Weed seed bank management is even more critical in brome grass than ryegrass

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Abstract
Brome grass is becoming a greater problem than ryegrass in some parts the South Australian and Victorian grain belts. Brome grass has a larger seed than ryegrass and is slightly less fecund and at this stage it is not clear if these species differences influence the cost of weed seed management. It is not clear which weed seed bank is more difficult to manage. We accessed historical published information about plant-to-plant competition with wheat and seed bank dynamics and re-analysed these data using the hyperbolic equations in the LUSO model for this weed, thereby creating a LUSO brome grass model to accompany the LUSO ryegrass model. Overall, brome grass at low population densities was less competitive than ryegrass, but as the population density increase, it became more competitive than ryegrass. Weed species effected the profitability of the optimal rotation. Moderate ryegrass populations damaged wheat yields more than brome grass, resulting in approximately a \$10/ha difference in annual returns over the 6-year crop sequence. Weed species altered the optimal rotation when the seedbank was low. When the seedbank exceeded 50 seeds/m^2, weed species did not affect the optimal rotation, and the rotations were the same, regardless of weed species. When set rotations were evaluated, brome grass damaged crops less, and the overall profits with a brome grass infestation were higher, regardless of the rotation. In all cases, assuming control costs for the two weed species were similar, minimising and managing the weed seed bank generated the highest profits.

Keywords
Crop rotation, crop sequencing, LUSO.

Introduction
Brome grass and ryegrass are ubiquitous foes in many Australian cropping systems. They have many similarities; both are winter grasses, and both have developed resistance to ALS inhibiting herbicides. In contrast, morphological differences include ryegrass producing more and smaller seeds and being slightly more erect than brome grass. Seed dormancy or persistence in brome grass and ryegrass is similar, where about 80% of seeds are expected to germinate in a particular year with rates of around 20% dormancy reported in both species (Kleemann and Gill 2013; Pannell et al. 2004).

Plant-to-plant competition does vary widely between species, and the impact that weeds have on crop yield can also vary with the season (e.g. Lawes and Renton 2015). Gill et al. 1987 reported on the yield damage caused by brome grass, where the equations varied slightly from those reported for ryegrass and used in models such as RIM (Pannell et al 2004) and LUSO (Lawes and Renton 2010). Ryegrass produces more seed, so has a greater maximum seed set of 30,000 seeds/m^2 compared with 12,000 seeds/m^2 for brome grass (Kleemann and Gill 2013). The resultant hyperbolic functions suggest ryegrass at low weed densities is slightly more competitive than brome grass, but brome grass becomes more competitive as weed densities rise, and this leads to a greater crop yield loss relative to ryegrass. For example, at 5 weeds/m^2, ryegrass causes an 8% yield loss and Brome grass would cause a 5% yield loss. At 50 weeds/m^2, ryegrass damage increases to 16%, while Brome grass damage increases to 22%. Such differences potentially affect the management strategies and the economic outcomes for each weed.

Here we explore the impact of these weed attributes on the rotational management of ryegrass and Bromegrass in the Victorian Mallee, over a medium (6 year) term management horizon. The focus is on the choice between cereal, canola and pulse crops, as well as fallow and pasture.

Methods
Weed Competition Parameterisation
Data from Gill et al. 1987 were used to inform the parabolic functions of Brome grass population dynamics in the LUSO model. Whilst they fitted a decay function to the relationship between yield loss and plant

density, the LUSO model uses a slightly different functional form where a crop-weed competition coefficient drives yield damage and is related to the plant density of both crop and weed (Lawes and Renton 2010). Different functional forms can lead to slightly different conclusions about the impact that weed plant density may have on crop yield. LUSO functions as an optimisation model, that can identify an optimal rotation given a series of enterprise choices, or it can evaluate a set rotation. The methods are mathematically identical to those used in RIM (Pannell et al. 2004). Weed seed set is also determined by these competition parameters, shown in Table 1.

Table 1. Weed-crop competition coefficients between ryegrass and wheat and bromegrass and wheat.

Wheat – ryegrass coefficient	Wheat - Bromegrass coefficient	Ryegrass – wheat coefficient	Bromegrass – wheat coefficient
0.030	0.176	0.091	0.29

Crop sequences

LUSO was parameterised for a Victorian Mallee farming system with the simple choice of a wheat, canola, pulse or pasture enterprise. Fallow was not considered. For default model assumptions, wheat was the most profitable enterprise with a gross margin of \$154/ha, canola returned \$82/ha, pulse (most likely field pea) returned \$100/ha and pasture generated a \$50/ha gross margin. In the default model run both grass weeds were controlled, while weed populations were severely reduced in a well-managed legume pasture.

In order to explore whether the presence of weeds influenced the profitability of the crop sequence, four typical rotations (Table 2) were analysed for each weed species separately, with starting seed populations of 5, 10, 25, 50, 100, 200, 400 seeds/m^2.

Table 2. Crop sequences used in LUSO simulations with ryegrass and brome grass.

Sequence	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Continuous Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
Pulse-Wheat	Wheat	Wheat	Pulse	Wheat	Wheat	Pulse
Pulse-Canola-Wheat	Canola	Wheat	Wheat	Pulse	Wheat	Wheat
Pasture Wheat	Pasture	Wheat	Wheat	Pasture	Wheat	Wheat

Results

The optimal rotations hardly varied between ryegrass and brome grass. At low seedbanks (5 seeds/m^2), wheat was selected four times and a pulse crop was selected twice, regardless of the weed species present. At 25 seeds/m^2, brome grass resulted in one more wheat crop than ryegrass. Thereafter, pulse breaks were required in alternate years to more effectively manage either seed bank (Table 3). When the weed seed bank reached 400 seeds/m^2, pasture was introduced to manage brome grass population, but not ryegrass. The best rotations for both weeds were similar until seed banks reached 400 seems/m^2. At such high weed density, a pasture phase was required to manage the brome grass population, but not ryegrass. Despite similar crop sequences, the cumulative return after 6 years when ryegrass was present in the system was around \$50-60/ha lower than for a brome grass infestation. This is because at low weed densities, ryegrass reduced crop yields more than brome grass. As the seedbank increased, ryegrass profit remained relatively stable. In contrast, profit declined from \$172 to \$134 with a brome grass infestation (Table 3).

Table 3. Selected crop sequences and associated profit for a ryegrass and a brome grass infestation with various starting seedbanks. Key: W = wheat, P = pulse and Past = pasture.

Seedbank	5		25		50		100		400	
Year	Rye	Brome	Rye	Brome	Rye	Brome	Rye	Brome	Rye	Brome
1	W	W	P	W	P	P	P	P	P	Past
2	W	P	W	P	W	W	W	W	W	W
3	P	W	P	W	P	P	P	P	P	P
4	W	P	W	P	W	W	W	W	W	W
5	P	W	P	W	P	P	P	P	P	P
6	W	W	W	W	W	W	W	W	W	W
Cumulative Profit	\$117	\$172	\$108	\$165	\$108	\$148	\$108	\$143	\$105	\$134

The seed bank dynamics were similar between the weed species. However, at 25 seeds/m^2, where a rotational difference did occur (Table 3), the brome grass population was allowed to increase to over 100 seeds/ m^2. In contrast, the ryegrass population was kept at very low levels of less than 50 seeds/m^2.

The four set rotations (Table 2), generated different returns in response to both the weed seed bank size and the weed species (Figure 1). With a very low seedbank (5 weeds/m^2), continuous wheat generated the highest cumulative profit with brome grass, and second highest profit with ryegrass. However, for both weed species, the continuous wheat sequence became unprofitable once the starting weed seed bank reached 50 seeds/m^2. At higher starting seed banks with continuous wheat, brome grass generated greater losses than ryegrass. At low seedbanks, the profits for a brome grass sequence were higher than ryegrass. These differences reflect the relative impact that different competition factors have on overall profit.

Overall, the wheat-pulse rotation was the most profitable crop sequence when both seed banks were at a low or moderate level (5 to 25 plants/m^2). However, it became unprofitable at 200 brome grass plants/m^2 and at 300 rye grass plants/m^2 (Figure 1). The canola-wheat-pulse rotation was generally a poor performer with ryegrass, but remained profitable with brome grass, even at nearly 400 seeds/m^2.

At low weed densities, the pasture-wheat rotation generated cumulative returns approximately \$20/ha lower than the best-performing equivalent crop sequences. The relative performance of this rotation improved until it became the most profitable sequence with weed populations above 100 seeds/m^2.

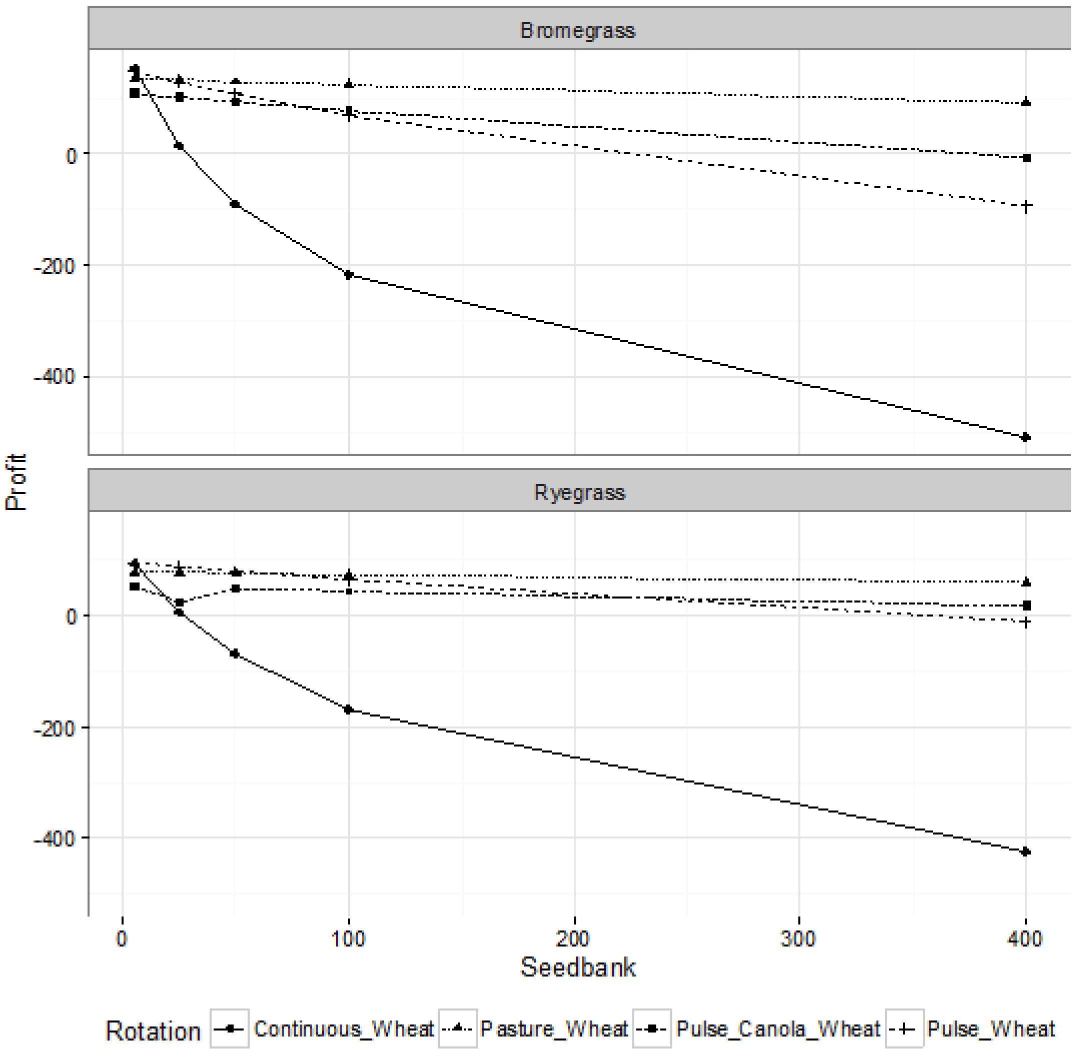

Figure 1. Cumulative profit (\$) after 6 years for the continuous wheat, pasture wheat, pulse canola wheat and pulse wheat sequences when grown with varying seedbanks of ryegrass or brome grass.

Conclusion

The population dynamics and competitive attributes of weed species such as ryegrass and brome grass affect the economic outcomes of particular crop sequences. More competitive weeds are more damaging to crop yields, and have a more negative effect on economic returns. However, competition is nuanced and influenced by the weed density. Using bio-economic modelling, we demonstrated that adjusting crop sequences is an effective way to manage the weed seed bank, regardless of the (grass) weed species. Providing farmers with viable and reliable break crop and pasture options offers an economical and sustainable pathway to manage weeds in the farming system.

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