Soil management techniques to improve soil water use in raised bed cropping in south west Victoria

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Abstract
Cultivation of heavy clay soils, with the application of gypsum, is often used to improve root exploration of the soil profile and hence, achieve greater water and nutrient efficiency to enable higher crop yields. Soils in south-western Victoria derived from Tertiary basalts have high clay content and often dispersive subsoils. These soils are prone to waterlogging and raised beds have been used to help overcome the problem. Also there are issues of heavy subsoil restricting rooting depth and hence efficient water extraction from the soil profile, particularly in the grain filling period. Deep cultivation of the soil has been proposed to overcome the subsoil limitations. To address the issues of waterlogging and subsoil constraints this study investigated deep ripping, with and without the use of gypsum, and the use of direct drill techniques. Soil water use and plant root density were measured.
Soil water use indicated that the use of direct drill, compared to deep ripping, was favoured during years with dry autumn or delayed autumn breaks. Surface soil water was conserved in the direct drill treatments. Furthermore the use of deep ripping, with and without the use of gypsum did not significantly increase the rooting density to a greater depth than direct drill.

Key Words
Deep ripping, direct drill, gypsum, root growth, water use efficiency, grain yield.

Introduction
Until the introduction of raised bed cropping in south-western Victoria, grain production had been limited by the propensity of the basaltic soils for waterlogging. The risk of waterlogging of crops has virtually been eliminated through the use of raised beds (Wightman and Kealy 2000). Unfortunately there is a problem of lower yields than predicted at the time of anthesis, due to poor availability of water in the spring during grain filling. This has been attributed to the heavy clay and dispersive subsoils. Furthermore, rooting depth may also be restricted due to the high soil strength of the heavy clay subsoil (Atwell 1990a; Atwell 1990b; Atwell 1990c; Atwell 1993).

A further problem of the soil is the low subsoil permeability which restricts rainfall infiltration (Peverill et al. 1999). To address this problem deep ripping can be used to improve infiltration by forming continuous cracks (Russell and Russell 1973), decrease the bulk density, and subsequently improve aeration of fine textured B horizon soils (Glínski and Lipiec 1990).

Another technique to address high clay content soils, particularly sodic soils is the application of gypsum. Studies have shown significant improvement in grain yields with the application of gypsum (Ford et al. 1993; Howell 1987; Millthorpe and Newman 1979; Oster 1982). An increase in grain yield was obtained when the use of gypsum was combined with deep ripping on a duplex (non-sodic soil) in Western Australia (Hamza and Anderson 2003). As there is limited use of gypsum in south-western Victoria (Gardner et al. 1991), this project investigated deep ripping, gypsum application and direct drilling, to enable plants to access more soil water and nutrients in the profile.

Methods
An experiment was conducted on a site east of Cressy (38°04' S, 143°41' E), the soil classed as a Sodosol (Isbell 1996), typical of the basaltic soils in south-western Victoria. The soil, typical of a sodosol, has dispersive subsoil with an increase in pH and EC at depth (Table 1).

Table 1. Chemical and physical characteristics of the Cressy soil

Depth cm	Bulk density $Mg\ m^{-3}$	pH $_{CaCl2}$	EC_{sat} dSm^{-1}	ESP %
0 - 10	1.08	5.7	0.7	10.5
10 - 20	1.51	6.2	1.2	22.3
20 - 30		5.1	0.4	21.4
30 - 40	1.54	6.5	1.9	28.0
50 - 60	1.57	7.4	3.4	34.6
70 - 80		7.8	4.0	38.3

Treatments

The experimental site was chisel ploughed in 1999, to a depth of 7-10 cm, to alleviate compaction from long term grazing, then converted to raised beds in May 2000 and a crop of canola grown. Cultivation treatments were applied in May 2001 (Table 2). A randomised block design was used with 4 treatments replicated 3 times. T1 received no further tillage throughout the experiment. T2 had continuous cultivation, while the deep ripped treatments, T3 and T4 were only deep ripped in the first year. After the deep ripping operation in 2001, the raised beds were reformed. T4 was split in the second year to test a further application of gypsum, without cultivation. Sowing was performed, after stubble burning, using no till machinery (tine spacing of 175 mm).

Table 2. Treatments used at Cressy

	T1	T2	T3	T4a[1]	T4b
2001	DD	SC-10 cm	DR-40cm	DRG[2]	
2002	DD	SC-20 cm	DD	DD	DDG[2]
2003	DD	DR-40cm	DD	DD	DD

Treatment descriptions: DD - direct drill, DR – deep rip with "Airway" cultivator (7 tines/2 meter bed width), DRG – deep rip to 40 cm with application of gypsum, DDG – direct drill plus gypsum, SC – shallow cultivation with "Airway" cultivator (7 tines/2 m bed width) Note 1: Treatment 4 was split in 2002 Note 2: Gypsum broadcast before cultivation (2001) or sowing (2002) at the rate of 2.5 t/ha

Soil water measurements

In 2001 soil water was measured with a Diviner capacitance probe for a limited period, after anthesis to harvest in the 2001 season. Measurements indicated soil water may have increased after cultivation (not statistically tested). For the following seasons soil water was measured with a neutron probe, recording every 20 cm to 100 cm. Soil water measurements were made at approximately fortnightly intervals on the centre bed in each of the 12 plots.

Root length density

Intact soil cores were sampled after the harvest in 2001 and 2002. In 2001 single cores (cylinders 50 x 50 mm) from each plot were taken at the following depths, 5-10, 25-30, 45-50 and 75- 80 cm. In 2002 duplicate cores (38 mm diameter x 1 m length) were sampled from each plot, in 10 cm increments, from the surface to a depth of 80 cm. Cores were soaked overnight in water. Soil was removed by washing cores with water through sieves of decreasing mesh size and the roots separated from organic matter by flotation. Recovered roots were scanned in conjunction with Rhizo V4.1 software (Régent Instruments Inc. 4040 Blains St. Québec G2B 503 Canada).

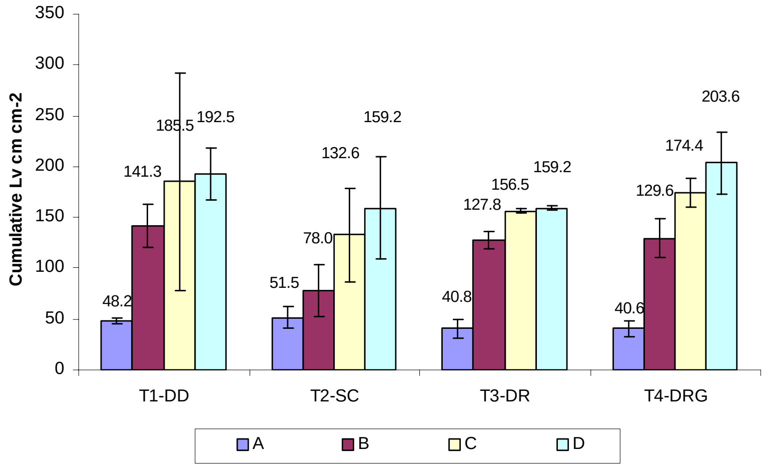
Grain harvest

Grain yield was estimated by either sampling the crop with a plot harvester (2001 and 2003), or by using hand cuts (2002). Total biomass was obtained using hand cuts in 2002 and 2003.

Results and Discussion

Root length density-2001

The use of deep ripping and gypsum did not significantly ($P < 0.05$) increase the total root density to 80 cm, compared to direct drill (Figure 1). The addition of gypsum, when deep ripping, resulted in greater root growth (not significant. $P < 0.05$) to 80 cm than the deep ripped treatment. Both shallow cultivation, T2, and deep rip without gypsum, T3, had less cumulative root density (n.s. $P < 0.05$) to 80 cm than the other two treatments. Comparison of cumulative root length density, Lv, to 30 cm (B) shows a greater density (n.s. $P < 0.05$) of roots in the direct drill treatment, compared to shallow cultivation (T1-T2, $P = 0.14$). Several authors (Cannell and Hawes 1994; McCalla and Army 1961; Unger and McCalla 1980), have reported an increased root length density in the surface layers when direct drill (or conservation tillage), has been adopted over a continuously cultivated cropping system. The recording of a greater density of roots in the surface soils, of no tillage treatments, could be attributed to increased soil moisture in the surface soil (McCalla and Army 1961). In other cases a greater soil strength reduced the elongation of the main root axes and stimulated branching (Cannell and Hawes 1994). Lal (1989) proposed a generalized root profile model with more roots in the surface under no till (direct drill) compared to ploughed soil, and less roots in deeper layers.



Data derived from Lv for 4 depths as follows:
A = Lv($_{5\text{-}10\ cm}$) x 5, B = A + Lv($_{25\text{-}30\ cm}$) x 5, C = B + Lv($_{45\text{-}50\ cm}$) x 5, D = C+ Lv($_{75\text{-}80\ cm}$) x 5.
Error bars are standard error of the mean. Treatments: (see Table 2)
No significant interactions ($P < 0.05$)

Figure 1. Cumulative root length densities (Lv) of barley crop at Cressy in 2001

Root length density-2002

Cultivation to 20 cm, T2, showed no significant increase in root length density to 20 cm compared to direct drill, T1 and T2 (Table 3). At deeper depths, similar patterns of roots were found to those in 2001; the direct drill had greater cumulative densities than the cultivated treatment (not significant $P < 0.05$). The addition of gypsum when deep ripping in 2001 appeared to be beneficial when the treatments were direct drilled in 2002. T4b produced greater root densities than T3 to 80 cm, while T4a and T4b had greater cumulative root densities than the other treatments to 20 cm (significant $P < 0.05$, Table 3). There was not a significant difference ($P < 0.05$) for the cumulative densities to 80 cm between all direct drilled treatments in 2002.

Table 3. Cumulative root length densities[2] (cm cm^{-2}) and levels of significance from ANOVA of wheat roots at Cressy in 2002.

Cumulative Depth	T1 DD	T2 Shallow cultivation	T3 DD	T4a DD	T4b DD + Gypsum
$C_{0\text{-}10\ cm}$	97.9	99.6	87.4	154.8	149.3
$C_{0\text{-}20\ cm}$	137.5 a	153.4 a	134.8 a	226.1 b	238.8 b
$C_{0\text{-}30\ cm}$	282.8	217.1	186.1 a	338.8	363.1 b
$C_{0\text{-}40\ cm}$	395.9	302.0	225.3	389.9	410.1
$C_{0\text{-}50\ cm}$	427.8	371.1	276.9	507.8	534.8
$C_{0\text{-}60\ cm}$	463.0	419.3	325.9	579.3	613.8
$C_{0\text{-}80\ cm}$	470.8	439.9	346.9 a	620.2	656.8 b

Note 1: Densities in the same row with different subscripts are significant ($P < 0.05$)
Note 2: Data derived from the 7 depths as follows:
$C_{0\text{-}10\ cm}$ = Lv $_{(0\text{-}10\ cm)}$ x 10, $C_{0\text{-}20cm}$ = $C_{0\text{-}10\ cm}$ + Lv $_{(10\text{-}20\ cm)}$ x 10, $C_{0\text{-}30\ cm}$ = $C_{0\text{-}20cm}$ + Lv $_{(20\text{-}30\ cm)}$ x 10
$C_{0\text{-}40\ cm}$ = $C_{0\text{-}30\ cm}$ + Lv $_{(30\text{-}40\ cm)}$ x 10, $C_{0\text{-}50\ cm}$ = $C_{0\text{-}40\ cm}$ + Lv $_{(40\text{-}50\ cm)}$ x 10
$C_{0\text{-}60\ cm}$ = $C_{0\text{-}50\ cm}$ + Lv $_{(50\text{-}60\ cm)}$ x 10, $C_{0\text{-}80\ cm}$ = $C_{0\text{-}60\ cm}$ + Lv $_{(70\text{-}80\ cm)}$ x 10.

Soil Water
In the initial year of the experiment, a good growing season rainfall was experienced; in particular there was very high rainfall in April (Table 4).

Table 4. Growing season rainfall (mm) for Cressy site throughout the experiment.

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2001	125	10.5	50	0	62.5	40.5	72.5	50.5	411.5
2002	15	31	42.5	64.5	20	31.5	28	72	304.5
2003	34.5	18.0	53.5	45.5	68.0	43.5	87.0	13.0	363.0
Average	45	50	49	46	48	51	52	48	389.0

Limited soil water measurements in 2001 indicated possibly increased soil water in deep ripped treatments (not statistically tested). In 2002 a program of soil water measurements, at approximately fortnightly intervals, was undertaken to enable confidence in, if any, soil water differences between treatments.

Soil water-2002
Rainfall in 2002 was 85 mm below average (Table 4). Water use in T3 was least (not significant) and the conversion to grain the most efficient (not significant) (Table 5). This was opposite to treatment T1. In contrast T1 had the highest water use (not significant). Soil water measurements indicated that T1 used more water in the lower section of the profile than T3. The further addition of gypsum to treatment T4 in 2002 did not increase the water use but resulted in better water use efficiency (T4a and T4b in Table 5). Previous work with addition of gypsum has highlighted the need for cultivation when adding gypsum (Baumhardt *et al.* 1992).

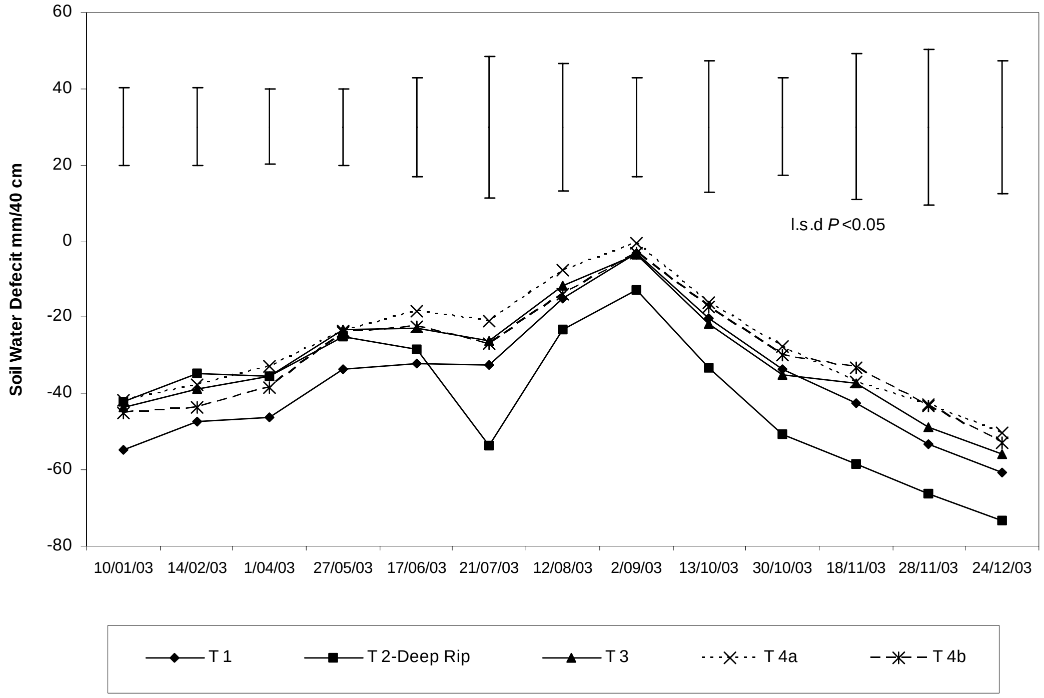
Table 5. Soil water use (mm) and water use efficiency at Cressy in 2002

Treatment	T1	T2	T3	T4a	T4b	l.s.d
	DD	SC	DD	DD	DD+G	($P < 0.05$)
Water use[1]	436	392	383	422	399	76
WUE[2]	13.2	14.5	15.7	12.8	13.6	22

1: Water use (mm) = Soil water (initial) – soil water (final) + total growing season rainfall. Surface runoff, probably small, was not measured and deep drainage assumed to be negligible.
2: Water Use Efficiency (kg ha^{-1} mm^{-1}) = Yield of grain (kg/ha) / Water use (mm)

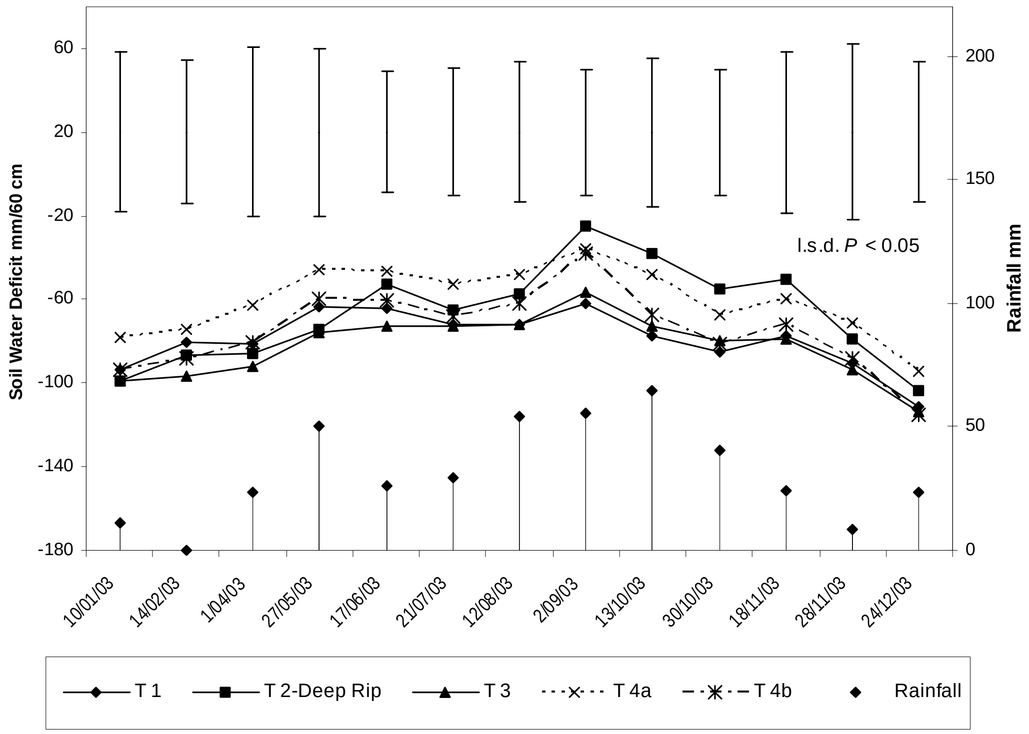
Soil water-2003
In 2003, growing season rainfall was 26 mm below average (Table 4). Deep ripping and sowing took place in late June after a very dry period in May.

Figure 2 shows that deep ripping caused the loss of soil water in the upper portion of the soil profile in treatment T2. The loss appeared to be partially compensated in the following period with increased infiltration later in the season, compared to the other treatments. Never the less, the increased infiltration was not sufficient to produce greater soil water than the other treatments (Figure 2). T2 had the greatest soil water, at depth, at anthesis, although this was not significantly different to the other treatments (Figure 3). Soil water use decline in the anthesis to harvest appeared to be greatest in T2. Unfortunately, due to the large deviation within the treatments there can be no firm conclusions as to the benefit of deep ripping on soil water.



Vertical bars show l.s.d. (P < 0.05) for soil water data at each date.
Soil water deficit = Field capacity (FC) – SW measurement calculated from NMM measurement.
FC: 10-50 cm = 171 mm

Figure 2. Soil water, 10 - 50 cm depth, 2003



Vertical bars show l.s.d. (*P* < 0.05) for soil water data at each date.
Rainfall value is cumulative between soil water measurements.
FC (see calculation Figure 2): 50-110 cm = 287 mm

Figure 3. Soil water, 50 - 110 cm, 2003.

Table 6 shows that the use of deep ripping did not significantly ($P < 0.05$) increase the water use or increase water use efficiency compared with the use of direct drill.

Table 6. Soil water use (mm) and water use efficiency, 2003.

Treatment	T 1 Direct drill	T 2- Deep Rip	T 3 Direct drill	T 4a Direct drill	T 4b Direct drill	l.s.d. ($P < 0.05$)
Water use (mm)	402.4	422.7	402.5	407.5	394.0	48.8
WUE	16.0	15.4	16.1	15.6	15.6	28.5

Water Use Efficiency (kg ha^{-1} mm^{-1}) = Yield of grain (kg/ha) / Water use
*See definition of WUE in Table 5

Grain yield

There was no significant increase in grain yield in any year with the use of deep ripping, with and without gypsum (Table 7).

Table 7. Grain yield and total above ground biomass (t/ha) in all years.

	Treatment*					l.s.d.
Year	T1	T2	T3	T4a	T4b	($P < 0.05$)
2001-G	7.03	7.43	8.26	8.15		1.36
2002-B	12.51	12.68	13.22	12.63	13.36	3.33
2002-G	5.69	5.65	5.83	5.38	5.61	1.67
2003-B	16.96	16.20	18.45	19.24	18.02	5.43
2003-G	6.43	6.50	6.47	6.35	6.16	1.40

Crop sequence: 2001 barley, 2002 wheat, 2003 barley *See treatment description in Table 2
G-grain yield, B-above ground biomass

Summary

The application of deep cultivation plus the addition of gypsum to the basaltic soils of south-western Victoria aimed to improve root exploration, and achieve more efficient use of the soil resource, particularly in soil water.

In the initial year of the experiment the use of deep ripping, with and without gypsum, was not significantly better than the use of direct drill for root exploration at depth. In the second year, 2002, there was a significant difference in root growth between deep rip followed by direct drill and the deep rip with two applications of gypsum followed by direct drill. The slow effect of gypsum on reducing sodicity may have caused the lack of effect in 2001 when gypsum was initially used with the deep rip.

Increased infiltration of water was seen after deep ripping in 2003 resulting in increased soil water which then appeared to be accessed by plants in the period after anthesis. But the gain in soil water was offset by loss of soil water, due to poor rainfall, following the deep ripping. This highlights the problem with the use of deep ripping in achieving gains in soil water in periods of erratically distributed rainfall.

Deep ripping, with and without gypsum, did not increase the water use or water use efficiency during this experiment. In the initial year of the experiment, the lack of significant difference in either grain yield or root density may be due to the slow effects of gypsum in ameliorating the subsoil. The subsoil has been shown to be sodic, high bulk density, increasing pH and salt content at depth (Table 1). These properties would contribute to a hostile chemical and physical environment for plant root growth. For a more complete understanding of the effects of deep ripping and gypsum on these subsoils, a complete measure of these properties would need to be undertaken over a longer time period after initial deep ripping with gypsum.

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