Managing water and N across years and crop sequences to drive profit

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Take home messages

- Matching N supply to water limited yield targets annually is an ongoing challenge. But with legacies of carry-over N and water, how do these decisions play out over a crop sequence?
- Our system experiments investigate interactions of crop sequence and early sowing systems (+/- grazing) with two N fertiliser strategies (decile 2 (low); 7 (high)) on WUE, production and profit
- In the consecutive dry seasons of 2018/2019, grain yield did not respond to the higher N fertiliser strategy, but grazed forage and hay yields were increased by applied and carry-over N. In the wet 2020 season, responses to N fertiliser were strongly influenced by crop sequence – less response to N in more intense sequences, and in sequences with legumes
- As for the dry 2018-19 seasons, there were legume options as profitable as wheat and canola in 2020 despite higher disease management costs, although canola was the most profitable option at the higher rainfall Greenethorpe site where subsurface acidity may impact some legumes
- Overall average annual earnings before interest and taxes (EBIT) over 3 years were higher for early-sown, grazed systems ($600-$1400/ha) than for timely-sown, un-grazed systems ($200 - $800/ha). Grazed systems responded profitably to higher N, while the profitability of ungrazed systems depended on the crop intensity and the N strategy.

Background – changing the water and N-use paradigm from crop to crop sequence

Australian farmers have been enthusiastic adopters of crop benchmarking tools (e.g. French and Schultz or Yield Prophet®) to compare the performance of **individual crops** to water-limited potential. However, in dryland farming systems, it makes sense to consider the efficiency of water use **across the crop sequence**, to account for the inevitable legacy effects of one crop to the next (i.e. carry over effects on water, N, weeds and disease).

In southern NSW, significant improvements in the water-use efficiency and profitability of crops have been achieved in recent years with improved crop sequences, better fallow management and new earlier sowing systems with suitable varieties (including grazed crops). Diversifying the crop sequence to maintain profit and manage biotic constraints can increase the average profitability across 3-4-yr crop sequences by $150 to $200/ha compared with common sequences, even when individual crops were well managed. Earlier sowing systems are also proving efficient and profitable for individual wheat and canola crops (including grazed crops), but the legacy of dry or low-N soils left by these higher-yielding crops may affect following crops. Our experiments and simulation studies suggest earlier sowing strategies can provide benefits across the crop sequence, but this is influenced by rainfall, crop sequence and **modified by N management**.

Our farming systems project is unique in exploring these interactions to develop strategies to convert annual rainfall into more profit across a crop sequence while managing costs, risk, soil fertility, weeds and diseases. Here we provide a brief overview of the overall project, and the focus of this paper is on understanding how nitrogen strategies play out in terms of productivity and profitability across a range of different systems involving different sequence, sowing time and grazing choices.

The Southern Farming Systems Project – a brief description

To cover the range of soils and climates in southern NSW, sites were established at Wagga Wagga (core site), Greenethorpe (higher rainfall), Condobolin (lower rainfall) and Urana (different soil type). A range of different sequences were established to compare with the common baseline of canola-wheat-wheat sequences typical of the area (Table 1). These included more intensive cereal sequences (wheat and barley), a range of high value (lentil, chickpea) and low-value (lupin, faba) legume options and a forage option (high density legume, mainly vetch) grazed and/or cut for hay. The treatments generated different water and N-use patterns as well as weed, disease and cover legacies monitored by the team. For some sequences, we included interactions of early sowing (March-early April) and timely sowing (mid-April-mid May) of the wheat and canola options. The early-sown options at Wagga and Greenethorpe were grazed by sheep in winter, a recent and profitable management choice on mixed farms with significant implications for water and N use.

Together with the experimental measurements at the 4 sites, we are validating and running APSIM simulations to extrapolate the results across more seasons and explore the data more fully.

N strategies

The N management strategies compared across some systems were based on either a conservative (decile 2) outlook, or a more optimistic (decile 7) outlook for spring in each season. For each non-legume crop in each year of the sequences, the soil N was measured pre-sowing and a potential yield estimate was made in winter based on the starting soil water and N and the seasonal conditions up to that time. Nitrogen was then top-dressed as urea assuming either a decile 2 or a decile 7 finish to the season. Assuming an average season is decile 5, this means that often the decile 2 N strategy would be too low, and the decile 7 treatment too high for the yield potential in any year. Using this approach, the legacies of carry-over N from either legumes or unused fertiliser N would be accounted for in the pre-sowing tests, and less N required accordingly. This approach (compared to set N rates) better mimics farmer practice, and also allows consideration of the risk and reward for conservative or robust N strategies. In the following sections we will focus on selected results that explore the consequences of these strategies in terms of productivity, efficiency and risk in the different systems outlined in Table 1.

Table 1. Selected treatments common to most sites including crop sequence, time of sowing and N strategies. Early-sown treatments included winter grazing of the crops at Wagga and Greenethorpe.

Treatment description	Sequence	Sowing time	N strategy (decile 2 or 7)	Grazing
Baseline	Canola-wheat-barley	Timely	2, 7	
Intense baseline	Canola-wheat	Early, timely	2, 7	Yes
Diverse high value 1	Lentil-canola-wheat	Early, timely	2, 7	
Diverse high value 2	Chickpea-wheat	Timely	2	
Diverse low value	(Faba/lupin)-canola-wheat	Timely	2	
Diverse (mix)	HDL*-canola-wheat	Early, timely	2, 7	Yes
Continuous wheat	Wheat-wheat-wheat	Timely	2, 7	
Fallow	Fallow-canola-wheat	Early, timely	7	

* HDL = high density legume dominated by vetch

A brief recap on the dry 2018-2019 seasons

The 2018 and 2019 seasons were consecutive decile 1 seasons across the sites, while 2020 was decile 7-9 across the sites (Table 2).

Table 2. Annual rainfall (irrigation in brackets) at the experiment sites in 2018 and 2019 and the long-term median rainfall.

Site	2018	2019	2020	LTM
Greenethorpe	359	353	726	579
Wagga Wagga	403	320	557	526
Urana	276	222	488	449
Condobolin	218 (120)	162 (118)	685	434

As would be expected, the productivity and profitability of the individual crop options differed significantly between the decile 1 conditions in 2018 and 2019, and the wetter conditions in 2020. A detailed consideration of the productivity and profitability of the different crops and systems under the dry conditions in 2018 and 2019 was provided in two previous papers (see reference section at the end of this paper).

As a brief summary of the results, despite the decile 1 conditions, the annual earnings before interest and taxes (EBITs) for different crop options varied from -$500 to $1700/ha in 2018, and -$500 to $1200/ha in 2019, with the 2 year average annual EBITs varying from $-50 to $1000/ha across the sites.

Early-sown grazed crops were highly profitable (double to triple non-grazed equivalents) even without grain harvests, while many grain-only crops were low yielding or cut for hay. Both barley grain and hay were profitable options in the dry years, and there was a noticeable effect of the amount of stubble cover remaining over summer (range 0.9 to 9 t/ha depending on crop and sequence).

Legumes and N fertiliser in the dry years

Grain legume crops, and diverse sequences including legume options outperformed baseline canola-wheat sequences at all sites during the dry 2018-2019 seasons. This resulted from both the profitability of the legumes in their own right, and the legacy of water (20-60 mm) and N (50-100 kg/ha) that influenced subsequent crops in the sequence.

The higher N strategy (decile 7) generally provided increased biomass for grazing crops or hay cuts but had either no effect or a negative effect on grain yield and profit in the dry years. However, the N carried over from one season to the next to influence biomass (positively) and yield (variable effects) in subsequent years.

At the completion of the first two years of the project there were systems at all sites achieving annual average EBITs across the 2 dry years **$200 - $600/ha above the Baseline C-W-W system**.

The 2020 season – major crop responses observed

At the time of writing, the 2020 data set for Wagga and Greenethorpe had been finalised so examples for those sites are included. Data for the other sites will be available for the presentation. The high rainfall in 2020 shifted the agronomic management focus from water management and decisions on graze-out and hay cutting in spring, to a focus on higher N fertiliser requirements and disease management.

Overall yield and profit levels were high in 2020, but some observations were consistent

The excellent seasonal conditions meant that both the yield and EBIT of the individual crop options across the sites were generally higher in 2020 than in the previous seasons (Table 3). The ranges in yield and profit for the crops shown in Table 3 are driven by effects of different crop sequence and N strategy which will be discussed further in following sections.

Table 3. Summary of overall yield and EBIT range for different crops in 2020. Highest yields did not correspond to highest profit at either sites for the different crop types. (compare grey squares).

Crop	Sowing (date)	Graze	Variety	Grazing (dse.d/ha)	Yield range (t/ha)	EBIT range ($/ha)
Wagga Wagga						
Canola	E (10/3)	G	Hyola® 970CL	730 - 1780	2.1-3.6	$1220 - $1630
Canola	E (31/3)	NG	Hyola 970CL	-	3.6-3.9	$1290 - $1500
Canola	T (23/4)	NG	43Y92	-	3.5-4.3	$1202 - $1590
Wheat	E (10/3)	G	Bennettᶲ	1360 - 2070	5.3-6.1	$1250 - $1370
Wheat	E (31/3)	NG	Bennettᶲ	-	5.4-6.1	$455 - $657
Wheat	T (12/5)	NG	Beckomᶲ	-	5.2-7.5	$645 - $1120
Barley	T (12/5)	NG	LaTrobeᶲ	-	7.5-8.0	$720 - $780
Chickpea	T (12/5)	NG	Captainᶲ	-	3.3	$988
Lentil	T (12/5)	NG	HallmarkXTᶲ	-	4.2-4.4	$1708 - $1851
Lupin	T (12/5)	NG	Batemanᶲ	-	4.8	$1453
HDL vetch	E (10/3)	G	Timokᶲ	1200	-	$1260
Greenethorpe						
Canola	Early	G	Hyola970CL	2690 - 3600	3.2 - 3.9	$2700 - $2800
Canola	Early	NG	Hyola970CL	-	2.9 - 3.1	$1,100
Canola	Timely	NG	HyTTec® Trophy	-	4.4 – 4.9	$2000 - $2200
Wheat	Early	G	Bennettᶲ	1600 - 2150	3.7-6.2	$1,100 - 1700
Wheat	Early	NG	Kittyhawkᶲ	-	8.0-8.3	$1400 - $1500
Wheat	Timely	NG	Coolahᶲ	-	6.8-8.7	$1080 - $1550
Chickpea	Timely	NG	Captainᶲ	-	4.1	$1331
Lentil	Timely	NG	HallmarkXTᶲ	-	3.1	$1100
Faba	Timely	NG	Samiraᶲ	-	5.3	$652
HDL vetch	Early	G	Morava	1480	4.4 (hay)	$1468
HDL vetch	Timely	NG	Morava		4.9 (hay)	1,050

HDL=High Density Legume dominated by vetch, E=early sowing, T=timely sowing, G=grazed, NG = ungrazed and dse.d/ha = dry sheep equivalents per day per hectare.

Some consistencies in crop performance in 2020 with 2018 and 2019 include:

- Overall yield and profit levels are higher at Greenethorpe than Wagga reflecting the higher rainfall and longer growing season. However, yields and profit levels of some crops (e.g. lentils) were superior at Wagga
- Early sown grazed crops were among the most profitable at both sites and outperformed early-sown grain-only options in most circumstances. Grain-only crops of wheat at the Wagga site had

similar yields to grazed crops, while the same comparison for canola yield at Wagga showed grazing reduced grain yield. At Greenethorpe the results differed with grazing canola producing higher yield than un-grazed crops of the same variety
- Timely-sown grain legume options at Wagga matched or exceeded the profit generated by un-grazed timely canola and wheat, while at Greenethorpe grain legumes matched the cereals, but not canola, which was the most profitable option (by ~$500/ha). Lentils were the most profitable at Wagga, while the chickpea and vetch did best at Greenethorpe
- The top barley yield was higher than that of wheat at Wagga however the profit was higher for the wheat.

Responses to crop sequence and N fertiliser strategies in 2020

Early-sown grazed crops

The early-sown wheat and canola crops both responded significantly and similarly to crop sequence and N fertiliser at Greenethorpe and Wagga in 2020. Table 4 summarises the key responses using the data from Greenethorpe. In the canola-wheat-canola sequence, the additional N (in soil and applied) in the decile 7 strategy (~extra 100 kg N /ha) increased canola grazing and yield by 765 dry sheep equivalent (dse) days/ha and 0.2 t/ha respectively, and wheat grazing and yield by 515 dse days/ha and 2.5 t/ha. This generated an increase in EBIT of $103/ha for canola and $598/ha for wheat.

Diversifying the sequence with a high density legume (HDL) (with decile 2 N strategy) compared to the canola-wheat-canola strategy with decile 2, increased the grazing of canola by 906 dse days/ha but reduced canola grain yield by 0.5 t/ha so that the EBIT was similar. In contrast in the grazed wheat, the diversified sequence had an increase in grazing (387 dse d/ha), yield (0.6 t/ha) and EBIT ($278/ha) but did not match the EBIT of the decile 7 N treatment, predominately due to the higher grain yield.

The N legacy of the HDL measured at sowing was 34 kg N/ha in the canola and 67 kg N/ha in the wheat, and it is likely to provide further benefits from greater in-season mineralisation.

Table 4. Response to crop sequence and N strategy in early-sown grazed canola and wheat crops at Greenethorpe in 2020. Data for soil N at sowing (0-2m) and applied fertiliser N are shown.

Sequence 18-19-20	Crop variety	N strategy	Graze (dse.d/ha)	Yield (t/ha)	EBIT ($/ha)	Nitrogen supply (kg/ha)		
						Soil	Applied	TOTAL
Canola								
C-W-**C**	C = Hyola 970	D2	2689	3.7	$2708	210	100	310
C-W-**C**	C = Hyola 970	D7	3454	3.9	$2839	167	259	426
W-HDL-**C**	C = Hyola 970	D2	3595	3.2	$2774	244	65	309
Wheat								
W-C-**W**	W = Bennett	D2	1631	3.7	$1137	227	15	242
W-C-**W**	W = Bennett	D7	2146	6.2	$1735	196	137	333
HDL-C-**W**	W = Bennett	D2	2018	4.3	$1414	294	15	309

W-Wheat, C=Canola, HDL=high density legume, D2= nitrogen treatment for a decile 2 rainfall projected from mid-winter and D7 = nitrogen treatment for a decile 7 rainfall projected from mid-winter.

Timely sown un-grazed crops

The timely-sown wheat and canola crops also responded significantly to crop sequence and N fertiliser at the sites in 2020, demonstrated here in data from Wagga Wagga (Table 5).

In the canola, a positive yield response to N was only observed in the canola-cereal systems but no yield response in sequences that included legumes. The lowest canola profit ($1232/ha) was generated by the intense baseline low N system, while the equal highest profit occurred in the baseline with decile 7 N ($1578/ha) and the diverse HDL with decile 2 N ($1590/ha). In this case, the diverse treatment profit was generated at lower total cost ($650/ha *vs* $700/ha) reducing production risk.

Table 5. Effect of previous sequence and N strategy on the yield and profit of timely sown canola (upper Table) and wheat crops (lower Table) at Wagga Wagga in 2020. Diverse sequences that include a legume are shown in grey. Total Min N at sowing (0-1.4m) and top-dressed N are shown.

System	Sequence 18-19-20	N strategy	Yield (t/ha)	Crop intensity	EBIT ($/ha)	Nitrogen supply (kg/ha)		
						Soil	Applied	TOTAL
Timely canola (43Y92) sown 23 April								
Baseline	W-B-**C**	D2	3.7	1 in 3	$1355	86	80	166
Baseline	W-B-**C**	D7	**4.3**	1 in 3	**$1578**	123	170	293
Intensive baseline	C-W-**C**	D2	3.5	1 in 2	$1232	79	106	185
Intensive baseline	C-W-**C**	D7	**4.0**	1 in 2	**$1440**	150	138	288
DivHV1	W-Le-**C**	D2	3.8	1 in 3	$1383	111	106	217
DivHV1	W-Le-**C**	D7	3.6	1 in 3	$1202	105	178	283
DivMix	W-HDL-**C**	D2	4.1	1 in 3	$1590	124	53	177
DivMix	W-HDL-**C**	D7	4.2	1 in 3	$1356	99	188	287
DivLV	W-Lu-**C**	D2	4.0	1 in 3	$1475	67	106	173
Timely wheat (Beckom⑪) sown 12 May								
Baseline	B-C-W	D2	7.3	1 in 3	$1095	51	101	152
Baseline	B-C-W	D7	7.0	1 in 3	$1013	111	101	212
Intensive baseline	W-C-W	D2	6.9	1 in 2	$960	52	101	153
Intensive baseline	W-C-W	D7	6.9	1 in 2	$917	61	147	208
ContW	W-W-W	D2	5.2	1 in 1	$645	111	41	152
DivHV1	Le-C-W	D2	7.0	1 in 3	$1014	57	87	144
DivHV1	Le-C-W	D7	7.4	1 in 3	$1079	81	129	210
DivMix	HDL-C-W	D2	7.0	1 in 3	$1007	73	78	151
DivMix	HDL-C-W	D7	7.5	1 in 3	$1114	79	129	208
DivLV	Lu-C-W	D2	7.0	1 in 3	$1049	89	60	149
DivHV2	W-Ch-W	D2	6.4	1 in 2	$901	88	60	148

W-Wheat, C=Canola, B=Barley, Le=lentil, Lu=Lupin, HDL=high density legume, D2= nitrogen treatment for a decile 2 rainfall projected from mid-winter and D7 = nitrogen treatment for a decile 7 rainfall projected from mid-winter. Soil nitrogen is measured pre-sowing and applied nitrogen is spread as urea. DivHV1 = Diverse high value 1, DivMix = Diverse (mix), DivLV = Diverse low value, DivHV2 = Diverse high value 2.

In contrast to the canola, the timely wheat only responded to higher N in the diverse sequences and not in the canola-wheat sequences, and it appears sequence and crop intensity had a much more significant overriding effect on wheat yield than nitrogen. For example, the yield of the continuous wheat (1 in 1 intensity, decile 2) was only 5.2 t/ha, the yields in the sequences that were 1 in 2 intensity and with decile 2 nitrogen were 6.4 to 6.9 t/ha, while the yields in sequences that were 1 in 3 and D2 nitrogen were 7.0 to 7.5 t/ha. The highest yields of 7.4 to 7.5 t/ha were in diverse sequences with decile 7 N. In most cases the extra cost of N was not reflected in higher profit, while the effects of crop intensity on profit were clear.

System performance across the 3-year sequence

Overall average annual EBITs across the 3 years were higher at Greenethorpe (Figure 1) than at Wagga Wagga (Figure 2) as would be expected by the higher rainfall and yield potential at the site.

Grazed crops remain the most profitable option at both Greenethorpe and Wagga Wagga (see green (lighter) bars) at both sites across the 3-year period and were also the most profitable in individual years (not shown). The grazing income was significant in all years, including the drought years and more than offsets any impact on grain yield. The profits from grazed crops were also responsive to fertiliser N in both the intense C-W sequence and in the diverse sequence with the HDL, however the return on investment and on N was generally improved in the diverse sequence with decile 2 N strategy at both sites.

The 3-year average annual EBITs among the un-grazed treatments were relatively consistent except for the early-sown un-grazed sequence at Greenethorpe and the early-sown fallow and ley-phase at Wagga Wagga. These treatments suffered as a result of the poor performance of the early-sown winter wheat and canola which generally flowered too late and suffered badly in the drought, and to income forgone in fallow and ley phase.

Of the other ungrazed treatments, there were several at both sites with EBITs that exceeded the baseline system (black in Figures 1 and 2) and these included diverse options with decile 2 N strategy at both sites. In the diverse systems at both sites, the decile 2 N strategy has been more profitable than the decile 7 N strategy. The same trend is also the case for the intense baseline and baseline systems at Greenethorpe, while at Wagga the decile 7 N strategy has been marginally more profitable, suggesting a greater responsiveness to N at that site. The decile 2 N strategy generally has a marginally better return on investment overall, but a much higher return on N investment. The response to nitrogen should be considered in the context of two decile 1-2 seasons and one decile 5-6 season.

The continuous wheat system (timely wheat with decile 2 N) has performed well at Greenethorpe though not as well at Wagga Wagga, and this is presumably due to the lack of significant disease pressure during and after the consecutive droughts in 2018-2019, and lack of significant weed pressure. Fungicides were cost effective in controlling disease in the wheat year and high stubble loads retained water in the dry seasons.

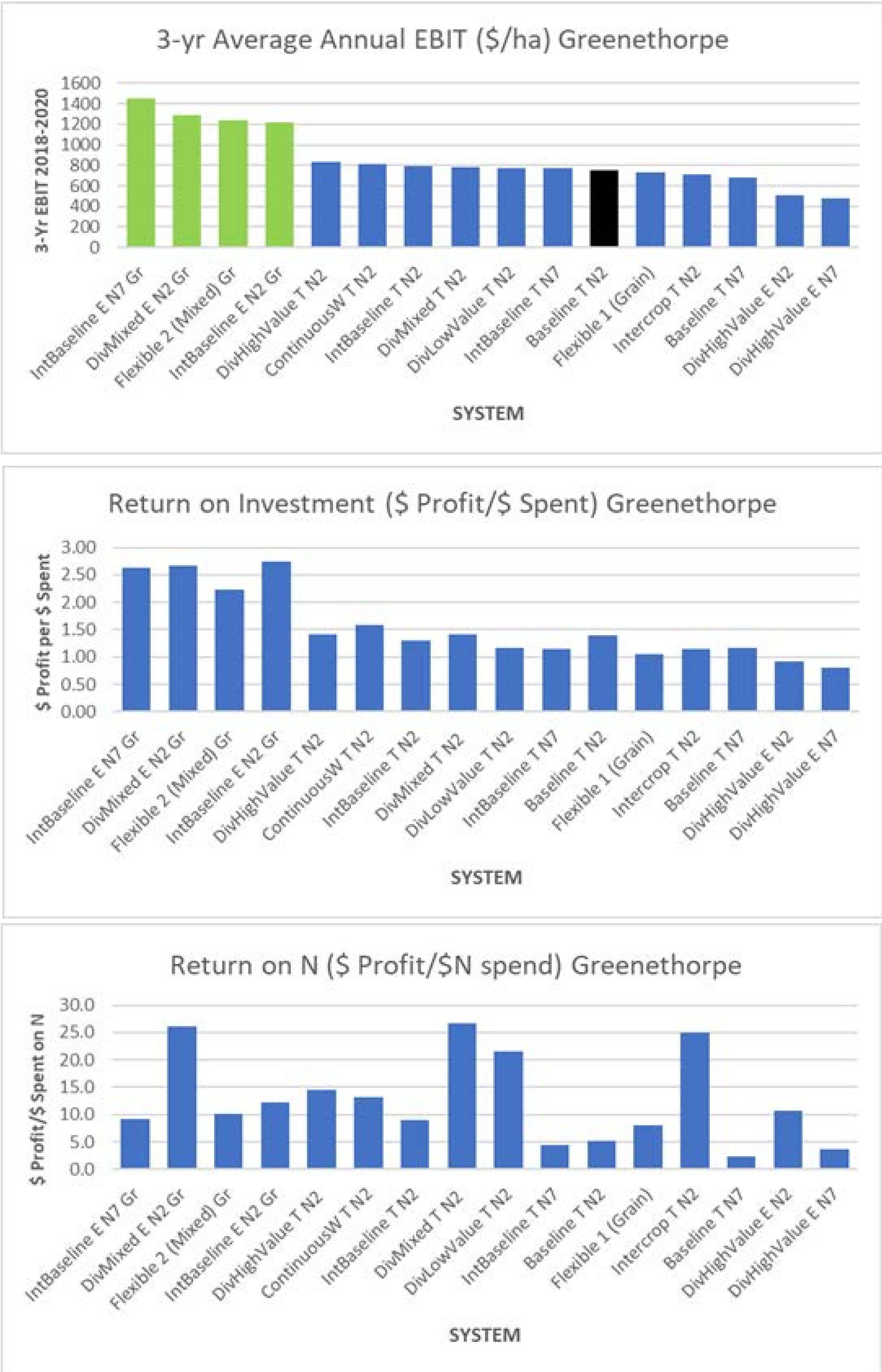

Figure 1. Average annual EBIT (top), return on investment (centre) and return per $ spent on N fertiliser across 3 years (2018-2020) for a range of systems at Greenethorpe. Systems are arranged in order of highest to lowest annual average EBIT in all panels. (green=grazed; black=baseline)

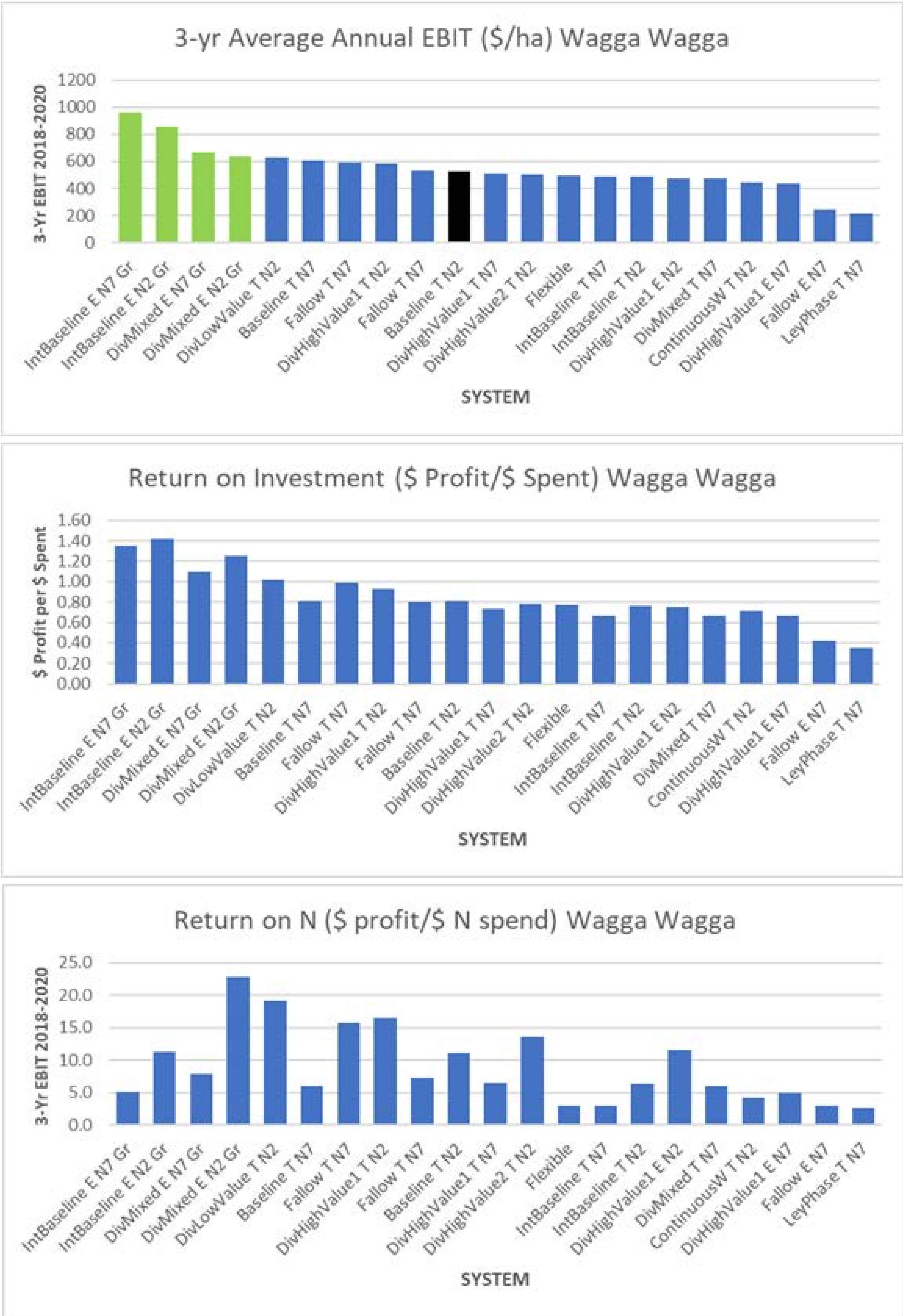

Figure 2. Average annual EBIT (top), return on investment (centre) and return per $ spent on N fertiliser across 3 years (2018-2020) for a range of systems at Wagga Wagga. Systems are arranged in order of highest to lowest annual average EBIT in all panels. (green=grazed; black=baseline)

Conclusions

The results of these system experiments show that both sequence and N strategies have significant effects on crop productivity, profitability and risk in individual years, and these effects can differ depending on individual seasonal conditions. However, the significant legacy effects of crop sequence (crop intensity and legume inclusion) and N strategy across seasons mean that the profitability of the systems over 3 years can play out differently to responses observed in a single season. Further analysis and simulation of this data set will explore this in more detail.

The current area sown to wheat in cropping systems of NSW varies between 55 and 60% which approximates one wheat year every two growing seasons. Years like 2020 represent opportunities to maximise farming systems profits. Results from this farming systems research indicate that on-farm income could be increased if the wheat area were reduced to 30% or approximately one wheat year in every three growing seasons. Profit in this sequence (1:3) are maximised for wheat where more aggressive nitrogen strategies are pursued.

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Appendix 1: Determining earnings before interest and tax (EBIT)

To calculate the annual EBIT for all treatments, we have initially used the following assumptions/prices.

A. Expenditure

1. All herbicides/fungicides/insecticides, seed dressings, fertilisers, GRDC levies and crop insurance costs were obtained from the annual NSW winter cropping guide or the annual SAGIT farm gross margin and enterprise planning guides with links at:
   i. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops
   ii. https://grdc.com.au/resources-and-publications/all-publications/publications/2019/farm-gross-margin-and-enterprise-planning-guide
2. All seed was priced according to purchasing as pure treated seed from seed companies. i.e. In 2019, prices used were wheat seed at $1/kg, faba bean seed at $1.20/kg, chickpea seed at $1.80/kg and canola seed ranging between $23-30/kg
3. All operations costs (sowing, spraying, spreading, haymaking, harvest) were based on the principal that a contractor performed the task. These costs were extracted from the yearly SAGIT Farm gross margin and enterprise planning guides. i.e. In 2019 prices used included sowing at $50/ha, ground spraying at $10/ha, cereal harvest at $70-85/ha, cut/rake/bale hay at $115/ha, with links at: https://grdc.com.au/resources-and-publications/all-publications/publications/2019/farm-gross-margin-and-enterprise-planning-guide
4. All variety levies for all crops and varieties were determined from the variety central website at: (e.g. for pulses) http://www.varietycentral.com.au/varieties-and-rates/201920-harvest/pulse/

B. Income

1. Wheat, barley and canola grain prices were obtained on the day of harvest from the AWB daily contract sheet for specific regions relating to trial location at: https://www.awb.com.au/daily-grain-prices
2. Pulse grain prices were obtained on the day of harvest from Del AGT Horsham and confirmed with local seed merchants.
3. Hay prices were obtained in the week of baling from a combination of sources including The Land newspaper and local sellers.

Appendix 2: Determining grazing value

To determine the estimated value of grazing the early sown crops, we have used the following formulae:

Winter grazing value ($/ha) = Plant dry matter (kg) removed x Liveweight dressed weight (c/kg) x Feed conversion efficiency (0.12) x Dressing % (lambs) x Feed utilisation efficiency (0.75)

Dressed weight and value:

- Lambs = 22.9kg (3 year average of light, heavy and trade lambs)
- Dressed weight = $6.25/kg (3 year average NSW)
- Dressing percentage = 50%

An example of 45kg lambs grazing winter Hyola 970 canola:

3800kg plant DM removed x $6.25 x 0.12 x 50% x 0.75 = $1069/ha

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