

Variable legacy effects of crop sequences

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Keywords

- farming systems, grain, hay, soil water.

Take home messages

- Crop legacy effects outlined in this paper relate to two consecutive dry seasons (2018 and 2019).
- Earnings before interest and tax (EBIT) in 2019 was highly correlated with the conversion efficiency of water to product (kg/ha/mm) and this was affected by crop species, sowing time and nitrogen management over both the 2018 and 2019 growing seasons.
- Barley (grain only) following canola (Greenethorpe) or wheat (Wagga Wagga) had an excellent water use conversion efficiency and was more profitable when harvested for grain compared with hay production.
- Higher EBITs were often achieved with wheaten hay compared with wheat grain, especially with early sown crops.
- Negative EBIT for wheat grain production could be avoided by opting for hay production, however this was not always true for canola.
- The 2019 EBIT for wheat or canola hay production was often lowest where early sown canola or wheat was grown in 2018 and low nitrogen management was applied.

Background

Financial returns from a single crop ignore the potential impacts of longer-term financial performance of the crop sequence. Crop legacy effects include differences in nitrogen (N), water and disease carryover as well as weed management considerations. These effects are often impacted by crop choice, sowing time and in-season N management. Under drought conditions such as those in 2018 and 2019, most sequence effects will be driven by water availability. The profit of the current AND consecutive seasons can be influenced by crop choice, input costs, N management and management decisions to graze crops, cut hay or harvest grain.

In recent times optimising early sowing opportunities for establishing wheat and canola with potential increased rooting depths highlight how access to deep stored soil water can provide additional value that cannot be captured by other crop species or later sowing times. However, if previous crop history has dried the profile significantly then establishing early sown crops strategically after pulse crops may be one way to increase the probability of improved soil water status through the soil profile and facilitate deeper soil water replenishment.

In the 2018 and 2019 seasons, grain crop production was limited by drought conditions with many growers choosing to graze crops or cut crops



for hay rather than harvesting for grain. The impact of hay cutting options on soil water are not always predictable. For example, early crop termination of canola will stop transpiration earlier in the growing season compared with canola left for grain production, provided complete and timely control of the canola regrowth is achieved. Conversely wheaten hay options often substantially decreased the residue cover to a greater extent than hay strategies applied to canola which may influence soil water storage. This may lead to different fallow efficiency and growing season transpiration efficiency, both of which have large impacts on subsequent crops. Based on this reasoning, one could speculate that there may be greater negative legacy effects on soil water from cutting wheaten hay (large residue loss) compared to canola hay (lower residue loss).

This paper considers the profitability of different options in the 2018 and 2019 seasons, and also the 2018 crop legacy effects that influenced the 2019 outcomes. The focus, in particular is on comparisons of crop choice and management impacts on grain or hay production as well as how these choices may impact on financial returns.

Experiment outline

Four contrasting locations were selected in 2017 that represented a range of soil types,

environmental factors and encompassed a diverse range of grower and consultant groups. The main core experiment site is located at the Wagga Wagga Agricultural Institute with three regional node sites located at Condobolin Research and Advisory Station, Greenethorpe and Urana. There are six treatment sequences that are common to all sites with the Wagga Wagga site encompassing all treatments. The crop sequence treatments applied are provided in Table 1. All sites were sown to wheat in 2017 with the treatment sequences starting in 2018. Data from the Wagga Wagga, Greenethorpe and Urana sites are presented in this paper.

Methods used for determining hay production

Hay dry matter (t/ha) = total crop dry matter greater 15cm high x 0.7 (account for losses)

Results and discussion

Wagga Wagga farming systems site in 2019

The Wagga Wagga farming systems site received approximately 185mm of rainfall from April to October and an estimated summer fallow conservation of 20mm. Annual average rainfall from April to October at this site is 350mm and expected average summer fallow conservation is 42mm. Growing season soil evaporation is typically in the range of 70mm to 115mm. The crop sequence treatments applied are provided in Table 1.

Table 1. Farming system sites with sowing, nitrogen and winter grazing strategies applied to different crop sequences.

Crop sequences	Urana		Wagga Wagga		Greenethorpe	
	Sowing	Nitrogen	Sowing + grazing	Nitrogen	Sowing + grazing	Nitrogen
Canola-Wheat	E, T	Low, High	E+G, T	Low, High	E+G, T	Low, High
Canola-Wheat-Barley	T	Low	T	Low, High		
Canola-Wheat-Wheat					T, L	High
Lentil-Canola-Wheat	E	Low, High	E, T	Low, High	E	Low, High
Lupin-Canola-Wheat			T	Low		
Faba bean-Canola-Wheat	T	Low			T	Low
Chickpea-Wheat			T	Low	T	Low
Biserrula-Wheat			T+G	High		
*Legume-Canola-Wheat	T	Low	E+G, T	Low, High	E+G, T	Low
Faba bean/Canola-Wheat			T	Low	T	Low
Wheat-Wheat-Wheat			T	Low, High	T	Low
Fallow-Canola-Wheat	E	High	E, T	High		
Canola-Wheat (12 t/ha)			T	Low		
Canola-Wheat (6 t/ha)			T	Low		
Flexible one	Flexible	Flexible	Flexible	Flexible	Flexible	Flexible
Flexible two	Flexible	Flexible			Flexible	Flexible

E = Sown early over late March to mid-April period, E+G = As above plus winter grazing, T = Sown timely over late April to mid-May period, Low = Low nitrogen budgeting based on decile 2 to 4 rainfall projections, High = High nitrogen budgeting based on decile 6 to 8 rainfall projections, *Legume = Vetch, balansa clover and arrowleaf clover, Flexibly = the local consultants' choice (James Madden and John Stephenson (Urana), Greg Condon (Wagga Wagga) and Tim Condon and Peter Watt (Greenethorpe), Chris Baker (Condobolin)).



Crop choice

The 2019 EBIT performance for grain production tended to be highest for barley and lowest for canola with wheat intermediate. Similar comparison for hay production was obtained; barley equal to wheat and both of these crop choices often performed better than canola (Table 2).

Sowing time

Un-grazed early sown crops of wheat or canola in 2019 with the same 2018 sowing time and cropping history (for example; wheat/canola or canola/wheat) produced lower grain yields in 2019 than timely sowing of these species. Hay production for these treatments reduced differences between sowing times (early verses timely) as measured by financial outcomes (Table 2).

Nitrogen

Nitrogen added to timely sown wheat where the crop sequence was canola/wheat increased wheat **hay yield** and EBIT, while N added to this sequence decreased wheat **grain yield** and EBIT. Nitrogen added to 2019 timely sown canola in a wheat/canola rotation increased both hay and grain yields and EBIT (Table 2).

At the Wagga Wagga site, the 2018 crop choice and N management affected the hay production of the 2019 early sown canola (Hyola®970CL). Hay production was highest following lentils, and lowest following wheat (a difference of approximately 1.5t/ha) while the canola hay after the vetch-trifolium

hay was intermediate. (Figure 1). The difference of approximately 1.5t/ha in hay production equated to a difference in EBIT of \$169/ha. In this example the 2018 crop choice had a larger effect on hay production than N management. These results suggest multi-year returns need to be considered when making crop sequence decisions.

2019 profits

Earnings before interest and tax are provided for the Wagga Wagga farming systems site (Table 2 and Figure 2). The cluster (Figure 2) that provided the best positive earnings for grain and hay production included Planet[®] barley (closed circle), some treatments of timely (early May) sown Beckom[®] wheat with high N (open square) and all treatments of low N (open triangle) as well as some treatments of timely (late April) sown canola (var. Pioneer[®]43Y92 CL) with high (open diamond) and low N (open circle), (Figure 2).

The best financial results for 2019 timely canola occurred after the 2018 forage mix (vetch + Trifoliums) or lentil (var. Hallmark[®]) while best financial results for timely wheat were achieved after chickpea (var. Slasher[®]) or biserrula (var. Casbah). The poorest results for hay and grain production were obtained by early sown canola (var. Hyola[®]970, cross and dash symbols) which was grazed in winter. These treatments failed to respond to the rainfall and losses were greatest where the preceding crop (2018 crop) was early sown wheat (var. Kittyhawk[®]).

Table 2. A subset of the Wagga Wagga farming systems cropping only treatments for production (grain or hay, t/ha), income (\$/ha), costs (\$/ha) and earnings before interest and tax (EBIT, \$/ha).

Treatment	Sow	Nit	Crop 2018	Crop 2019	Hay cut (t/ha)	GROSS INCOME (\$/ha)	TOTAL COSTS (\$/ha)	Hay EBIT (\$/ha)	Grain Yield (t/ha)	GROSS INCOME (\$/ha)	TOTAL COSTS (\$/ha)	Grain EBIT (\$/ha)
Wheat/vetch/canola	T	2	Beckom	Vetch	2.9	\$920	\$445	\$475	-	-	-	-
Wheat/barley/canola	T	2	Beckom	Planet	4.6	\$1,072	\$613	\$459	3.2	\$1,150	\$540	\$610
Biserrula/wheat	T	7	Cashbah	Beckom	5.0	\$1,248	\$720	\$528	2.8	\$1,146	\$608	\$538
Canola/wheat	T	7	43Y92 CL	Beckom	5.1	\$1,276	\$729	\$547	1.1	\$436	\$589	-\$153
Canola/wheat	T	2	43Y92 CL	Beckom	4.2	\$1,059	\$625	\$434	1.8	\$747	\$522	\$225
Chickpea/wheat	T	2	Slasher	Beckom	5.2	\$1,302	\$692	\$610	2.7	\$1,096	\$563	\$533
Canola/wheat	E	7	Hyola 070	Kittyhawk	4.7	\$1,168	\$692	\$476	0.1	\$45	\$576	-\$531
Canola/wheat	E	2	Hyola 071	Kittyhawk	3.3	\$817	\$562	\$255	1.0	\$414	\$495	-\$81
Canola/wheat	T	7	Beckom	43Y92 CL	4.2	\$1,048	\$723	\$325	1.4	\$848	\$613	\$235
Canola/wheat	T	2	Beckom	43Y92 CL	3.2	\$791	\$609	\$182	1.1	\$682	\$540	\$142
Canola/wheat	E	7	Kittyhawk	Hyola 970	2.0	\$656	\$598	\$58	-	-	-	-
Canola/wheat	E	2	Kittyhawk	Hyola 970	1.7	\$494	\$550	-\$56	-	-	-	-
Canola/wheat/lentil	T	7	Hallmark	43Y92 CL	4.7	\$1,175	\$757	\$418	1.5	\$887	\$625	\$262
Canola/wheat/lentil	T	2	Hallmark	43Y92 CL	4.4	\$1,089	\$702	\$387	1.7	\$1,002	\$589	\$413
Canola/wheat/lentil	E	7	Hallmark	Hyola 970	3.4	\$846	\$691	\$155	-	-	-	-
Canola/wheat/lentil	E	2	Hallmark	Hyola 970	3.1	\$770	\$647	\$123	-	-	-	-

E = Sown early over early April period, T = Sown timely over late April to mid-May period, Nit 2 = Low nitrogen budgeting based on decile 2 rainfall projections July to October, Nit 7 = High nitrogen budgeting based on decile 7 rainfall projections July to October.



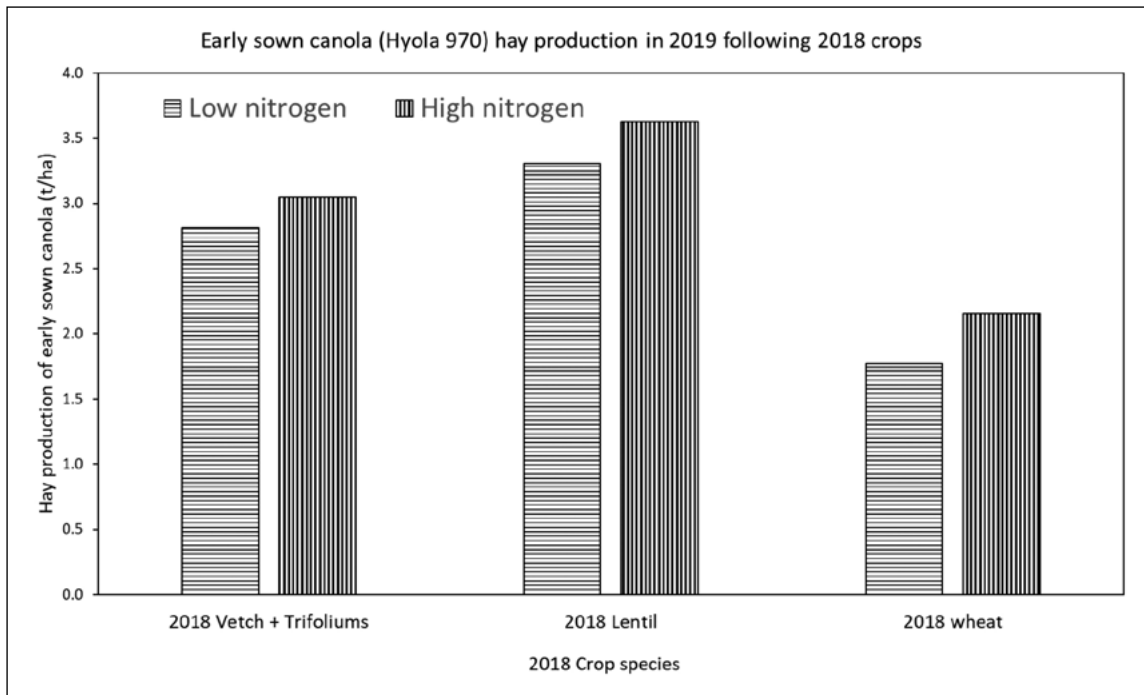


Figure 1. Early sown canola (var. Hyola®970) cut for hay in 2019 that was previously cropped in 2018 with either a vetch plus Trifolium mix cut for hay, lentils (var. Hallmark[®]) or wheat (var. Kittyhawk[®]) harvested for grain. Low nitrogen assumed July to October rainfall was decile 2 and high nitrogen management assumed July to October rainfall was decile 7.

Grain production for lentil (0.72t/ha), chickpea (0.54t/ha) and lupin (var. Batman (1.3t/ha)) in 2019 indicated that lupin was the most profitable under the conditions experienced (Figure 2). The same comparison for hay production indicates chickpea were the more profitable legume crop. In each case

these grain legume crops were sown with Beckom[®] wheat in 2018.

There was a tendency for high N fed crops of timely sown wheat (open square) and canola (open diamond) that had previously been cropped to canola and wheat to have better hay returns than

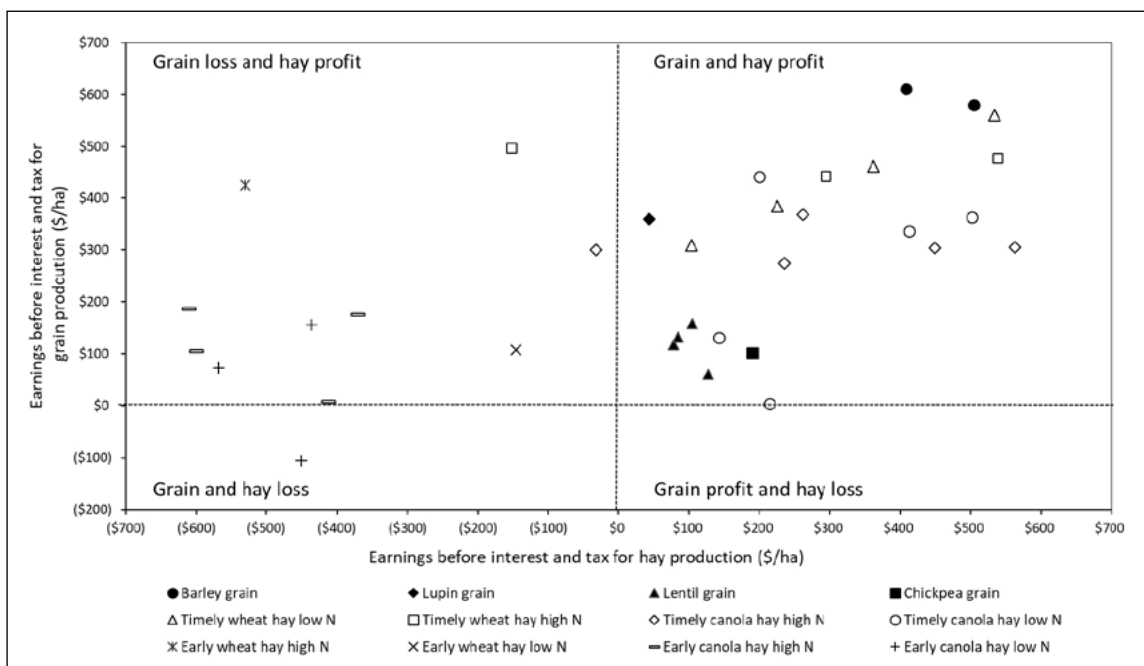


Figure 2. 2019 EBIT for grain or hay production for various crops and management practices at the Wagga Wagga farming systems site.



grain returns (Figure 2). However, the opposite was true if the timely sown wheat followed biserrula or the canola followed the forage legume mix (vetch + Trifoliums). This indicates the 2018 crop influenced the preferred financial choice for either grain or hay production in 2019 (2018 crop history not shown in Figure 2).

There was a strong positive correlation between EBIT and the amount of product produced per mm of water received. This emphasises the importance of crop legacy effects, summer fallow efficiency, and minimising in-crop evaporation. The best water use efficiency (WUE) of grain production in 2019 was achieved by barley (2019) following wheat (2018) while the best WUE for hay production was achieved by timely high N canola after vetch (open diamond) and timely wheat with high (open square) and low N (open triangle) after biserrula and chickpea, respectively (Figure 3).

Greenethorpe farming systems site

All treatments implemented at the Greenethorpe farming systems site are outlined in Table 1. In 2019, the Greenethorpe site received 98mm between the 23 and 31 March and 128mm of rainfall from April to October with the average estimated summer fallow water conservation of approximately 40mm (157mm December 2018 to February 2019). Early wheat and canola crops were sown between 23 and 27 March 2019, Planet^d barley sown on the 24 April with all other timely crops sown between 1 and

14 May 2019. The production, income, costs and EBIT for a subset of the treatments that relate to a cropping only enterprise is provided in Table 3. In the cropping ONLY treatments, the top three most profitable sequences included barley harvested for grain following timely canola (4.7t/ha), legume hay following timely wheat (3.7t/ha hay dry matter (DM)) and timely wheat hay/low N following timely triazine tolerant canola (canolaTT) (5.1t/ha hay DM) (Table 3).

The highest hay yields and EBITs were produced from timely wheat following timely canola (average 5t/ha hay with \$562/ha EBIT), compared to early wheat following early canola producing 3.5t/ha hay DM with \$297/ha EBIT. The timely wheat grain yield ranged between 2.3t/ha and 2.8t/ha (EBITs \$262/ha to \$496/ha, respectively), with higher grain yields in any second year of timely wheat (2.8t/ha compared with less than 2.6t/ha) due to increased soil moisture concentration with higher surface stubble load.

The faba bean and chickpea pulse crops following timely wheat produced higher EBITs than timely canola (\$406/ha and \$277/ha compared with less than \$34/ha). The timely canola averaged 3t/ha hay DM or 0.8t/ha to 1.1t/ha grain indicating in this dry season, canola hay was more profitable than canola grain. All early sown crops had insufficient moisture to produce a grain yield, so they were either cut for hay or grazed, with the early canola following lentils only producing approximately 2.4t/ha hay DM (and a negative EBIT) (Table 3). These results indicate that under two years of dry conditions early sown crops

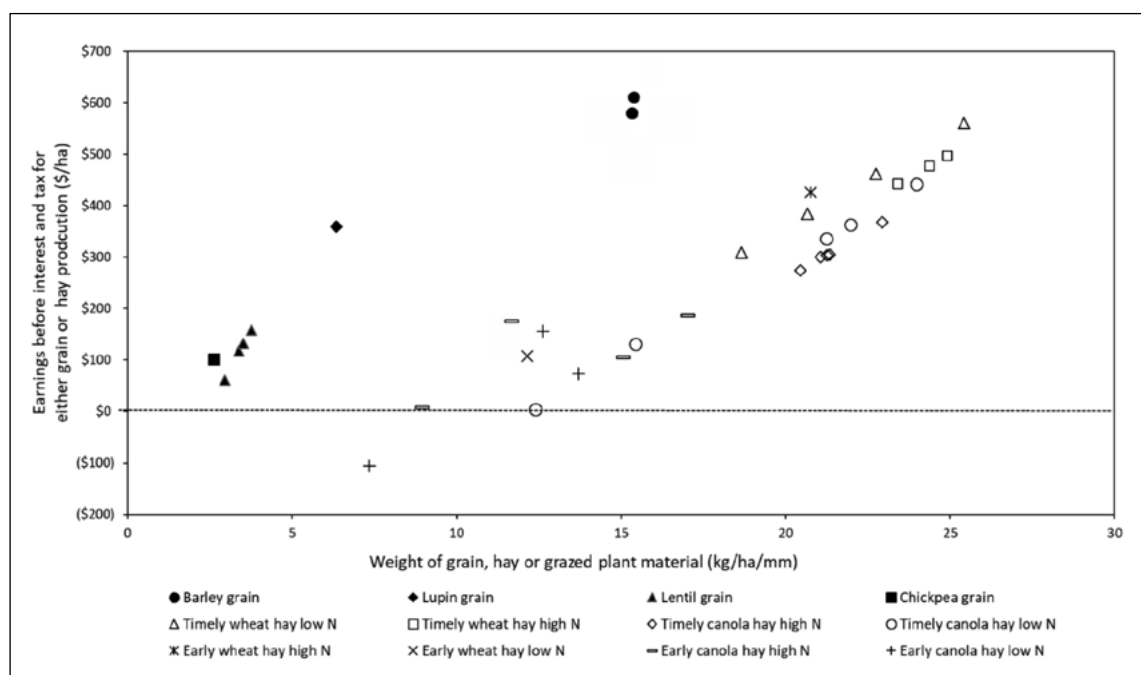


Figure 3. 2019 EBIT, for grain or hay production for various crops and management practises at the Wagga Wagga farming systems site.



Table 3. A subset of the Greenethorpe farming systems cropping only treatments for production (grain or hay, t/ha), income (\$/ha), costs (\$/ha) and earnings before interest and tax (EBIT, \$/ha).

Treatment 2019	Crop 2018	Crop 2019	Sow	Nit	Var 2019	Income Method	Hay DM (t/ha)	Grain Yield (t/ha)	GROSS INCOME (\$/ha)	TOTAL COSTS (\$/ha)	EBIT (\$/ha)
Flexible 1	Canola TT	Barley	F	F	Planet	Grain		4.7	\$1,398	\$470	\$928
Legume (Hay)/Timely/NG	Wheat	Legume Hay	T	2		Hay	3.7		\$1,280	\$527	\$754
Wheat/Timely/N7 (C-W) HAY	Canola TT	Wheat	T	7	Coolah	Hay	5.1		\$1,270	\$683	\$587
Wheat/Timely/N2 (C-W) HAY	Canola TT	Wheat	T	2	Coolah	Hay	4.8		\$1,212	\$674	\$538
Wheatyr2/Timely/N2 (W-W-W) Grain	Wheat	Wheat	T	2	Coolah	Grain		2.8	\$1,031	\$535	\$496
Wheatyr2/Timely/N2 (C-W-W) Grain	Wheat	Wheat yr 2	T	2	Coolah	Grain		2.8	\$1,018	\$534	\$484
Wheat/Timely/N2 (ChP-W)	Chickpea	Wheat	T	2	Coolah	Grain		2.6	\$939	\$527	\$411
Fababean	Wheat	Fababean	T	2	Samira	Grain		2.3	\$1,404	\$999	\$406
Wheat/Timely/N2 (C-W) Grain	Canola TT	Wheat	T	2	Coolah	Grain		2.4	\$860	\$523	\$337
Wheat/Early/N7 (Len-C-W) HAY	Canola- Hyola 970	Wheat	E	7	Bennett	Hay	3.6		\$889	\$571	\$318
Chickpea	Wheat	Chickpeas	T	2	Slasher	Grain		1.2	\$996	\$719	\$278
Wheat/Early/N2 (Len-C-W) HAY	Canola- Hyola 970	Wheat	E	2	Bennett	Hay	3.4		\$840	\$563	\$277
Wheat/Timely/N7 (C-W) Grain	Canola TT	Wheat	T	7	Coolah	Grain		2.1	\$781	\$519	\$262
Canola/Timely/N2 (C-W) HAY	Wheat	Canola	T	2	HyTecTrophy	Hay	3.1		\$782	\$687	\$96
Canola/Timely/N2 (C-W) Grain	Wheat	Canola	T	2	HyTecTrophy	Grain		1.2	\$682	\$648	\$34
Canola/Timely/N7 (C-W) HAY	Wheat	Canola	T	7	HyTecTrophy	Hay	2.9		\$729	\$705	\$24
Lentil/N7	Wheat	Lentils	T	7	HallMarkXT	Grain		0.9	\$524	\$554	-\$30
Canola/Early/N7 (Len-C-W) HAY	Lentil	Canola	E	7	Hyola 970	Hay	2.5		\$614	\$657	-\$43
Canola/Early/N2 (Len-C-W) HAY	Lentil	Canola	E	2	Hyola 970	Hay	2.3		\$564	\$622	-\$58
Canola/Timely/N7 (C-W) Grain	Wheat	Canola	T	7	HyTecTrophy	Grain		1.0	\$594	\$671	-\$77
Canola/Timely/N2 (Leg-C-W) Grain	Legume Hay	Canola	T	2	HyTecTrophy	Grain		0.8	\$458	\$638	-\$180

E = Sown early over late March to mid-April period, T = Sown timely over late April to mid-May period, Nit 2 = Low nitrogen budgeting based on decile 2 rainfall projections July to October, Nit 7 = High nitrogen budgeting based on decile 7 rainfall projections July to October, F = Flexibly = the local consultants' choice, Tim Condon and Peter Watt.

are impacted the greatest, with timely canola being impacted more than timely wheat and timely wheat impacted more than timely barley.

At the Greenethorpe site the amount of product produced per mm of water was positively correlated with EBIT (Figure 4) and negatively correlated with cost of production (data not shown). High conversion

efficiencies provided 20kg to 30kg of product per mm of water and low conversion efficiencies produced approximately 5kg of product per mm of water. Coolah[®] wheat cut for hay and Planet[®] barley harvested for grain produced the highest product weights per mm of water. HyT Tec[®] Trophy canola and Hallmark[®] lentils for grain production produced the

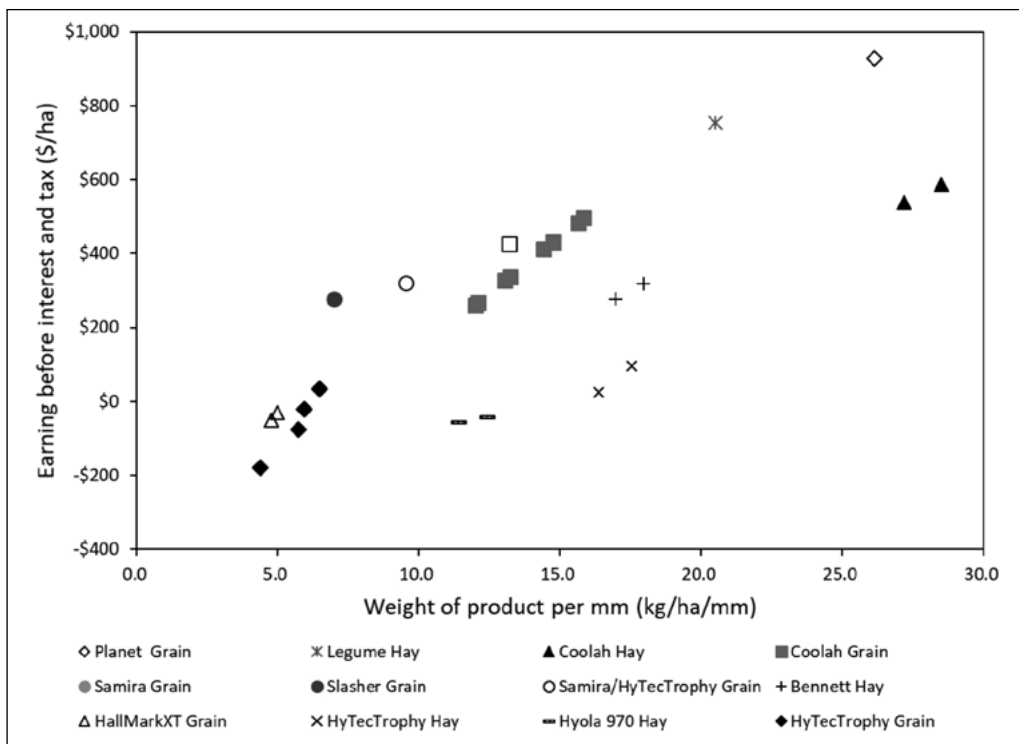


Figure 4. EBIT (\$/ha) for grain, grazing and/or hay production of various crops and management practises and weight of product produced per mm of water (kg/ha/mm) for the Greenethorpe farming systems site.



Table 4. A subset of the Urana farming systems cropping only treatments for production (grain or hay, t/ha), income (\$/ha), costs (\$/ha) and earnings before interest and tax (EBIT, \$/ha).

Treatment	Sow	Nit	Crop 2018	Crop 2019	Grain		GROSS	TOTAL	
					Hay cut	Yield	INCOME	COSTS	EBIT
					(t/ha)	(t/ha)	(\$/ha)	(\$/ha)	(\$/ha)
Wheat/vetch/canola	T	2	Beckom	Vetch	0.8	-	\$228	\$440	-\$212
Wheat/barley/canola	T	2	Beckom	Planet	1.1	-	\$259	\$480	-\$221
Canola/wheat	T	7	43Y92 CL	Beckom	-	3.1	\$1,340	\$473	\$867
Canola/wheat	T	2	43Y92 CL	Beckom	-	2.8	\$1,193	\$444	\$749
Canola/wheat	E	7	Hyola 070	Kittyhawk	-	1.9	\$911	\$484	\$427
Canola/wheat	E	2	Hyola 071	Kittyhawk	-	1.6	\$688	\$424	\$264
Canola/wheat	T	7	Beckom	43Y92 CL	-	1.0	\$614	\$450	\$164
Canola/wheat	T	2	Beckom	43Y92 CL	-	1.0	\$628	\$441	\$187
Canola/wheat	E	7	Kittyhawk	Hyola 970	0.9	-	\$182	\$615	-\$434
Canola/wheat	E	2	Kittyhawk	Hyola 970	0.6	-	\$157	\$542	-\$385
Canola/wheat/lentil	T	7	Hallmark	43Y92 CL	-	1.0	\$626	\$488	\$137
Canola/wheat/lentil	T	2	Hallmark	43Y92 CL	-	1.5	\$890	\$447	\$443
Canola/wheat/Fababean	T	2	Samira	43Y92 CL	-	1.0	\$628	\$440	\$188

E = Sown early over early April period, T = Sown timely over late April to mid-May period, Nit 2 = Low nitrogen budgeting based on decile 2 rainfall projections July to October, Nit 7 = High nitrogen budgeting based on decile 7 rainfall projections July to October, Note: Emu damage on Planet[®] barley reduced the amount that could be captured for hay production.

lowest conversion efficiency of product per mm of water (Figure 4).

Urana farming systems site

All hay production in 2019 at Urana produced negative EBIT while all grain production produced positive EBIT (Table 4). Wheat tended to produce higher returns than canola and higher N tended to produce high wheat returns but similar or lower canola returns. This N effect was in contrast to the Wagga Wagga site (Table 2 and 4). The highest 2019 canola EBIT was produced from timely sowing canola after lentils while the highest 2019 EBIT for wheat was produced from timely sown wheat grown after timely sown canola (Table 4).

Conclusions

Crop choice, sowing time and N management in 2018 impacted on crop returns in 2019 and this challenges growers to think of the negative and positive effects of certain crops on the profitability of the crop sequence. While legume break crops provided consistent advantages for the subsequent crop this was not always the case with canola.

At the Greenethorpe and Wagga Wagga sites, hay options provided some advantages for specific 2018 and 2019 crop combinations. In some cases, this ensured losses from grain production were avoided but was not a guarantee for profitability. Grain production was still profitable at some sites (Urana) for certain crop combinations, particularly where timely sown cereal or canola followed legume forage or legume grain crops.

Crop species performance under drought conditions in southern NSW tended to be ranked as barley better than wheat, which is better than canola (barley > wheat > canola). Pulse crop performance under drought conditions in southern NSW tended to be ranked as faba bean which was equivalent to lupin which was better than chickpea which was equivalent to lentil (faba bean = lupin > chickpea = lentil).

The Vertisol soil at the Urana site provided better grain filling conditions and subsequently grain production was more profitable at this site than hay production.

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