha)							logrth resp[B] (R^2)
		0	½	1	2	4	8	16	
1	36	197	236	244	242	267	275	278	0.84
2	46	135	163	161	185	152	163	217	0.51
3	63	116	114	117	110	146	143	159	0.77
Avg	48	144	160	165	167	179	183	208	0.95
			Without press wheels						
1	36	183	256	236	258	269	275	286	0.69
2	46	111	104	102	143	139	154	174	0.87
3	63	132	132	116	140	138	168	167	0.72
Avg	48	138	154	142	171	173	192	200	0.91

[A] = Conventional seed placement.

[B] = Logarithmic correlation between banded wetting agent and lupin emergence.

Table 3: Cereal emergence for conventional and furrow sown with and without press wheels and with rates of banded wetting agent (means, n=3).

Site	Conv.[A] (pl/m^2)	Percent plant counts at 21-28 DAS, with press wheels at the following rate of banded wetting agent (L/ha)							Logrth Resp[B] (R^2)
		0	½	1	2	4	8	16	
4	68	159	176	187	174	186	192	194	0.67
5	95	115	85	100	132	102	126	100	0.02
6	78	105	127	137	124	135	135	159	0.70
7	103	112	130	116	115	106	106	118	0.10
8	70	123	124	150	116	137	140	140	0.18
9	72	125	136	140	124	146	136	124	0.00
10	70	129	133	129	133	141	141	120	0.00
11	72	100	100	110	118	136	153		0.96
12	66	117	135	129	139	132	142	141	0.60
13	99	104	117	120	123	127	132	139	0.94
Avg	80	116	124	129	128	131	136	135	0.85
			Without press wheels						
4	68	163	149	179	156	171	179	175	0.31
5	95	96	94	100	114	127	127	126	0.83
6	78	115	117	138	123	129	133	137	0.50
7	103	109	111	109	109	94	95	96	0.72
11	72	103	110	117	132	121	136		0.78
Avg	83	116	114	125	124	125	130	134	0.85

[A] = Conventional seed placement.

[B] = Logarithmic correlation between banded wetting agent and cereal emergence.

Figure 1: Effect of banded wetting agent, from all sites where comparisons existed, for with press wheels () and without press wheels (), on emergence of lupins (black shading, n = 3 sites) and wheat (outline of symbol, n = 5 sites {4,5,6,7 and 11}) on water repellent soils. (Power curves are fitted to x axis data plus 0.1 L/ha)

Press wheels

Applying press wheels usually improved emergence of furrow sown lupins and wheat at all rates of banded wetting agent (Figure 1). Press wheels increased lupin and wheat emergence by an additional 6 and 2%. Press wheel use was most beneficial with lupins at the low rates of banded wetting agent. Lupins were more responsive to press wheel use than was the wheat.

Banded wetting agent

Increasing banded wetting agent increased plant emergence and reduced spatial variation in emergence (data not presented) for both lupins and cereals. The lupins showed larger emergence increases to banded wetting agent than wheat.

Low rates of wetting agent further increased plant emergence when press wheels were used. The 0.5 and 1 L ha^{-1} rate of banded wetting agent, with press wheels, increased lupin emergence by 13 and 15% and wheat emergence by 6 and 11%. Without press wheels, the emergence improvements were smaller and less consistent with banded wetting agent.

At the 8 and 16 L ha^{-1} of banded wetting agent (plus press wheels), lupin emergence was increased by 28 and 45% and wheat emergence by 19 and 18% compared with no banded wetting agent. The emergence response was greatest and usually more reliable with less early rain: wheat emergence increased by 34% at 8 L ha^{-1} of banded wetting agent (sites 4, 6 and 11, with press wheels).

Soil wetting

At site 11, increasing the rate of banded wetting agent, with press wheels, from 0 to 8 L ha^{-1} linearly increased the the cross-sectional area of wet soil at 8 days after sowing by a factor of ten-fold from 300 to 3,170 mm^2 (with $R^2 = 0.91$). Better wetting of the soil with increasing banded wetting agent was also related to better cereal emergence (Figure 2).

Figure 2: Effect of banded wetting agent, with and without press wheels at site 11, on percentage of wet topsoil in a 10 cm by 18 cm cross-sectional area () of soil (n=6) and wheat emergence increase over conventional placement ().

Applying press wheels improved the relationship between increasing banded wetting agent and wet soil. The banded wetting agent greatly increased soil wetting, with the press wheels, even at the lowest rate of wetting agent. However, without banded wetting agent the press wheels did not increase soil wetting.

Climate and site effects on cereal emergence

Increasing early rainfall improved cereal emergence for all treatments except the conventional seeding technique (Table 4). The conventional treatment had 31% less plants emerged at 21-28 DAS compared with the estimated maximum emergence. Grouping the data on the basis of (a) severity of water repellence, (b) soil water evaporative losses and (c) air temperature at the time of sowing, did not improve the relationships between emergence and early rainfall.

Table 4: Estimated maximum emergence (% from maximum) for cereals: a measure of treatments not reaching the possible maximum and this measure compared to early rains.

	Estimated maximum	Percentage of plants not emerged compared to the estimated maximum possible emergence at 21-28 DAS					April to sowing
Site	emergence (pl/m^2)	control	furrow	furrow + PW[A]	furrow + PW[A] + WA[B]	furrow - PW[A] + WA[B]	rains (mm)
4	131	40	19	16	10	15	183
5	122	22	20	20	16	11	181
6	114	53	18	15	11	16	177
7	120	14	11	4	3	12	225
8	98	29	11	12	8	-	150
9	99	27	14	8	4	-	176
10	96	26	7	6	3	-	199
11	111	35	33	36	29	23	56
12	99	33	7	17	12	-	202
13	155	36	36	34	26	-	68
	Average	31	18	17	12	15	
	Early rainfall regressions against treatments						
	R^2	0.11	0.78	0.80	0.78	0.84	
	a	41.6	43.1	44.7	35.4	26.6	
	b	-0.06	-0.16	-0.17	-0.14	-0.07	
Significance level		ns	P<0.05	P<0.05	P<0.05	P<0.05	

[A] = Press wheels

B = Wetting agent at 1 L/ha

Grain yield responses

Insects and rabits were attracted to the quickest and best emerging treatments which were selectively damaged after emergence. Better weed emergence in the ameliorated treatments, which were often not checked, complicated potential grain yield benefits from the ameliorative treatments.

However, 3 sites were harvested (2, 4 and 6; one lupin and two wheat) and showed that furrow sowing alone, did not increase yield (Figure 3). Addition of press wheels increased yield by 30%. Applying wetting agent increased grain yield, with a strong positive relationship between grain yields and rate of banded wetting agent, both with press wheels (R^2 = 90) and without press wheels (R^2 = 94).

Figure 3: Effect of rates of banded wetting agent on crop yield, with () and without press wheels(), at sites 2, 4 and 6 (n=9).

Discussion

Furrow sowing, using press wheels and wetting agents, either singularly or in combination improved lupin and wheat emergence on these water repellent soils. Conventional sowing on water repellent soils consistently gave about 30% less plants compared to the best treatment, even when there were good early rains (200 mm). Therefore the adoption of furrow sowing, press wheel use and/or banded wetting agents, even in wet years, is likely to improve crop emergence on water repellent soils.

Furrow sowing has previously been shown to improve cereal emergence in Southern Australia by up to 100% (Bond, 1972; King, 1985; Crabtree, 1996a). Furrow sowing allows water to flow into furrows where it ponds, which enables much water to bypass the topsoil. Then the water can penetrate to the subsoil through preferential flow down wettable zones (Ritsema and Dekker, 1994; Crabtree and Gilkes, 1998a). Consequently, some seeds that are planted in the furrow may remain in dry soil.

Furrow sowing alone does not ensure even wetting and optimum emergence along the furrow as seen in Figure 2. Poor soil wetting and reduced emergence occurred in the furrow sowing only treatment compared to treatments where even low rates of banded wetting agent had been applied.

The addition of press wheels to furrow sowing improved lupin and cereal emergence. The press wheels improved furrow definition and may have compacted some of the dry soil around the seeds. Compaction of wettable soils increases seed:soil contact, when soils are moist (Hyder et al., 1955), which improves movement of water to seeds (Stout et al., 1961) but this may not occur for dry water repellent soils. Dry water-repellent soils are difficult to pack as water is not present between sand grains to act as a lubricant and therefore press wheels may not improve the seed:soil contact to the same extent as on wettable sands. High press wheel pressure (>3 N mm^{-2}) on water repellent soils has been shown to improve barley emergence and grain yield (Crabtree and Gilkes, 1996a) which was presumably due to increased packing achieved at high pressures.

More work is needed to define press wheel pressure requirements for these soils and the modes of action of press wheels. The press wheels used in this work gave several benefits, including; better break-down of soil clods in the furrow, they gave a more uniform sowing depth and increased the precision and accuracy of the banded wetting agent.

Banding wetting agent in the furrows ensured more uniform wetting along the length of, and across the furrows. This better soil wetting further increased crop emergence, even at 0.5 L ha^{-1} of banded wetting agent. This low rate gave 4-times more wet topsoil than the soil without wetting agent.

All three amelioration techniques gave the largest wheat emergence responses for drier starts to the season. It is therefore in the driest seasons that these techniques may offer the greatest benefits in improved plant emergence. In wet environments or years farmers may find furrow sowing disadvantageous on shallow duplex (texture contrasting) soils due to the increased risk of water-logging in the furrows.

Increases in grain yield resulting from these ameliorative techniques were often restricted by wet growing seasons and more weed, insect and rabit damage which was most common on the first emerging treatments. Most sites also subsequently wet uniformly soon after emergence and the beneficial amelioration effects increased, the sometimes, unchecked weeds which masked potential yield benefits from amelioration.

More recent work from sandy soils in Western Australia has shown that the banded wetting agents used in this work may encourage nutrient leaching from the topsoil (P. Blackwell pers comm) and this could influence grain yield. However, earlier work has shown that economic grain yield responses from banding low rates of wetting agents can occur with these wetting agents in dry seasons (Crabtree and Gilkes, 1998a).

In the last 5 years, widespread adoption of no-tillage sowing techniques on the south coast of Western Australia has ensured the use of furrow sowing and press wheels, most recently clay is being successfully used as a long-term ameliorant. Some farmers in this area, with the most serious water repellent soils are banding wetting agents at low rates (0.5-2.0 L/ha) and usually at wider row spacings of 25-36 cm, particularly with *Lupinus angustifolius*. The residual effect of better soil wetting that occurs in the previous years furrows has affected crop and weed emergence in the following year.

This work demonstrates that farmers would do well to immediately adopt furrow sowing and press wheel use in southern Australia for water repellent soils. In fact, since this work, local and widespread adoption of these techniques has occurred. Banding low rates of wetting agents has shown positive emergence and grain yields, enough so to encourage further experimentational refinement of the system.

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References

Bond R D 1972 Germination and yield of barley when grown in a water repellent sand. Agronomy Journal 64,402-403.

Crabtree W L and Gilkes R J 1998a (submitted) Banded wetting agent and compaction improves barley production on a water repellent sand. Agronomy Journal.

Crabtree W L and Gilkes R J 1998b (submitted) Improved pasture establishment and production on water repellent sandy soils'. Agronomy Journal.

Ritsema C J and Drekker L W 1994 How water moves in a water repellent sandy soil. American Geophysical Union 30,2519-2531.

Hyder D N Sneva F A and Sawyer W A 1955 Soil firming may improve range seeding operations. Journal of Range Management 8,159-163.

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 19,275-285.

King P M 1985 Management of sandy soils. Proc. of Jerramungup Soil Conservation District Advisory Committee Seminar. 'Lucerne Logic', Western Australia, 5 March pp 18-23.

McGhie D A 1983 Water repellent soils on farms. Western Australian Department of Agriculture. Farmnote 117/83.

Northcote K H 1979 A factual key for the recognition of Australian soils. Rellim Technical Publications: Glenside, South Australia.

Stout B A, Buchele W F and Snyder F W 1961 Effect of soil compaction on seedling emergence under simulated field conditions. Agricultural Engineering 42,68-87.

Wetherby K G 1984 The extent and significance of water repellent sands on Eyre Peninsula. Dept. of Agric. South Australia Technical Report 47.