Deeper ripping and topsoil slotting to overcome subsoil compaction and other constraints more economically: way to go!

Paul Blackwell, Bindi Isbister, Glen Riethmuller, Edward Barrett-Lennard, David Hall, Jeremy Lemon DAFWA, **James Hagan** QDAF **and Phillip Ward** CSIRO

Key messages

- Cropping soils with sandy textures at least 500mm deep need deep ripping to 550mm or more to decompact hardpans, and topsoil slotting to allow the crop to yield closer to estimated potential in a CTF system.
- Topsoil slotting, by using soil inclusion plates attached to the rear of deep ripper tines, can increase yield from deep sandy soils more than by deeper ripping alone. Deeper ripping with topsoil slotting also helped lessen grain losses from dry and hot spring weather.
- Soil ameliorants (lime, gypsum or organic matter) can also have more effect on sandy or clay textured subsoils and offer better returns on investment when slotted with topsoil at the time of deep ripping, if there are additional constraints.

Aims

Our primary aim is to increase the economic viability of deep ripping by improving its longevity using controlled traffic and mechanical and chemical stabilisation of the subsoil with organic matter and, for some clay soils, gypsum. Buried topsoil may also benefit crop nutrition in dry seasons. This report investigates the effectiveness and economics of deeper ripping and topsoil slotting, with or without pre-topdressing of ameliorants; lime, gypsum or chicken manure, for crop production on deep sand, duplex or clay soils at sites which include each port zone of the WA grainbelt.

Methods

A research deep ripper was designed and built with topsoil inclusion plates, based on a seven tine Grizzly Deep Digger with 500mm tine spacing. A new frame and wheels were added between the tines and the rear crumbler roller. Agrowplow hydraulic break-out tines with a capacity to rip to 600mm depth were added to the new frame to run in line with the front tines. Grizzly tines were altered to allow for variable mounting height. Topsoil slotting plates were designed to be attached behind the hydraulic tines. The deep ripper is 3.48m wide, 9m long and weighed ~9t.

Topsoil and surface applied lime have been observed to fall down more easily behind tines when various shaped attachments have been added to deep ripping tines (Davies et al 2015). Top soil slotting plates were designed to employ such processes at a larger scale. A pair of plates was bolted to the rear of each tine 150mm apart at the rear. The upper edge of the plates ran at the base of the topsoil approximately 100mm below the surface. Surface chains held at an angle forward were sometimes used to help direct surface material into the slots. The following crumbler roller also helped push material into the slots and firm the surface after ripping to create a more level seed bed. Slot filling was better at lower speeds, about 4km/h, and with a moist subsoil and dry topsoil.

Eight trials were started on six farms; details in Tables 1 and 2. To minimise effects of cropping traffic the host farms used Controlled Traffic Farming (CTF). Sites 1, 2, 3, 8, 6 and 5 were on deep sandy soils; 4 and 7 on clayey soils.

Table 1. Trial numbers, locations, hosts, soils, crops, rainfalls and occurrences of moisture and heat stress.

#	location	host	soil type	crop	sowing date & (GSR) mm
1&2	Binnu	Diepeveens	pale yellow sand (1), loamy yellow sand (2)***	Wheat (Mace ⓓ)	11th May 402mm (219mm) 12H Sept#
3	Moora	Lawson Grains	loamy yellow sand**	Canola (Hyola 404)	4th May 260mm (177mm) D 3H Sept#
8	Esperance*	Lawson Grains	sand over clay duplex***	Wheat (Mace ⓓ)	19th May 432mm (280mm)
4&5	Beacon	Faulkner Bros	calcareous loamy earth (Morrel) ****(4) deep sandy duplex (5)	Wheat (Mace ⓓ)	13th May 363mm (240mm) 5H Sept#
6	Broomehill	Thompsons	sandy loam over clay	Wheat (Mace ⓓ)	1st June 352mm (227mm) D 1H Sept#
7	Ongerup	Hardings	Gritty grey clay (sodic)##	Wheat (Mace ⓓ)	5th May 293mm (189mm) D 1H (46^{o}C) Sept#

*Munglinup, **severely non-wetting topsoil, *** perched water table, ****free carbonate in B horizon, D=dry spring, # H = days 30^{o}C or more, ## grey sandy loam duplex with a high proportion of coarse sand in the sodic clay subsoil.

Table 2. Deep ripping and top-dressing treatments at each site

Ripping	Description	Top-dressing	Sites
Nil	No deep ripping	5t/ha lime#	1 2 3 5 6
R300	Deep ripping to 300mm with the rear tines of the ripper only	10t/ha limesand	8
R"500".	deep ripping to about 300mm with the front leading tines and to 450-600mm with the rear tines, depending on conditions	5t/ha gypsum	4 7
R"500"TS	As treatment 3 and with topsoil slotting using the rear tines	10t/ha chicken manure	1 2 4 6 7

limesand at all sites and crushed limestone at site 6.

The deep ripping was in a systematic pattern using the wing zones of the farm seeder and the zone between the tramlines (2.5m wide by lifting the outer tines). Fuel use was recorded from the tractor. The top-dressing was in blocks 12m to 36m wide at right angles to the deep ripping, separated by blocks of similar width without top-dressing. Top dressings were selected based on soil test results and observations of soil constraints by subsoil acidity or sodic soil.

Measurements were taken more intensively at Binnu, Moora and Beacon and included soil moisture, penetration resistance at field capacity, density and air-filled porosity, soil chemistry, biomass, nutrient uptake, seed depth, tiller and plant numbers at 8 weeks. Head density, kernel weight, grain yield and grain quality were measured at harvest. More detail is presented in a longer paper available from bindi.isbister@agric.wa.gov.au.

The probabilities of differences between treatments was estimated at the 95% and 90% confidence level using a nearest neighbour smoothing within each top-dressed block and a split-plot analysis of variance. For the more complex Moora and Esperance sites we fitted a linear mixed model to the yield data using the REML procedure in GenStat Statistical Software, edition 18, to compare the incomplete factorial treatment structure for each transect.

For the economic value of the deeper ripping and topsoil slotting we calculated the additional profit made for each dollar spent (return on investment or ROI). This was assessed for one and five year projections assuming no loss of response. A one percent per year increase of yield from year two from lime application was also applied as a predicted benefit (Gazey et al 2014). Fuel use was10L/ha for R300 on sand and 20L/ha to 25L/ha on clay sites, 20L/ha to 35L/ha for R"500" on sand to sandy loam and 40L/ha to 50L/ha on clay sites. Plates added 2L/ha on sandy soils and can add about 30% more when used in moist clay. Wear and tear for ripping was estimated at $20/ha and $21/ha with topsoil inclusion plates, costs on clay sites could be higher. Cost of top-dressing lime ranged from $27/t at Binnu to $64/t at Broomehill. Cost of topdressing gypsum was $38/t at Beacon and $55/t at Ongerup. The composted pelletised chicken manure cost approximately $500/t without transport or spreading cost. The discount rate was 6%.

Results

Deep ripping into the dry upper clay B horizons of the duplex soils was more effective when the Grizzly parabolic front tines were tilted to a steeper more aggressive angle. Speed of ripping ranged from 3km/h to 6km/h.

Subsoil physical and chemical constraints are shown in Table 3. The deep sands and deep sandy duplex sites 1, 2, 3, 8, 6 and 5 had hardpans with >3.5MPa maximum penetration resistance at 350mm to 400mm. At these sites pH was as low as 4.2 to 4.5 in the subsoil, associated with a possible Al toxicity constraint. The duplex clay soils had either a moderately saline and high boron alkaline subsoil at Beacon (4) or a sodic dispersive subsoil at Ongerup.

Table 3. Subsoil constraint details at sites used for the deeper ripping and topsoil slotting trials.

Site and #	Max PR*	depth, mm	min pH#	Al^{+++} ppm	depth, mm	$EC_{1:5}$ dS/m2	depth, mm	ESP	depth, mm
Binnu 1	4.1	350	4.2	6.3	450				
Binnu 2	4.0	350	4.5	1.7	350				
Moora 3	4.3	400	4.6	3.2	350				
Esperance 8	4.75	450	4.6	4.6	550				
Broomehill 6	4.8	350	4.5	0.45##	450				
Beacon 5	(6.0)	(350)	4.6	2.9	150				
Beacon 4						0.49-0.59***	200-400		
Ongerup 7						0.15	300-500	>16	300-500

*PR=penetration resistance at approximately field capacity, #= pH in $CaCl_2$ nb depth column to the right,
=Al extractable in $CaCl_2$, ##=meq/100g exchangeable Al, *= high Boron, () = estimate.

Sowing depth was generally deeper in the deep ripped plots and plant establishment was reduced, especially by clods from the deep ripped sodic subsoil at Ongerup (7). Spring moisture deficits limited grain fill at Moora (3), and Ongerup (7). Heat stress conditions occurred often in September at Binnu (1 and 2), Moora (3), Beacon (4 and 5) and for one very hot day (46^{o}C) at Ongerup (7). The Esperance site had the most rain and wettest and coolest growing season.

The water use efficiency (WUE) at the Binnu site 1 was calculated as 5kg/mm better than nil (3kg/mm) with deeper ripping and topsoil slotting. The loamy sand site 2 had a WUE of 19kg/mm with topsoil slotted chicken manure, but was in a swale with a possible perched water table; therefore it was uncertain that the WUE was from rain alone.

Subsoil constraints to grain yield of the deep sands or deep sandy duplex sites were mostly overcome by deep ripping and topsoil slotting to 500 to 600mm in this first season, unless lime was also needed (Tables 4 and 5). Deeper ripping and topsoil slotting added about 1000, 1400, 1100 and 1700kg/ha at sites 1, 2, 3, and 6 respectively; site 3 was in canola. At Binnu site 1 the deeper ripping and topsoil slotting improved grains per head by more than 100% (Appendix 1), presumably by enabling a better water supply and better head cooling in the hot afternoons in August and September. Aluminium toxicity may have been a more dominant constraint at the Beacon (5) and Esperance sites requiring lime incorporation by topsoil slotting to overcome it; deeper ripping alone was not sufficient at Beacon (5).

Topsoil slotting of the deeper sandy sites tended to provide more grain yield, higher grain protein and less screenings than deeper ripping, dependent on the spring finish. The drier spring at Broomehill resulted in less protein and more screenings. Topsoil slotting with previous lime top-dressing provided greater yield at Esperance when compared to deeper ripping alone. The Binnu sites had greater yield, better grain protein and less screenings with topsoil slotting and deeper ripping than deeper ripping alone. When topsoil was combined with lime it added 550, 800, 600 and 1000 kg/ha yield at Binnu (1 and 2), Esperance (8) and Beacon (5) compared to deeper ripping alone.

Some of the deeper sandy sites also became constrained by crop water supply in drier springs due to higher biomass, often from the fertility boost from manure, i.e. Binnu (1) and Broomehill; also from lime use at Broomehill. This reduced water supply for grains often led to more screenings and small grain and poorer grain set per head, unless compensated by deeper ripping and topsoil slotting.

Best returns on investment (ROI) for the deeper sandier soils came from deeper ripping with topsoil slotting (Tables 4 and 5). First year ROI for trials with dry growing seasons in 2015 ranged from $6 to $16 per dollar invested. The anticipated improved yield response to liming increased the predicted ROI in later years.

Deep ripping of the higher clay content soils at Beacon (Morrel) and Ongerup (gritty grey clay) had contrasting effects. The high electrolyte Morrel soil at Beacon (site 4) supressed yield with any depth of ripping, even when ameliorants (gypsum or manure) were top-dressed. However, inclusion of topsoil or topsoil with the ameliorant of high organic matter content reversed the yield loss and could improve yield by 1800kg/ha. The extra electrolyte from gypsum seemed to add to the osmotic stress in this soil, effectively increasing water stress, inducing smaller grain, more screenings and less yield. Manure seemed to stabilise the soil and double the infiltration of rain (other measurements with a rainfall simulator). This would increase spring water supply and explain the doubling of the grains per head of the deeper ripping and topsoil slotting with manure compared to the control. The benefits would be larger in a more common dry hot finish and the ROI of this for 5 years were very poor, but at least neutral for slotting topsoil alone.

The high exchangeable sodium percentage subsoil grey clay at Ongerup (site 7) showed best return on investment by only ripping to 300mm, avoiding the more dispersive subsoil and associated clods. Applying gypsum or manure increased yield when deeper ripped and topsoil slotted, despite a spring moisture deficit. Topsoil slotting with gypsum was encouraging because two of the three replicates were better with gypsum than just slotting topsoil alone. The topsoil slotting at this site often also increased grain protein in the relatively dry spring with one very hot (46^{o}C) afternoon in September. The main benefit of deep ripping and adding organic matter and gypsum was to reduce waterlogging and improve soil aeration for root growth and function of the crop.

Conclusions

Cropping soils with sandy textures at least 500mm deep need deep ripping to 550mm or more to decompact hardpans and topsoil slotting to allow the crop to yield closer to estimated potential in a CTF system. First year returns on investment for trials with dry growing seasons in 2015 ranged from $6 to $16 per dollar invested (ROI).

Topsoil slotting, with soil inclusion plates attached to the rear of deep ripper tines, can increase yield from deep sandy soils more than by deeper ripping alone. Deeper ripping with topsoil slotting also helped lessen grain losses from dry and hot spring weather. If slotting maintains the decompaction response longer it will provide very good returns on investment.

Table 4. Grain yield (GY) and return on investment (ROI, $/$invested) of treatments in first year at the deeper sand sites GY = grain yield, Bold and underlined is at least 95% probability difference, bolding alone is at least 90% probability difference from Nil rip or top dress. Yellow highlight for ROI>10.

	No top-dressing				5t/ha limesand (10t/ha Esprnce)				10t/ha chicken manure			
1. Binnu	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**
GY, t/ha	0.65	**1.49**	**1.69**	0.63	0.78	**1.38**	**1.83**	0.78	1.07	**1.66**	**1.57**	0.83
ROI 1 Yr	-1	5	6		-1	0	1	-2	-1	-1	-1	-1
ROI 5yrs	0	26	31		0	4	8	-5	-1	-1	-1	-1
2. Binnu	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**
GY, t/ha	1.51	2.25	**3.34**	1.90	2.05	**2.78**	**3.57**	2.11	**2.58**	**3.47**	**4.20**	2.23
ROI 1 Yr	-5	1	8		-1	0	2	-5	-1	-1	-1	-1
ROI 5yrs	-17	10	39		0	5	11	-17	-1	-1	0	-1
8.Esprnce	**R300**	**R600**	**R600TS**	**nil**	**R300**	**R600**	**R600TS**	**nil**				
GY, t/ha	2.48	3.12	3.28	2.87	3.60	3.58	**4.16**	3.57				
ROI 1 Yr	-4	1	2		-1	-1	0	-1				
ROI 5yrs	-16	6	10		1	1	2	1				
	No top-dressing						5t/ha limesand					
3.Moora (canola)	**R300**	**R300+ SPD**	**R550**	**R550 TSsw**	**R550 TSw**	**nil**	**R300**	**R300 +SPD**	**R550**	**R550T Ssw**	**R550 TSw**	**nil**
GY, t/ha	1.46	**2.13**	**2.67**	**2.59**	1.74	1.46	**2.14**	**3.00**	**2.86**	**2.94**	**2.63**	1.87
ROI 1 Yr	-1	2	16	14	3		1	2	3	3	2	0
ROI 5yrs	-1	14	76	66	16		8	13	18	18	14	4

SPD = spaded, sw= swale (between tramlines), w = wing of air seeder. Deep ripping and topsoil slotting also increased canola oil content by an average of 2.5% with or without lime application.

Soil ameliorants (lime, gypsum or organic matter) can also have more effect on sandy or clay textured subsoils and offer better return on investment when slotted with topsoil at the time of deep ripping if there are additional constraints. The possible benefits to Morrel soils of deeper ripping with topsoil slotting and addition of organic matter are very encouraging. Benefits to a grey clay of deeper ripping with topsoil slotting and addition or organic matter and gypsum are also encouraging.

The economic viability of organic matter addition to deep ripped subsoil needs further investigation of rates and direct incorporation of manures and other relatively high nitrogen content organic sources, for all the soil types used in this research. Employment of *in-situ* supply from residues of pasture and grain legumes in rotation with cereal or oilseed crops may prove more economically viable and less risky; also urea with low nitrogen content crop residues.

The ROI preliminary analysis here also needs nesting within a whole farm economic analysis in realistic time frames. At a whole farm scale, lower cost per ha strategies which cover large areas per year, e.g. digging deeper with the seeding gear, may complement more expensive strategies like deeper ripping and ameliorants to make best use of feasible annual investment. A similar analysis has been made previously for water repellency (Blackwell et al. 2014).

A smart investment strategy will also integrate setting up a CTF system with the subsoil amelioration to reduce preliminary ripping costs, by lifting tines for permanent tramlines, and to reduce traction and floatation problems of cropping to protect the investment in improved subsoils.

Best bet suggestions are to deep rip deep sandy soils with topsoil slotting to 500mm or deeper and set up CTF in the same season; also apply lime depending on the results of soil measurements and test strips of deep ripping and topsoil slotting with or without top-dressing lime. More investigations are required to clarify the effects of ripping and topsoil slotting with organic matter or gypsum on Morrel and Grey Clay soils.

Key words

Subsoil compaction, deep ripping, topsoil slotting, lime incorporation, organic matter, controlled traffic farming.

Table 5. Grain yield (GY) and return on investment (ROI, $/$invested) of treatments in first year at the duplex soil sites. Bold and underlined is at least 95% probability difference, bolding alone is at least 90% probability difference from Nil rip or top dress. Yellow highlight for ROI>10.

	No top-dressing				5t/ha limesand (10t/a Esprnce)				10t/ha chicken manure			
6. Beacon	**R300**	**R450**	**R450TS**	**nil**	**R300**	**R450**	**R450TS**	**nil**				
GY, t/ha	**3.12**	**3.75**	**3.66**	3.46	3.84	3.46	**4.50**	3.76				
ROI 1 Yr	-3	1	0		-1	-1	0	-1				
ROI 5yrs	-11	6	4		1	-1	3	1				
7. Brmehill	**R300**	**R500**	**R500TS**	**nil**	**R300**	**R500**	**R500TS**	**nil**	**R300**	**R500**	**R500TS**	**nil**
GY, t/ha	**2.41**	**3.15**	**3.15**	1.49	1.99	**2.97**	**2.92**	1.87	2.07	**2.91**	**3.08**	1.55
ROI 1 Yr	5	6	6		0	2	2	0	-1	-1	-1	-1
ROI 5yrs	24	32	30		4	11	11	5	-1	-1	-1	-1
	No top-dressing				5t/ha gypsum				10t/ha chicken manure			
5.Beacon	**R300**	**R450**	**R450TS**	**nil**	**R300**	**R450**	**R450TS**	**nil**	**R300**	**R450**	**R450TS**	**nil**
GY, t/ha	2.25	2.18	2.76	2.70	2.27	**1.99**	2.77	2.69	3.28	3.10	**4.52**	**4.02**
ROI 1 Yr	-4	-4	-1		-2	-2	-1	-5	-1	-1	-1	-1
ROI 5yrs	-15	-13	0		-3	-5	-1	-18	-1	-1	-1	-1
8.Ongerup	**R300**	**R400**	**R400TS**	**nil**	**R300**	**R400**	**R400TS**	**nil**	**R300**	**R400**	**R400TS**	**nil**
GY, t/ha	**3.53**	**3.27**	3.24	3.05	3.27	**3.76**	**3.75**	2.95	**3.76**	**3.59**	**3.58**	**3.87**
ROI 1 Yr	3	0	0		-1	0	0	-1	-1	-1	-1	-1
ROI 5yrs	15	3	3		0	1	2	-1	-1	-1	-1	-2

Acknowledgments

Davies S, Gazey C, Parker W, Blackwell P, Riethmuller G, Wilkins A, Negus P, Hollins T, Gartner D and Lefroy W (2015) Lime incorporation into acidic subsoils – assessing cost, efficacy, value and novel approaches Agribusiness Crop Updates 2015 Perth. http://www.giwa.org.au/2015-crop-updates

Gazey C, Oliver Y, Fisher J, Andrew J and Carr S (2014) 20 years of soil acidity RD and E in Western Australia—what have we learnt? Agribusiness Crop Updates 2014 Perth. http://www.giwa.org.au/2014-crop-updates

Blackwell P, Hagan J, Davies S, Bakker D, Hall D, Roper M, Ward P and Matthews A (2014) Smart no-till furrow sowing to optimise whole-farm profit on non-wetting soil. Agribusiness Crop Updates 2014 Perth. http://www.giwa.org.au/2014-crop-updates

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. Key assistance came from Matt Roesner, Richard Stone (Curtin Uni), Mark Dawson, Scott Thompson of Broomehill, Wes Harding of Ongerup, Lawson Grains, Faulkner brothers of Beacon and Piet Diepeveen and Damian Harris of Binnu. Also Ty Henning, Grantly Stainer, Tracy Hobbs, Quenten Knight. Wayne Parker, Chad Reynolds, Jana Kendle, Anna Kennedy, Anne Smith, Jo Walker, Liam Harte, Callum Gale (CBH), Virginia Smee, Chris Gazey and Mario d'Antuono.

Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

GRDC Project Number: DAW000243

Paper reviewed by: Wayne Parker

Appendix 1. Grain quality and value details from the sites growing wheat.

	No top-dressing				5t/ha limesand (10t/a Esprnce)				10t/ha chicken manure			
1. Binnu	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**
Yield t/ha	0.65	**1.49**	**1.69**	0.63	0.78	**1.38**	**1.83**	0.78	1.07	**1.66**	**1.57**	0.83
Protein %	**11.9**	**11.5**	**14.7**	13.4	*10.6*	**9.2**	11.4	11.8	**10.5**	**9.4**	11.8	11.8
Scrns %	3.1	**3.9**	2.9	2.2	2.0	1.2	1.5	1.2	1.8	2.1	1.6	1.5
2-2.5mm %	**33**	**39**	**33**	26	26	26	28	23	24	**32**	28	22
grains/head	21	**45**	**46**	19	28	**44**	**48**	24	27	**31**	**28**	21
heads/m2	85	93	**107**	88	**74**	79	**102**	84	**104**	**138**	**140**	**103**
GRADE	H2	H2	H1	H1	APW1	ASW1	APW1	H2	APW2	ASW1	H2	H2
price $/t	**287**	**287**	**297**	**297**	**282**	**274**	**282**	**287**	**279**	**274**	**287**	**287**
2. Binnu	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**
Yield t/ha	1.51	2.25	**3.34**	1.90	2.05	**2.78**	**3.57**	2.11	**2.58**	**3.47**	**4.20**	2.23
Protein %	**8.6**	**8.3**	9.7	10.1	10.4	9.7	**10.9**	**11.0**	**9.0**	**8.3**	**9.3**	10.1
Scrns %	1.8	1.6	1.0	1.6	1.6	2.2	1.9	1.9	1.5	1.8	1.3	1.6
2-2.5mm %	20.5	**15.6**	20.9	22.1	24.4	26.1	**29.4**	25.8	18.8	**17.0**	22.2	22.5
grains/head	16.6	22.2	**28.4**	20.2	23.2	**30.4**	**36.2**	24.4	22.2	**26.6**	**29.6**	20.7
heads/m2	224.0	240.3	**269.3**	234.7	219.2	226.0	252.5	218.5	**272.0**	**298.6**	**343.5**	255.8
GRADE	ASW1	ASW1	ASW1	APW2	APW2	ASW1	APW1	APW1	ASW1	ASW1	ASW1	APW2
price $/t	**274**	**274**	**274**	**279**	**279**	**274**	**282**	**282**	**274**	**274**	**274**	**279**
8.Esperance*	**R300**	**R600**	**R600TS**	**nil**	**R300**	**R600**	**R600TS**	**nil**				
Yield t/ha	2.48	3.12	3.28	2.87	3.60	3.58	**4.16**	3.57				
Protein %	8.94	9.93	9.74	9.51	9.4	10.1	**11.0**	10.0				
Scrns %	7.14	6.38	5.68	5.11	5.71	6.34	**6.79**	5.60				
GRADE	ASW1	ASW1	ASW1	ASW1	ASW1	APW2	APW2	APW2				
price $/t	**252**	**252**	**252**	**252**	**252**	**264**	**264**	**264**				
5. Beacon	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**Nil**				
Yield t/ha	3.12	3.75	3.66	3.46	3.84	3.46	**4.5**	3.76				
Protein %	8.8	9.2	8.9	9.2	**9.7**	8.8	**9.8**	9.2				
Scrns %	4.64	4.38	**2.87**	6.43	**3.53**	**1.35**	**2.91**	**2.23**				
2-2.5mm %	**40.65**	49.24	44.78	56.35	46.84	**30.39**	**40.56**	**37.73**				
grains/head	46	49	**40**	48	46	45	48	47				
heads/m2	197	225	258	227	231	194	260	220				
GRADE	ASW1	ASW1	ASW1	ASW1	ASW1	ASW1	ASW1	ASW1				
price $/t	**275**	**275**	**275**	**275**	**275**	**275**	**275**	**275**				
6. Broomehill	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**
Yield t/ha	**2.406**	**3.148**	**3.149**	1.488	1.988	**2.965**	**2.919**	1.87	2.069	**2.908**	**3.078**	1.553
Protein %	14.9	12.2	12.6	13.8	13.6	12.6	13.2	13.9	12.9	12.7	12.4	14.4
Scrns %	19.3	**6.1**	**11.4**	22.7	25.7	14	26.9	22.2	22.2	**8.3**	16.8	19.1
GRADE (hdr scr)	AUW1	H2	AUH2	AUW1	AUW1	AUW1	AUW1	AUW1	AUW1	AUH2	AUW1	AUW1
price $/t	**232**	**282**	**274**	**232**	**232**	**232**	**232**	**232**	**232**	**274**	**232**	**232**

*Esperance site some plots were excluded due to possible subirrigation from a shallow water table

Appendix 1. continued

	No top-dressing				5t/ha gypsum				10t/ha chicken manure			
4. Beacon	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**Nil**
Yield t/ha	2.249	2.184	2.761	2.702	2.266	**1.992**	2.772	2.694	3.28	3.102	**4.522**	**4.016**
Protein %	10.6	10.9	10.6	10.8	**11.7**	**11.9**	**11.5**	**11.9**	11.0	**11.3**	11.0	11.1
Scrns %	1.82	1.63	1.76	1.97	**6.67**	**8.71**	**6.54**	**7.46**	2.18	2.79	2.86	2.51
2-2.5mm %	41.9	**39.6**	44.5	45.9	**62.4**	**65.8**	**64.2**	**72.0**	46.1	42.7	47.9	51.2
grains/head	32	**42**	27	28	35	33	32	38	**47**	**77**	**60**	**50**
heads/m2	111	**83**	171	161	**96**	**93**	137	118	129	**75**	140	160
GRADE	APW1	APW1	APW1	APW1	AUH2	AUH2	AUH2	AUH2	APW1	APW1	APW1	APW1
price $/t	**282**	**282**	**282**	**282**	**272**	**272**	**272**	**272**	**282**	**282**	**282**	**282**
7. Ongerup#	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**	**R300**	**R550**	**R550TS**	**nil**
Yield t/ha	**3.53**	**3.27**	3.24	3.05	3.27	**3.76**	**3.75**	2.95	**3.76**	**3.59**	**3.58**	**3.87**
Protein %	13.0	12.9	**15.4**	13.6	13.4	12.9	13.8	13.6	**18.8**	**16.0**	**21.7**	**23.4**
Scrns %	19.3	21.9	30.4	28.7	**13.4**	**12.9**	**13.8**	**13.6**	19.3	19.7	**13.9**	**14.7**
GRADE	AUH2	AUH2	AUH2	AUH2	AUH2	AUH2	AUH2	AUH2	AUH2	AUH2	AUH2	AUH2
price $/t	**274**	**274**	**274**	**274**	**274**	**274**	**274**	**274**	**274**	**274**	**274**	**274**

The farm header yield had 8% screenings from the same paddock, so we used a realistic screenings value for the grain grade.