Profitable crop sequences to reduce ryegrass seedbank where herbicide resistent ryegrass is a major constraint to the sustainability of cropping systems

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Abstract
The profitability of cropping sequences involving pulse break crops (grain or brown manure-BM), canola and wheat high and low input (H & L), fallow and cereal hay and the respective effectiveness of each treatment in reducing the seed bank of an annual ryegrass (ARG) population resistant to multiple post-emergent herbicides, was investigated at Eurongilly in southern NSW between 2012 and 2015. Sequences that involved either canola or a spray topped lupin grain crop in year 1 followed by cereal hay or RoundupReady (RR) canola in year 2 provided high gross margins and significantly reduced ARG seed bank over the 3 year crop sequence. Cheaper double break combinations using a fallow or pulse BM in year 1 followed by RR canola in year 2 resulted in lower gross margins, but were the most effective in reducing the seedbank. The seed bank at the site changedfrom 1815 seeds/m² in year 1 to between 56 and 3140 seeds/m² at the conclusion of the experiment depending on crop sequence. RR canola in year 1 followed by high input wheat (Sakura® pre-em & post emergent Boxer Gold®) in year 2, and wheat (Sakura®) in year 3 was the most profitable sequence, but was less effective at reducing the seedbank (219 seeds/m²) compared to most double break options (56-142 seeds/m²) with the exception of triazine tolerant (TT) canola followed by cereal hay (300 seeds/m²).

Key words
Canola, cereals, crop sequences, herbicide resistant ryegrass, pulse legumes, wheat.

Introduction
There is substantial evidence indicating wide-spread resistance or partial resistance of ARG (Lolium rigidum Gaudin) to a wide range of herbicide groups (Broster et al., 2011) across south eastern Australia. Consultation with grower groups and agribusiness collaborators identified difficulties in managing grass weeds as a main constraint to wheat production, and the primary driver of decisions to grow broad leaf break crops. This paper outlines the main findings to date on sequence profitability and effectiveness at reducing seed banks of herbicide resistant ARG from experiments that examined the impact of different inputs and herbicides applied to canola, pulse legumes, or wheat crops. The experiments address two key questions:

(1) Do crop sequences that include a break crop improve the profitability of subsequent cereal crops in the presence of herbicide resistant ARG?
(2) Can herbicide resistant ARG be managed more cost-effectively under break crops than cereals?

Methods and Materials
Experiments were established in 2012 in a paddock at Eurongilly in south-eastern NSW on red chromosols (Isbell, 1996) where herbicide-resistant ARG was known to be present with seed bank of 1815 plants/m^2. The susceptibility/resistance of the ARG was tested by Plant Science Consulting SA. Results indicated that the ARG was resistant or partially resistant to group A herbicides Haloxyfop (70%), Clethodim (55%), Pinoxaden & Cliquintocet-methyl (65%), and Group B herbicides Iodsulfuron-methyl-sodium (95%), but 100% susceptible to one Group A herbicide, Butroxydim and to Group M (Glyphosate). The crops/treatments established in the each of the three years were:
Year 1: Canola (RR & TT), legumes (pulse grain or brown manure), wheat (High & Low input) or fallow;
Year 2: Canola (RR), wheat (high or low input) or cereal wheat (Hay);
Year 3: Wheat.

Two input rates, high (H) or low (L) were included for wheat treatments with the (H) treatments used to examine a combination of effects including: 1) new but expensive pre- and post emergent herbicides 2) increased sowing density for increased competition 3) higher fertiliser rates (nitrogen and phosphorus) in

canola and wheat for increased early vigour and competition. In the (H) treatment, the total input costs were significantly greater than (L) treatments, but they had the potential to return higher yields and gross margins (GM). Plant density aimed for in the canola, lupin and field peas (BM) were 40 plants/m^2, lentils at 120 plants/m^2, wheat (H & L) at 75 and 150 plants/m^2. Canola was seed dressed with Jockey® & Gaucho® and fertilized with MAP @ 25 & 75kg/ha (L & H) with wheat (L & H) seed dressed with Raxil® or Dividend® and fertilized with MAP @ 25 & 75kg/ha, respectively. All treatments had an initial knockdown spray of glyphosate 450 @ 1.6 L/ha. A brief outline of herbicides is summarised below. Detailed information is available on request.

Year 1 treatments imposed, input/risk categories and input costs (2012):
1. TT Canola*:* cv. Crusher open pollinated; NH_4SO_4 (100 kg/ha) pre-sow, urea top dressed (100 kg/ha). Triflur®X @ 2 L/ha + Atrazine 900 @ 1.1 kg/ha; Factor® @ 80 g/ha + Atrazine 900 @ 0.9 kg/ha. Total input cost = $249/ha.
2. RR Canola*:* cv. Hyola®505 hybrid; NH_4SO_4 (100 kg/ha) pre-sow, urea top dressed (200 kg/ha). Triflur®X @ 2 L/ha, Round-Up Ready® @ 0.9 kg/ha at 2-3 leaf & 6 leaf. Total input costs = $427/ha.
3. Fallow: fallow established in September 2012 with an application of glyphosate 450 @ 2 L/ha, Ally® @ 5 g/ha, double knocked with Gramoxone® 250 @ 2 L/ha. Total input costs = $35/ha.
4. Field peas & Lupin BM: cv's Morgan & Mandelup. Triflur®X @ 2 L/ha + Simazine 900 @ 1 kg/ha; BM spray of glyphosate 450 @ 2 L/ha + Lontrel™ @ 150 ml/ha + Hammer® @ 25 ml/ha (early September); glyphosate 450 @ 2.5 L/ha (mid October). Total input costs = $120/ha and $129/ha, peas and lupins, respectively.
5. Lupin grain: cv. Mandelup. Triflur®X @ 2L/ha + simazine 900 @ 2.2 kg/ha; Factor® @ 180 g/ha; spray top with Gramoxone® 250 @ 400 ml/ha (mid November). Total input costs = $168/ha.
6. Wheat (L): cv. Spitfire; urea @ GS30 (100 kg/ha). Triflur®X @ 2L/ha + Diuron 500 @ 1 L/ha; Boxer®Gold @ 1.5 L/ha at 2-3 leaf stage. Total input costs = $169/ha.
7. Wheat (H): cv. Spitfire; urea @GS30 (200 kg/ha). Sakura® 850WG @ 118 g/ha + Avadex® Xtra @ 2 L/ha; Boxer®Gold @ 2.5 L/ha and Axial® @ 150 ml/ha at 2-3 leaf stage. Total input costs = $430/ha.

Two sowing times in 2012 were late April (canola and lupin) and mid May (field peas BM and wheat). All plots were kept weed-free during summer fallow period. Initial plots were 40m in length x 1.8 m with each treatment replicated four times.

Year 2 treatments (wheat or second break crop) in 2013: All plots from year 1 were split into three sub-plots. Four treatments were sown in early May 2013 being RR canola, wheat (H & L) and cereal hay (wheat). Wheat (H & L) was sown into all year 1 treatments and RR canola was sown into pulse, wheat or fallow year 1 treatments only. Cereal hay was sown into canola year 1 treatment to act as a double break. Nitrogen as urea was differentially applied to all year 2 treatments to achieve a wheat grain yield of 7 t/ha in the wheat (H), 4 t/ha in the wheat (L) and 3.5 t/ha in canola based on mineral N concentrations measured prior to sowing. The herbicides used in year 2 were similar to those used in year 1 for the respective crop and input category.

Year 3: All plots were sown to wheat cv. Suntop (Dividend®) + MAP + Impact® @75 kg/ha. Herbicides included Weedmaster®Argo™ (1.9 L/ha), Hammer® (45 ml/ha), Sakura® 850WG (118 g/ha), Avadex®Xtra (2 L/ha). Urea was top dressed at GS30 between 87 and 187 kg/ha to achieve a target wheat grain yield of 5 t/ha for all treatments based on levels of mineral N measured prior to sowing in different treatments.

In late March year 1 (pre-experiment), forty surface soil cores (6cm in diameter x 5cm deep) were randomly removed across the trial area with eight surface cores removed per treatment in April of year 2, year 3 and year 4 to measure changes in ARG seedbank. The soil was put into trays and watered over the following three months and all emerged ARG counted. GM were calculated using input costs and operations from SAGIT/NSW DPI GM books and commodity prices on day of harvest from cash prices at GrainCorp terminal at Junee, NSW.

Results

Crop yields and gross margins

In year 1 the most profitable crops were RR and TT canola which returned grain yields and gross margins of 3.5t/ha (GM =$1259/ha) and 3t/ha (GM = $1166/ha), respectively. The next most profitable crops were lupins (H) @ $683/ha (yield = 3.1t/ha), wheat (H) @ $257/ha (yield = 3.2t/ha), wheat (L) @ $250/ha (yield = 2.0 t/ha) and lentils @ $67/ha (yield = 0.7t/ha), with the brown manure or fallow treatments having negative returns (-$45 to -$250/ha). In year 2, the treatments with the highest gross margin were canola following fallow or brown manure treatments (> $1000/ha, grain yield avg = 3.5t/ha) with canola following wheat (H) or lupins (H) returning ~$900/ha (grain yield = 3.2t/ha). Over the 3 years, the most profitable sequence was RR canola - wheat (H) – wheat, with an average GM of $883/ha. Sequences with the highest average annual gross margins >$800/ha/yr were treatments that had canola (RR or TT) in year 1, with the next most profitable group having grain lupins in year 1 or canola year 2 (> $600/ha). The third group included sequences of fallow, combinations of wheat (H or L) or lentils in year 1, with the final group involving sequences with BM crops followed by wheat (H or L) (Table 1).

Interaction between crop treatments and ryegrass plant populations

ARG panicles (m^2) in spring year 1 in untreated areas were 1042, significantly more than wheat (L) with 534 panicles/m^2. All other treatments in year 1 had significantly less panicles than wheat (L), but the most effective ARG control was achieved by fallow, pulse BM or canola (H) (Table 1). By spring in year 2, there were significant differences in panicles/m^2 with four distinct categories (0-8, 14-71, 192-388 & >643 panicles/m^2) (Table 1). Main year 2 treatment effects continued into year 3 with significantly less panicles in order of: canola < hay = wheat (H) < wheat (L), and year 1 effects: fallow < pulses < canola = wheat (H) < wheat (L). Interactions were categorised into groups of (0-30, 60-166, 199-370, >536 panicles/m^2) (Table 1). Generally, double break sequences or those where wheat (H) treatments were grown following treatments with bare soil or less stubble from year 1 had significantly fewer panicles.

By autumn year 2, there was a significant three-fold increase in ryegrass seedbank populations (5492 seeds/m^2) following wheat (L) and by autumn year 3 a further significant 2.5 fold increase (13148 seed/m^2) after a second wheat (L) treatment. Comparatively, seedbank numbers reduced to 124 seeds/m^2 where canola (H) 2012 was followed by wheat hay (2013), and double breaks involving legumes, canola, fallow or hay resulted in the lowest seed banks following the 3 year sequences (Table 1). Main effects from year 1 and year 2 treatments were still apparent after the conclusion of the experiment in March 2015, with the year 2 treatments having a greater effect with significantly higher seedbank numbers remaining in order of: wheat (L) > wheat (H) > wheat (hay) > canola (meaned data not shown). The expensive herbicide costs ($142/ha) associated with consecutive wheat (H) treatments resulted in a significant reduction in seed bank by November 2014 (366 plants/m^2), but was not as effective as sequences involving break crops or a fallow.

Discussion & Conclusion

In the presence of a high population of herbicide resistant ARG, sequences that include a break crop were more profitable compared to continuous wheat (H or L). Canola was consistently the most profitable break crop, largely due to the high returns from canola itself, but legume grain crops were profitable and provided additional N in year 2. Although the TT canola / wheat (H) sequence was profiable, it was not as effective at reducing the ryegrass seebank and any sequence with wheat (L) resulted in an increase in ryegrass numbers. Break crops or fallow provided cheaper and more effective ARG control options. Two consecutive years of complete ARG control were required to reduce seedbanks to managable levels. The most profitable double break sequences were RR canola followed by a cereal hay or grain lupins followed by RR canola with these also very effective at reducing the seed bank. Sequences involving fallows and brown manures reduced production risk in subsequent years due to enhanced yield in the following wheat crops, but were not as profitable as continuous cropping.

Table 1 Average annual gross margin over 3 years compared to ryegrass seedbank (April 2013, 2014, 2015) and ryegrass panicle number (November 2012-2014) in Exp 1 at Eurongilly, NSW.
Crop 2012 pre-treatments are arranged in order of descending "SEEDBANK March 2015" seed counts.

Crop x input in 2012	Crop x input in 2013	Ryegrass panicles Nov 2012	SEEDBANK March 2013	Ryegrass panicles Nov 2013	SEEDBANK March 2014	Ryegrass panicles Nov 2014	SEEDBANK March 2015
		(panicles/m2)	(seeds/m2)	(panicles/m2)	(seeds/m2)	(panicles/m2)	(seeds/m2)
Fallow	Canola	0 (NM)^	290	0	NM	2	56
Lupin grain	Canola	43*	748	0	196	6	63
Lupin BM	Canola	0 (NM)^	152	0	NM	1	110
Fallow	Wheat (H)	0 (NM)^	290	2	NM	10	118
RR Canola	Wheat	0	208	0 (537)^	124	23	122
Pea BM	Canola	0 (NM)^	464	0	210	4	142
Lupin grain	Wheat (H)	43*	748	8	312	19	148
Pea BM	Wheat (H)	0 (NM)^	464	2	496	14	162
RR Canola	Wheat (H)	0	208	15	381	29	219
TT Canola	Wheat (H)	32	505	14	NM	82	252
Wheat (H)	Canola	78	777	0	259	20	267
Lupin BM	Wheat (H)	0 (NM)	152	2	NM	11	279
TT Canola	Wheat	32	505	0 (790)^	NM	23	300
Wheat (L)	Canola	504	5492	0	797	22	332
Wheat (H)	Wheat (H)	78	777	29	1379	60	366
Wheat (L)	Wheat (H)	504	5492	71	3412	121	523
Fallow	Wheat (L)	0 (NM)^	290	56	NM	100	970
Lupin BM	Wheat (L)	0 (NM)^	152	192	NM	308	1105
Lupin grain	Wheat (L)	43*	748	200	6614	122	1167
Wheat (H)	Wheat (L)	78	777	294	5508	147	2158
TT Canola	Wheat (L)	32	505	383	NM	229	2222
RR Canola	Wheat (L)	0	208	388	7770	200	2387
Pea BM	Wheat (L)	0 (NM)^	464	237	7413	157	3118
Wheat (L)	Wheat (L)	504	5492	898	13148	943	3140
P value (2012)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
P value (2013)			NA	<0.001	<0.001	<0.001	<0.001
P value (interaction)			NA	0.004	0.105	<0.001	0.699

*Lupins spray topped in Nov 2012 prior to ryegrass seed maturity
^Ryegrass panicles estimated at zero in 2012 and 2013 due to either spraying or cutting of hay prior to seed set
NM Not measured

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