Maximising crops and minimising weeds with smart phase farming

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Key messages

- Herbicidal and cultural control options applied later in the weed lifecycle, such as weed wiping using glyphosate, spray-topping using paraquat, mowing prior to ryegrass flowering followed by spray-topping, biomass cutting for hay/silage production, green manuring, and the non-selective use of glyphosate prior to ryegrass flowering (brown manuring) were effective at reducing annual ryegrass seed production by more than 80% compared to the untreated control.
- The highest serradella biomass was achieved following the application of flumetsulam applied post-sowing/pre-emergent and the second greatest serradella seed production was achieved following propyzamide and/or imazethapyr treatment.
- Paraquat, especially when used at the heading stage of ryegrass, reduced the ryegrass seed production to <2.5% of the untreated control (weedy control).
- Applying glyphosate or paraquat was effective at reducing ryegrass seed production, however these treatments also greatly reduced serradella seed production, making them unsuitable in self regenerating pastures.
- Using early intervention of weed control options in serradella significantly reduced the number of ryegrass and capeweed plants compared to late intervention options.
- Results of a three-year rotational trial showed the continuous wheat rotations generated the highest ryegrass seed, which further negatively impacted wheat yield compared to wheat in other rotations.
- Alongside the chemical fallows, serradella phases were the best at reducing seed inputs to the ryegrass seedbank.

Aims

Using pasture management to decimate weed seed banks during a pasture phase and increase the productivity and profitability of the subsequent crop phase.

Introduction

Profitable crops in rotation with pasture and livestock systems were traditionally the dominant farming systems in Australia. However, with increasing machinery capacity and the adoption of agronomic practices that improve water use, continuous cropping has become predominant, resulting in reduced species diversity in rotations and over-reliance on in-crop selective herbicides for weed control, which in turn has limited the diversity of weed management options. This has led to the widespread selection of herbicide resistance globally. Weeds are still a major threat to the productivity and sustainability of current farming systems, and more diversity is needed to disrupt the evolution of herbicide resistant weeds and weeds that evade current weed control practices. On many Australian farms, profitability and durability would greatly benefit from phase farming, in which a multi-year cropping phase is disrupted by a multi-year pasture phase that builds nitrogen, rapidly exhausts weed seed banks and decimates soil-borne crop pathogens.

Method

Experimental design

Studies were done at the UWA-Ridgefield farm near Pingelly in the 2019 and 2020 growing seasons (Trial 1 and 2); and Bolgart and Brookton in the 2019, 2020 and 2021 growing seasons (Rotational trials). The treatment structure consisted of 16 different single weed control techniques (Trial 1); five different weed control strategies (Trial 2); seven cropping rotations at two sites over three years (Rotational trials). Treatments at all trials were arranged in a randomised complete block design and replicated four times. A complete technical description of the site management can be found in **Error! Reference source not found.**, 2 and 3.

Table 1. Agronomic treatments of single weed control tactics (Trial 1) applied to serradella

	Treatments	Details
Ctrl	Weed-free control	(Knockdown, 1L/ha propyzamide + 100g/ha imazethapyr PSPE, 500mL/ha clethodim +100 g/ha butroxydim four-six leaf)
	Weedy control	Untreated control (UTC)
PSPE	Propyzamide	1.5L/ha
	Imazethapyr	100g/ha
	Imazethapyr + propyzamide	Imazethapyr 100 g/ha + propyzamide 1L/ha
	Flumetsulam	42g/ha
POST	Thistrol Gold	2L/ha, apply when serradella has at least two true trifoliate leaves, and weeds are still at the seedling stage
	Imazethapyr	150g/ha, applied after crop emergence when weeds are two-four leaf stage
	Flumetsulam	25g/ha
	Imazamox	50ml/ha
Full Canopy	Weed wiper	Wipe out taller growing weeds in the pastures and field crops with a special fabric soaked with the chemical mixture (250mL glyphosate, 250mL MCPA (LVE), 500mL water, 4g Logran, and 2% wetter).
	Green manuring	Incorporation of the actively growing pasture using the duck foot cultivator.
	Hay or silage production	Pasture may be cut for hay or silage to prevent weeds from setting seed.
	Spray-topping	Sterilisation of weed seed through the application of a non-selective herbicide (500mL/ha paraquat) using sub-lethal rates during reproductive growth stages to prevent the formation of viable seeds.
	Brown manuring	The use of non-selective (1.5L/ha glyphosate) herbicides to kill the whole pasture before setting seed.
	Mowing + spray-topping	Cut with forage harvester when considered suitable for grazing and spray afterward with (500mL/ha paraquat).

Abbreviations: Ctrl, control; PSPE, post-sowing pre-emergence, POST, post-emergence.

Table 2. Treatments of intensive weed control strategies (Trial 2) applied to serradella in 2019 and 2020

ID	Weed control strategies	Comments
1	Early-stage options (E-stage)	Tickle the soil in autumn, double knockdown, imazethapyr 100g/ha + propyzamide 1L/ha (PSPE), 500mL/ha clethodim + 100g/ha butroxydim (POST)
2	Excellent weed control (Excellent-ctrl)	Tickle the soil in autumn, double knockdown, imazethapyr 100g/ha + propyzamide 1L/ha (PSPE), 500mL/ha clethodim + 100g/ha butroxydim (POST), spray-topping (500mL/ha paraquat), weed wipers (250mL Roundup, 250mL MCPA (LVE), 500mL water, 4g Logran, 2% Wetter)
3	Glyphosate-free option (Gly-free)	Imazethapyr 100g/ha + propyzamide 1L/ha (PSPE), Imazamox 50mL/ha (POST), spray-topping (500mL/ha paraquat), weed wipers (250mL Roundup, 250mL MCPA (LVE), 500mL water, 4g Logran, 2% Wetter).
4	Late-stage options L-stage)	Spray-topping (500mL/ha paraquat), Weed wipers (250mL Roundup, 250mL MCPA (LVE), 500mL Water, 4g Logran, 2% Wetter)
5	Weedy control	Untreated control (UTC)
ID	**Grass species**	**Comments**
1	Barley grass	Common populations
2	Bromegrass	Common populations
3	Annual ryegrass	Common populations

Table 3: Treatments of different crop rotations and their impact on weed seed bank decline study (Rotational trials)[1]

Treatments	Year 1 (2019)	Year 2 (2020)	Year 3 (2021)	Year 4 (2022)
Rotation 1: Nil diversity continuous rotation wheat (control)	**Wheat** (Clearfield with standard management)	**Wheat** (Clearfield)	**Wheat** (Clearfield)	**Wheat** (Clearfield)
Rotation 2: Chemical fallow	**Chemical fallow** (knockdown herbicide applications to maintain weed-free, zero seed set.	**Chemical fallow** (knockdown herbicide applications to maintain weed-free, zero seed set.	**Chemical fallow** (knockdown herbicide applications to maintain weed-free, zero seed set.	**Wheat** (Clearfield)
Rotation 3: Diverse (break) continuous cropping rotation (control)	**Lupins** Autumn tickle Double knock Brown-manured (1.5 Glyphosate)	**Oats** (Cut for hay and spray-top)	**GM Canola** (Standard management)	**Wheat** (Clearfield)
Rotation 4: Brown manured serradella (cv. Eliza)	**Serradella** (Brown-manured) Autumn tickle to stimulate weed germination, Double knockdown, Seed Eliza (short season) serradella + Spinnaker and propyzamide (PSPE)	**Wheat** (Clearfield)	**Serradella** (Brown-manured) Autumn tickle to stimulate weed germination, Double knockdown, Seed Eliza (short season) serradella + Spinnaker and propyzamide (PSPE)	**Wheat** (Clearfield)
Rotation 5: Serradella (cv. Cadiz)	**Serradella** (seeded) – winter-clean/ spring spray-top	**Wheat** (Clearfield)	**Wheat** (Clearfield)	**Wheat** (Clearfield)
Rotation 6: Two-year serradella (cv. Margurita)	**Serradella** (seeded) Dry seeded, winter-clean herbicides /weed wipers	**Serradella** regenerated - winter-clean/ spring spray-top	**Wheat** (Clearfield)	**Wheat** (Clearfield)
Rotation 7: Three-year serradella (cv. Margurita)	**Serradella** (seeded) Dry seeded, winter-clean herbicides /weed wipers	**Serradella** regenerated winter-clean/ weed wipers	**Serradella** regenerated – winter-clean/ spring spray-top	**Wheat** (Clearfield)

Statistical models

Data were analysed using a linear mixed model with treatment fitted as a fixed factor and the blocking structure fitted as a random variable assuming heterogeneous variance for all species. As the data was collected from randomised plots, the spatial variability in the trial was not accounted for in the model. The parameters analysed for each site included plant density and aboveground biomass (serradella, annual ryegrass, dicot weed species), and annual ryegrass and serradella seed production. Only the annual ryegrass seed production data are presented in this paper. The analyses were conducted using R 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria) with the R-package *Asreml-R* (Gilmour et al 2015; Butler et al 2017). The test for the fixed effect was performed using the Wald-test.

Results

Annual ryegrass and serradella seed production (Trial 1)

The seed production of annual ryegrass was influenced by both the control tactic used and the timing of the tactic's application ($p < 0.001$). When control tactics were applied at the full canopy stage, the seed production of ryegrass was greatly reduced (Figure 1). The pooled seed production of annual

[1] This is not a systems/crop rotations trial as rotations treatments are phased each year.

ryegrass treated at full canopy stage was 478 seeds/m^2 in 2019 and 2410 seeds/m^2 in 2020, equating to 2–16% of untreated weedy control in 2019 and 2020, respectively. Annual ryegrass seed production was significantly higher when control tactics were applied either PSPE or POST timing ($p<0.001$) (Figure 1). For example, applying the group 2 herbicide imazethapyr POST only reduced annual ryegrass seed production by 64% in 2019, with no reduction in 2020 (Figure 1). The other Group 2 herbicide, flumetsulam, reduced annual ryegrass seed production by 36% and 12% in 2019 and 2020, respectively, with imazamox reducing annual ryegrass seed production by 55% and 38% in 2019 and 2020, respectively.

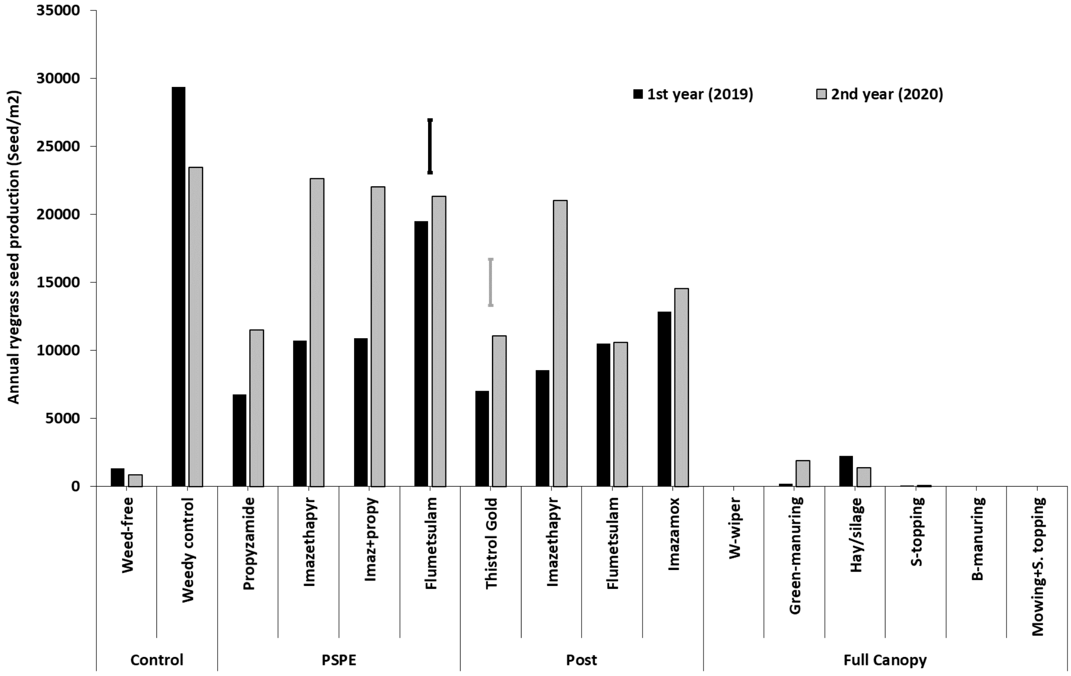

Figure 1. The effect of different weed management tactics (Trial 1) on annual ryegrass seed production, UWA Ridgefield farm 2019, 2020 (bars denote SED = 3379 for 2019 (black) and 3905 for 2020 (grey)).

Serradella seed production was significantly ($p<0.001$) affected by the application of weed control tactics (Figure 2). The highest serradella seed yield was achieved following the application of flumetsulam (PSPE) and the mixture of propyzamide and imazethapyr (PSPE). The application of weed control tactics applied at the full canopy stage was the most damaging to serradella seed production, with spray-topping with paraquat at the flowering stage of serradella reducing pod production by 50% and 75% in 2019 and 2020, respectively, compared with the untreated control.

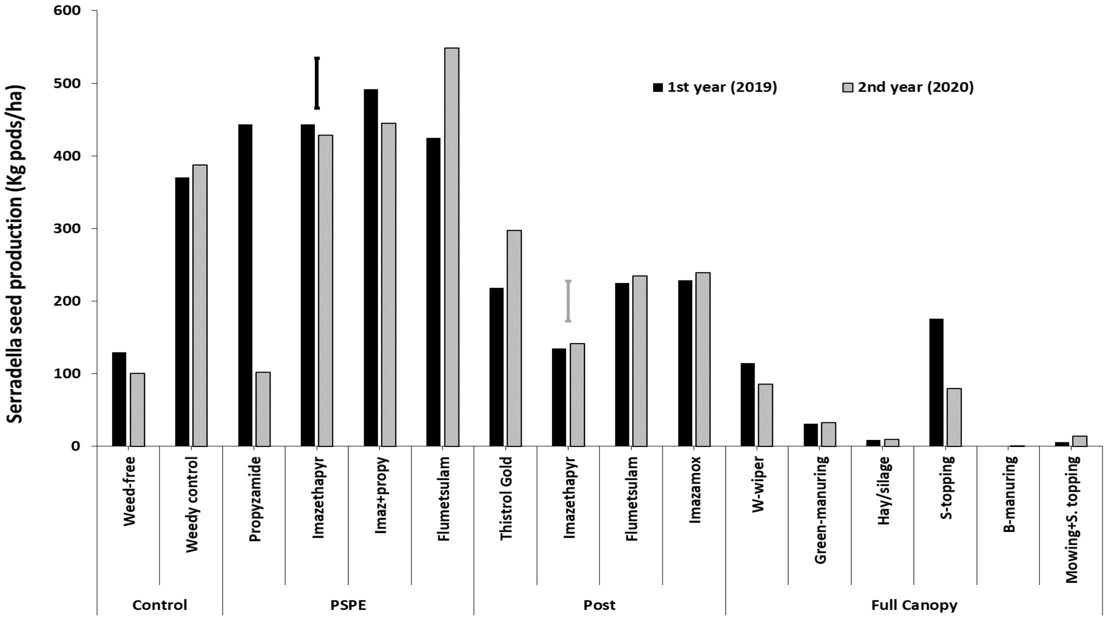

Figure 2. The effect of different weed management tactics (Trial 1) on serradella seed production, UWA Ridgefield farm 2019, 2020 (bars denote SED = 55.93 for 2019 (black) and 68 for 2020 (grey)).

Annual ryegrass and serradella seed production (Trial 2)

There was a significant interaction (p-value<0.001) effect between the weed species and the weed management combinations. Regardless of what had been done early in the growing season to better control weeds, late intervention as an individual weed control option or combined with other early weed control options using spray-topping or weed wiping was very effective (p-value<0.001) in reducing seed production of all monocot weeds (ryegrass, barley grass, and bromegrass) (Figure 3).

For the ryegrass, more than 22000 seed m^{-2} which is 86% of the untreated weedy control, were produced with the early-stage intervention of weed control compared to the excellent-control, glyphosate-free, and late intervention options, where seed production was reduced to 1, 1 and 0%, respectively. For barley grass and bromegrass, 100% seed set control was achieved with all the tested weed control combinations (early and late intervention).

The estimation of annual ryegrass seed inputs revealed that the late intervention of weed control through spray topping and weed wiping options for ryegrass seed set control, significantly reduced the final seedbank of the ryegrass (seed input) and input only around 3.5% of the untreated weedy control. On the other hand, sticking to the early intervention approaches in weed management resulted in the input of ryegrass seed of 85% of the untreated control.

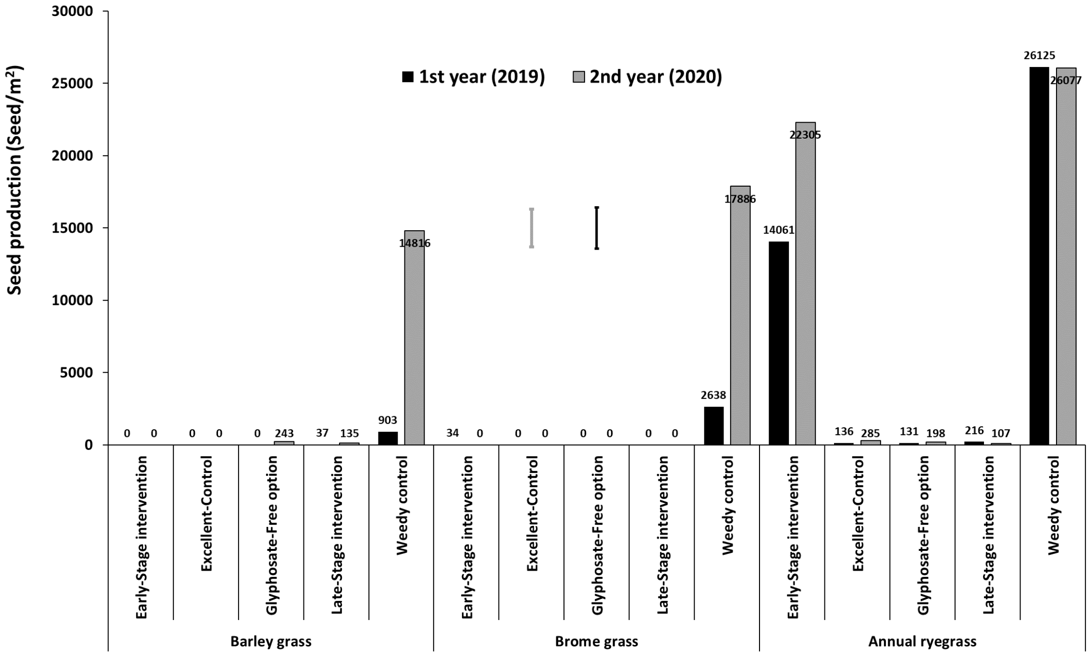

Figure 3: Effect of different weed management options (Trial 2) on the seed production of three grassy weeds (barley grass, bromegrass, and annual ryegrass), UWA-Ridgefield farm 2019, 2020. Bars are the SED = 2847 for 2019 and SED = 2606 for 2020.

Serradella seed production was significantly (p-value <0.001) affected by the implementation of the weed control strategies (Figure 4). For all grass species, the highest serredella seed production was achieved with the Excellent-control treatments. The second highest serradella seed production was achieved with the Glyphosate-free treatment (Figure 4). Although the late-stage intervention reduced the ryegrass seed production, it did not provide a safe window for serradella.

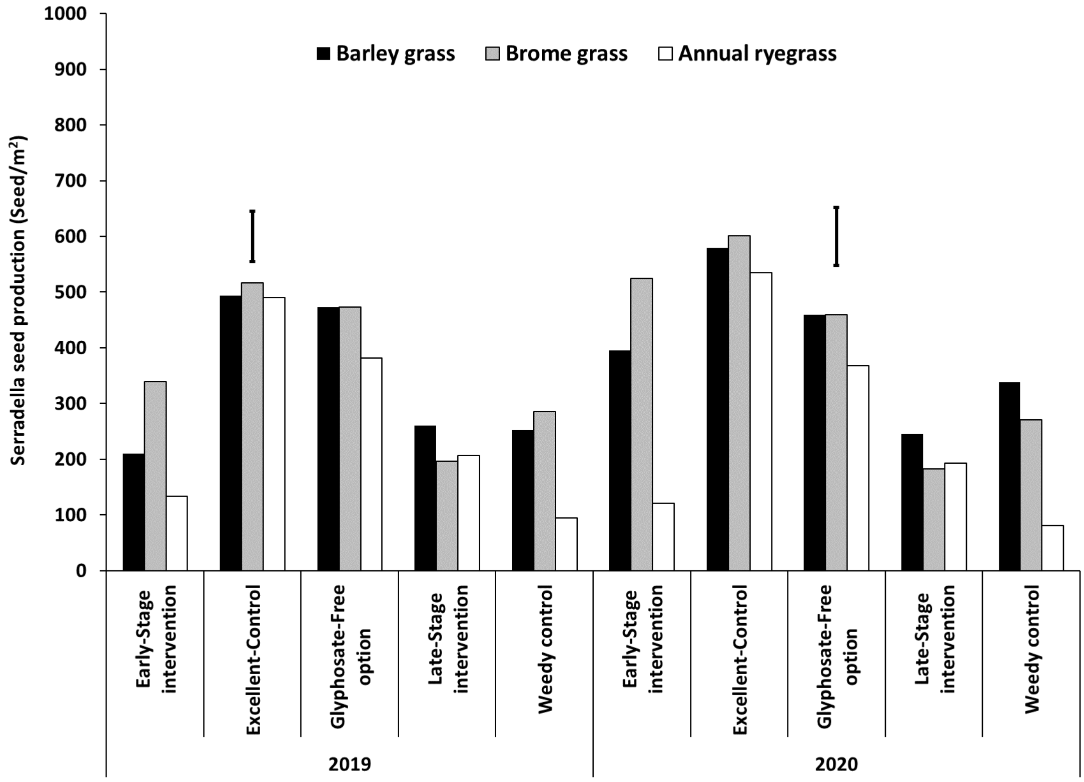

Figure 4: Effect of different weed management strategies (Trial 2) on serradella seed production infested with three grassy weeds (barley grass, bromegrass annual ryegrass), UWA-Ridgefield farm 2019 and 2020. Bars are the SEDs 2019 = 104.2, 2020=103.

Seedbank assessment (Rotational trials)

At the beginning of the study, an average of nearly 3800 seed/m^2 of ryegrass at Bolgart and 9200 seed/m^2 at Brookton were recorded from the seedbank of these sites. Following the first year of the rotation (measured 2019), ryegrass seed set control ranged from 36 – 100% of the original seedbank at Bolgart site. At the Brookton site, the ryegrass seed set (2019) control ranged from 61 – 100% of the original seedbank. After the second year of the study (2020) results of these trials showed that the maximum annual ryegrass production (>8000 seed/m2) occurred with the continuous wheat rotations at both sites and associated with the lowest wheat yields (data not shown). Nearly 100% ryegrass seed set control was achieved with the rest of the rotations included in these studies. Following the third year (2021), results showed the highest ryegrass seed produced with the continuous wheat rotations (Rotation 1) at both sites, which further negatively impacted the wheat yield compared to other wheat in other rotations. The study shows serradella phases can reduce a ryegrass seedbank (Figures 5 and 6).

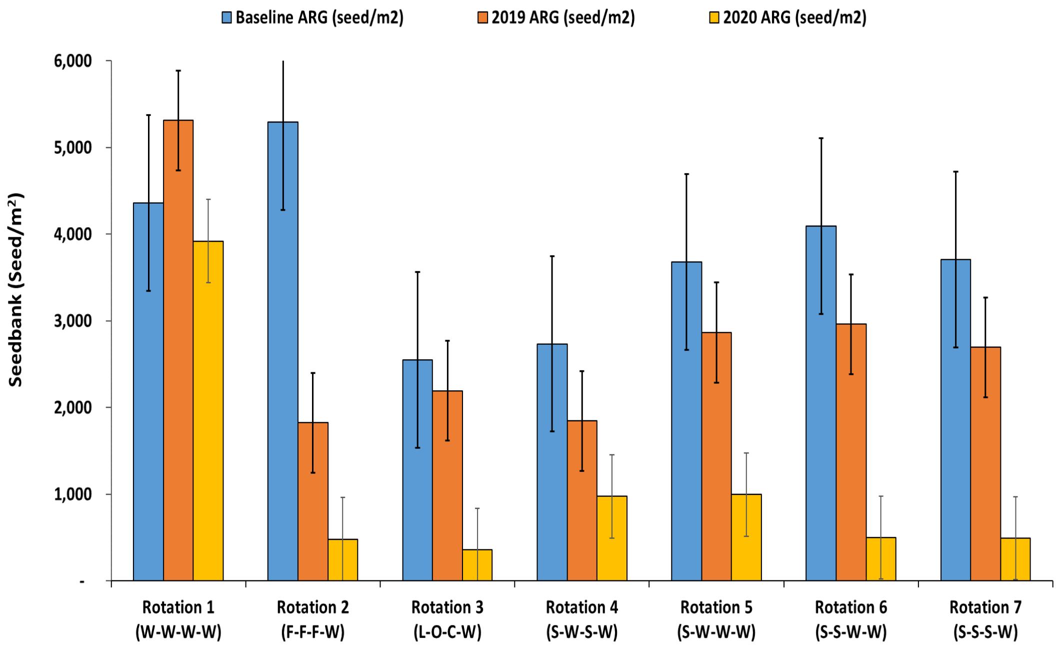

Figure 5. Soil seedbank of ryegrass (seed/m^2) at different crop rotations measured before the seeding (March), Site 1: Bolgart 2019 (Baseline), 2020 (following the first year) and 2021 (following the second year).

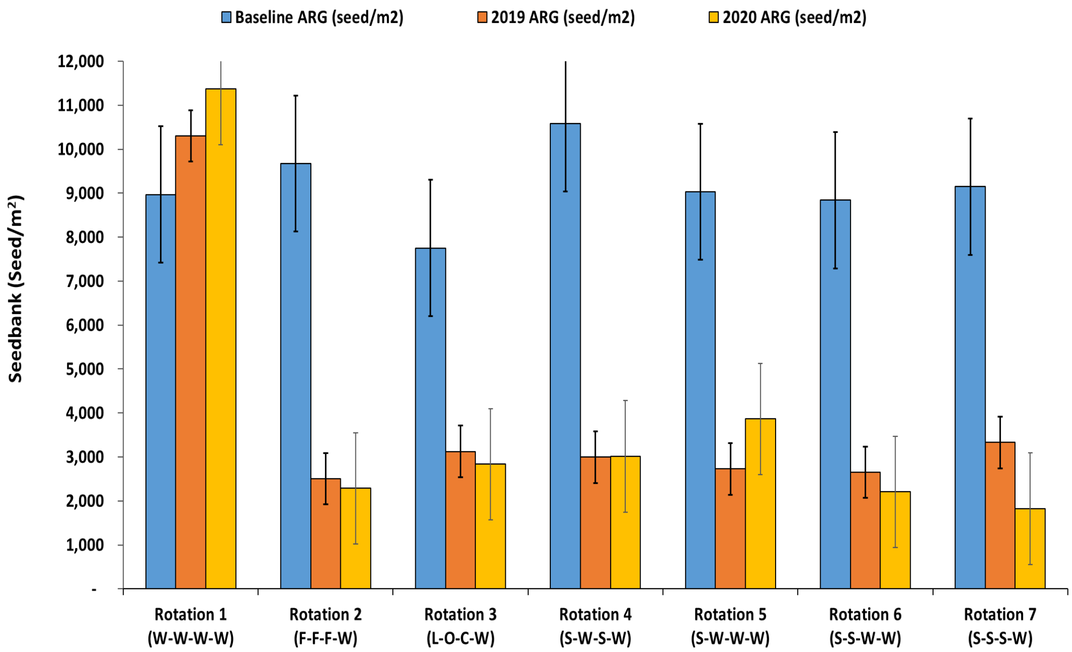

Figure 6. Soil seedbank of ryegrass (seed/m^2) at different crop rotations measured before the seeding (March), Site 2: Brookton 2019 (Baseline), 2020 (following the first year) and 2021 (following the second year).

Conclusion

Weeds such as annual ryegrass have the adaptive capacity to vastly decrease the profitability of cereal-sheep farming. Legume pasture phases offer a profitable non-cropping phase to control ryegrass through diverse herbicide and non-herbicide weed control techniques. The value of a pasture phase for weed management increases at (1) higher ryegrass seed burdens and (2) where herbicide resistance constrains the efficacy of in-crop weed control options. The single weed control options applied late in the growing season were the most effective tools in reducing the annual ryegrass seed production. Early intervention strategies of weed management in the serradella phase significantly reduced ryegrass numbers but not pasture biomass. Late intervention strategies were the most effective way to stop ryegrass from setting seed and significantly reduce the seedbank size. Serradella phases (mainly 2- and 3-years-long) were as effective as the rotations with chemical fallows and oats followed by GM canola, in driving down the seedbank size of annual ryegrass in the farming systems.

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