CSIRO PUBLISHING
Crop & Pasture Science, 2019, **70**, 800–806
https://doi.org/10.1071/CP19077

Comparative effects of grazing, herbicide or forage conservation on barley grass content in *Trifolium subterraneum* L. clover-based pasture

John W. Piltz[A,B,D], *Simon J. Flinn*[A], *and Leslie A. Weston*[C]

[A]NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, Private Mail Bag, Wagga Wagga, NSW 2650, Australia.
[B]Graham Centre for Agricultural Innovation (NSW Department of Primary Industries and Charles Sturt University), Wagga Agricultural Institute, NSW DPI, Wagga Wagga, NSW 2650, Australia.
[C]Graham Centre for Agricultural Innovation (an alliance between NSW Department of Primary Industries and Charles Sturt University).
[D]Corresponding author. Email: john.piltz@dpi.nsw.gov.au

Abstract. Barley grass (*Hordeum* spp.) is a relatively short lived annual that provides high quality grazing early in the season, but its seed heads cause contamination of wool and carcasses, and may irritate the mouth, eyes and nose of sheep. Treatments were imposed on established subterranean clover (*Trifolium subterraneum* L.) annual pasture in the same plots for three consecutive years (2015 to 2017) to evaluate changes in barley grass content. Treatments included: grazing alone (G), herbicide followed by grazing (HG), or a forage conservation harvest in early October, late October or early November consistent with an early silage harvest (ES), late silage harvest (LS) or hay cut (H). Grazing plus herbicide markedly reduced ($P < 0.05$) barley grass numbers compared with all other treatments, but increased ($P < 0.05$) the growth of annual ryegrass (*Lolium rigidum* L.). ES reduced ($P < 0.05$) barley grass and increased ($P < 0.05$) subterranean clover compared with H, but broadleaf weed content benefitted by LS in contrast to either ES or H. Although herbicide application was the most effective method for barley grass control, forage harvest timing could be used to beneficially manipulate pasture composition.

Additional keywords: forage conservation, pasture, grazing, herbicide, subterranean clover.

Received 21 February 2019, accepted 26 July 2019, published online 4 October 2019

Introduction

The traditional method of pasture improvement in many areas of southern Australia, particularly the mixed farming zone, has been autumn sowing of annual legume subterranean clover (*Trifolium subterraneum* L.). Controlling grass species before or at the time of sowing reduces competition and improves clover establishment; however, other species, including grasses, legumes and broadleaf weeds, will invade the pasture over time (Kemp and King 2001; Wolfe and Dear 2001). The level of incursion of individual species is dependent on their presence in the seedbank, pasture management, and competition between the species present (Sheppard 1996; Webster *et al*. 2003; Tozer *et al*. 2017). Barley grass (*Hordeum* spp.) and annual ryegrass (*Lolium rigidum* Gaud.) are the two main annual grass weeds of pasture in southern Australia (Owen *et al*. 2014; Llewellyn *et al*. 2016). Barley grass is an adventitious introduction from the early years of European settlement, and is a relatively short-lived annual that provides high quality grazing early in the season, but its seed heads cause contamination of wool and carcasses, and will irritate the mouth, eyes and nose of sheep (Smith 1968*a*; Cocks and Donald 1973). Previously annual ryegrass was commonly sown in southern Australian pastures as it produces high quality grazing and is beneficial in permanent pastures; however, it is an unwanted competitor in winter crops and has, over time, developed resistance to many herbicides used for its control (Cocks and Donald 1973; Walsh and Powles 2007; Powles 2008; Owen *et al*. 2014).

Changes in pasture composition due to management practises have been reported by several authors. In a review of the literature, Gill and Holmes (1997) stated that grazing can reduce the incidence of weeds by reducing weed numbers or seed set. They reported that grazing early in the season could reduce annual ryegrass numbers by 80% or more; however, later grazing was typically ineffective because seed shed had already occurred. Control was reliant on sufficient grazing pressure to ensure consumption of seed heads before seeds reached maturity. In contrast, other authors have reported that grazing does not affect the level of barley grass seed production and results in an increase in tiller numbers (Robards and Leigh 1967; Smith 1968*b*). Furthermore, the tillers were observed to become shorter and seed heads closer to the ground, which reduced the likelihood of damage from grazing. Cutting for hay or silage has also been reported to reduce annual ryegrass in the subsequent wheat crop (Gill and Holmes 1997; Burnett *et al*. 2005), but follow-up regrowth control was sometimes required for effective management (Burnett *et al*. 2006).

Barley grass typically does not persist in the soil whereas the annual ryegrass seedbank depletion rate is 70–80% per year (Peltzer and Matson 2002). In addition, barley grass has been shown to germinate and emerge earlier, and to establish more quickly than ryegrass (Cocks and Donald 1973), giving barley grass a competitive advantage.

The present experiment was conducted to test the hypotheses that forage harvesting, i.e. cutting for hay or silage, alters pasture composition compared with grazing, and, that the effect of forage harvesting on pasture composition varies with timing of the forage harvest.

Materials and methods

The experiment was conducted on an established annual pasture at the Wagga Wagga Agricultural Institute (35°04′S, 147°36′E) that had previously been sown to subterranean clover (*Trifolium subterraneum* L.) more than 5 years previously on a fine red sodosol soil (Isbell 1996). Grazing by sheep was the only activity conducted on the paddock before the experiment. At the time of experimental initiation, the pasture contained significant levels of barley grass (*Hordeum* spp.) and annual ryegrass (*Lolium rigidum* Gaud.) with lesser quantities of various broadleaf weeds and other species. The dominant subterranean clover cultivar was Woogenellup, with traces of Dinninup and Dwalganup. Yield and composition were determined on 20 August 2015, before the experimental initiation, by cutting 10 0.1 m^2 quadrats to a height of 50 mm above ground level from the pasture adjacent to, and representative of, the trial plots.

The trial was established in a uniform area of the paddock, with five treatments replicated four times, in a randomised complete block design (plots of 8 × 10 m). The treatments were applied to the same plots in each of the three consecutive years. Plots were adjacent to each other with a 1 m buffer between replicates, in a 2 × 2 spatial arrangement.

The five treatments examined were (i) grazing, (ii) grazing plus herbicide, or one of three forage conservation harvests timed to be typical of an (iii) early silage, (iv) late silage or (v) hay cut for the district: hereafter referred to as G, GH, ES, LS and H, respectively, with G considered as the control. Forage conservation harvests were timed according to prevailing weather conditions and when there was sufficient growth to conserve. Silage requires less wilting (drying) to achieve the desired target dry matter content than hay, and can be produced earlier in spring when weather conditions are less favourable for drying i.e. shorter days with less sun and heat. Lower yield at the time of harvest also assists with faster wilting and facilitates silage making early in the season. The window of opportunity for producing silage is also wider than for hay.

All treatments were imposed in 2015, 2016 and 2017, except for H, which was applied only in 2016 and 2017 due to experimental timing. Herbicide application occurred on 16 August 2016 (Verdict 520® (haloxyfop-R methyl ester; 75 mL/ha) plus Broadstrike® (flumetsulam; 20 g a.i./ha)) and 26 July 2017 (Verdict 520® (75 mL/ha)) before grazing, when most barley grass plants were at the tillering stage of development.

The primary target weed was barley grass in both years along with certain broadleaf weeds in 2016. The forage conservation harvest dates were 8, 20 and 29 October in 2015; 6 and 31 October and 15 November in 2016; and 29 September, 16 and 31 October in 2017. Harvest times were varied to match prevailing seasonal conditions for individual years. In 2015, the H plot senesced rapidly following 2 days of unseasonably hot and windy weather, which caused the clover plants to collapse, reducing the yield above cutting height. No pre-harvest sampling occurred on these plots; however, to avoid a year's delay in treatment application, these plots were harvested so as to remove the grass seed heads which remained above cutting height. The G and GH plots were grazed based on pasture availability and at high stocking rates for short periods. Grazing ceased when pasture available was estimated to be ~500 kg DM/ha. Commencement date of grazing, length of grazing and stocking rate are presented in Table 1.

Botanical composition was estimated for each plot using the BOTANAL procedure (Tothill *et al*. 1978) on a single common date during late winter/early spring in 2016 and 2017 (27 July 2016 and 24 August 2017), after the treatments had been imposed for one and two years respectively. The BOTANAL method was used to avoid damaging the plots before imposition of treatments, and there were 20 individual assessments per plot.

In 2016 and 2017, four 0.1 m^2 quadrats/plot were cut immediately before each grazing or forage conservation treatment: an additional four 0.1 m^2 from all plots except the H treatment were cut on 29 November 2016 to assess regrowth. All quadrats were cut to a height 50 mm above ground level to simulate the yield for grazing and forage harvesting. Samples were separated into their components which were dried individually at 80°C for 24 h in a fan forced oven. Botanical composition, sample dry matter (DM) content and yield (kg/ha) were calculated for each quadrat. All sampling and botanical assessments were performed avoiding a minimum distance of 1 m from the edge of each plot.

Table 1. Date, period and stocking rate (SR) for grazing and grazing plus herbicide treatments

Year	Grazing			Herbicide plus grazing		
	Date	Period (hours)	SR[A]	Date	Period (hours)	SR[A]
2015	29 September	40	7 (1000)	29 September	40	7 (1000)
2016	19 September	24	8 (1143)	19 September	24	8 (1143)
	20 October	24	6 (857)	20 October	24	6 (857)
2017	15 September	24	2 (286)	18 September	24	2 (286)
	–	–	–	29 September	24	2 (286)

[A]SR, stocking rate (sheep per hectare).

Sheep also grazed all plots during summer through to late winter/early spring as per normal management practise to remove surplus pasture and control summer weeds. These grazing events occurred on 11 December 2015, 23 January 2015 to 7 January 2016, 7 April 2016, 28 July to 2 August 2016, 2 to 5 December 2016, and 29 August 2017, and timing was dependent on the amount of pasture or weed biomass present.

Plant emergence counts (four 0.1 m^2 quadrats per plot) were conducted on 17 April 2016 (subterranean clover only), 23 June 2017, 8 December 2017 and 24 July 2018.

All statistical analyses were conducted using the REML directive in GENSTAT (ver. 18, VSN International, Hemel Hempstead, UK). Botanical composition (BOTANAL) and germination counts were analysed with year, treatment and the interaction as fixed effects, and replicate and plot as random effects. Yield and botanical composition before each grazing or harvest was analysed with individual treatment harvests, i.e. the treatment × date interaction, as the sole fixed effect and replicate and plot as random effects. Since the yields from additional grazing and regrowth events were also measured in 2016, the quadrat yields from each plot was averaged for each harvest, and combined to give a total yield for each plot over the year. These total yields were analysed with treatment as the sole fixed effect and replicate as the random effect. The emergence count (20 per plot) conducted on 8 December 2017 was analysed with treatment as the sole fixed effect and replicate and plot as random effects. Yield of subterranean clover, annual ryegrass and barley grass at the first harvest in both 2016 and 2017 was analysed with treatment, year and the interaction as the fixed effects and replicate and plot as the random effects.

This experiment was conducted with approval from NSW Department of Primary Industries' Animal Ethics Committee (ORA 16/19/011).

Results

The initial pasture composition was: 68.6% subterranean clover, 19.8% grass species, 11.0% broadleaf species and 2.0% miscellaneous species, with, a total harvestable yield of 2982 kg DM/ha on 20 August 2015.

Total annual rainfall was 802.0 mm in 2016 and 479.6 mm in 2017 at Wagga Wagga. Furthermore, September 2016 rainfall (171 mm) exceeded the long-term average (49.4 mm) and allowed pasture growth to continue later into the season with a final harvest of all treatments except H on 29 November 2016. In contrast, in 2017, rainfall from April to September (165.5 mm) was considerably below average (295.1 mm) and growth past the initial harvest was limited.

The proportion of subterranean clover, annual ryegrass, barley grass and shepherd's purse in late winter/early spring of 2016 and 2017, determined by BOTANAL, all varied ($P < 0.001$) due to the interaction between treatment and year (Table 2). Annual ryegrass, except for GH, and subterranean clover was lower ($P > 0.05$) in 2017 compared with 2016 for all treatments, whereas barley grass was higher ($P > 0.05$), except for GH. In 2016 the proportion of barley grass was lower ($P > 0.05$) for ES and LS compared with G and H, with GH intermediate and not different to any treatment; but in 2017 the treatments had diverged ($P > 0.05$) such that barley grass content of GH < ES < LS < G < H. The proportion of shepherd's purse in 2017 was higher ($P < 0.05$) than in 2016 for ES and LS, with LS in 2017 being higher than all other treatment by year combinations.

Silvergrass (*Vulpia* spp.) content varied ($P = 0.18$) with year, but was only a minor constituent of the pasture mix at 0.06 and 0.4% in 2016 and 2017 respectively. Several other broadleaf weed species were present, including *Erodium* spp., capeweed (*Arctotheca calendula* L. K.Lewin), fumitory (*Fumaria* spp.), marshmallow (*Malva parviflora* L.) and mustard (*Sisymbrium* spp.), in levels too low and sporadically distributed to statistically analyse and therefore are not reported.

Consistent with the BOTANAL results, differences existed between individual treatment harvests in 2016 and 2017 for a range of species including subterranean clover ($P < 0.001$), annual ryegrass ($P < 0.001$), barley grass ($P < 0.001$), wild oats (*Avena fatua* L.) ($P < 0.001$), shepherd's purse (*Capsella bursa-pastoris* L.) ($P < 0.001$) and soft brome (*Bromus hordeaceus* L.) ($P = 0.009$) (Table 3). Subterranean clover for all treatments and annual ryegrass content for all treatments except for GH, were higher ($P < 0.05$) at the first harvest in 2016 compared with the first harvest in 2017: conversely that of barley grass was lower ($P < 0.05$) for all treatments except GH (Table 3). Differences associated with year were attributed to dry conditions encountered in 2017, rather than treatment effects. In 2016, subterranean clover content was higher ($P < 0.05$) for GH than all other treatments at the first harvest, whereas at the final harvest it was lower ($P < 0.05$) for G and did not differ between GH, ES and LS.

Table 2. Proportion of subterranean clover, annual ryegrass, barley grass and shepherd's purse present on 27 July 2016 and 24 August 2017 determined by the BOTANAL procedure

The P-value for all treatment × year interactions was < 0.001. The initial pasture composition was: 67.7% subterranean clover, 19.5% grass species, 11.0% broadleaf species and 2.0% miscellaneous species and a total harvestable yield of 2982 kg DM/ha on 20 August 2015. Total annual rainfall was 802 mm in 2016 and 479.6 mm in 2017 at Wagga Wagga

Treatment	Proportion of sward (%)							
	Clover		Annual ryegrass		Barley grass		Shepherd's purse	
	2016	2017	2016	2017	2016	2017	2016	2017
Grazing	59.7	20.0	10.0	2.1	24.9	74.3	0.1	0.9
Grazing + herbicide	66.7	54.6	10.3	30.9	19.9	2.5	0.4	2.1
Early silage	68.2	58.3	14.1	7.2	12.3	28.5	0.1	3.4
Late silage	70.4	29.8	10.9	3.9	15.2	44.3	1.3	10.1
Hay	66.1	6.9	5.5	1.2	24.5	87.0	0.1	0.6
l.s.d. ($P < 0.05$)	9.98		5.14		9.23		2.18	

Table 3. The yield and proportion (g/kg) of various plant species present before grazing or harvesting of subterranean clover pasture

Treatment	Yield (kg DM/ha)[A]	Plant species proportion (g/kg) Clover	Annual ryegrass	Barley grass	Wild oats	Soft brome	Shepherd's purse
		2016 harvest 1					
Grazing	4244	584.5	176.8	217.8	0	0	0
Grazing + herbicide	3531	796.9	155.2	25.4	0	0	0
Early Silage	5656	657.0	223.5	93.2	0	0	6.9
Late silage	9404	657.6	156.1	178.5	2.0	0.56	0.5
Hay	6102	579.4	166.0	162.4	63.7	22.3	0
		2016 harvest 2					
Grazing	2971	519.4	206.2	267.2	0	0	0
Grazing + herbicide	2765	826.1	140.4	32.6	0	0	0
		2016 harvest 3					
Grazing	2484	675.2	169.3	155.5	0	0	0
Grazing + herbicide	2639	895.2	95.4	9.4	0	0	0
Early Silage	3103	828.8	112.6	58.6	0	0	0
Late silage	1661	819.2	84.0	83.6	12.6	0	0
		2017 harvest 1					
Grazing	2412	108.3	25.6	862.7	0.0	0.0	3.4
Grazing + herbicide	460	193.0	700.7	76.8	0.0	8.3	21.1
Early Silage	1340	268.7	39.4	660.0	1.4	2.1	28.4
Late silage	2671	69.5	35.8	832.6	0.0	23.7	38.4
Hay	2469	11.9	70.8	900.2	8.5	8.3	0.4
		2017 harvest 2					
Grazing + herbicide	791	543.6	412.8	7.7	0	0	30.7
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	<0.001
l.s.d. ($P < 0.05$)	653.0	105.48	79.88	71.68	26.88	14.26	23.22

[A]Yield above 5 cm cutting height.

Barley grass content was lower ($P < 0.05$) for GH than G at all comparative harvests, and for ES than LS at the first harvests in 2016 and 2017, but not the third harvest in 2016; and was also lower ($P < 0.05$) than H at the first harvest in 2017 but not 2016. Annual ryegrass content was higher ($P < 0.05$) in GH compared with all other treatments at the first harvest in 2017. Significant ($P < 0.05$) quantities of wild oats, soft brome and shepherd's purse were also present in treated plots on various occasions, whereas several other species including *Erodium*, *Medicago* spp., capeweed, fumitory, marshmallow and silvergrass were present in limited numbers.

At the first harvest in 2016 and 2017, the yields increased ($P < 0.05$) such that GH < G < ES and H < LS, and GH < ES < G and LS and H respectively (Table 3). At the final harvest in 2016 yield of LS was lower ($P < 0.05$) than G, GH or ES. The interaction between treatment and year was also significant ($P < 0.001$) for yield (kg DM/ha) of the subterranean clover, annual ryegrass and barley grass components at the first harvest in 2016 and 2017.

In 2016 the combined yield over all harvests was highest ($P < 0.05$) for LS, lowest ($P < 0.05$) for H, with ES, G and GH intermediate and different to either LS or H (Fig. 1).

Subterranean clover numbers increased ($P < 0.05$) in each successive year for GH and ES, and between 2016 and 2017 for G; and was higher ($P < 0.05$) for GH and ES in 2017 and 2018 compared with all other treatments, whereas LS was higher ($P < 0.05$) than H in 2017 (Fig. 2). The number of annual ryegrass plants was higher ($P < 0.05$) for GH in than all other plots in both years, whereas LS was higher ($P < 0.05$) than H in 2018.

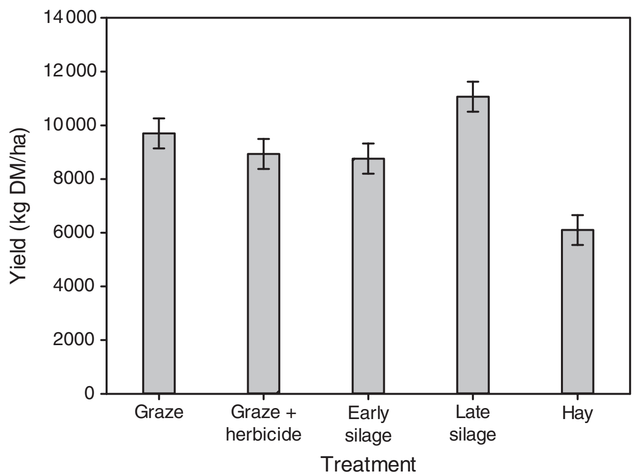

Fig. 1. Total pasture yield, including weeds, over all harvests in 2016. Total pasture yield varied ($P < 0.001$: l.s.d. ($P < 0.05$) = 1107.8) with treatment.

Barley grass numbers were higher ($P < 0.05$) in 2018 compared with 2017 for all treatments except GH, and, in contrast with annual ryegrass, the number of barley grass plants was lower ($P < 0.05$) for GH than all other plots except ES and LS in 2017. The H treatment had the highest ($P < 0.05$)

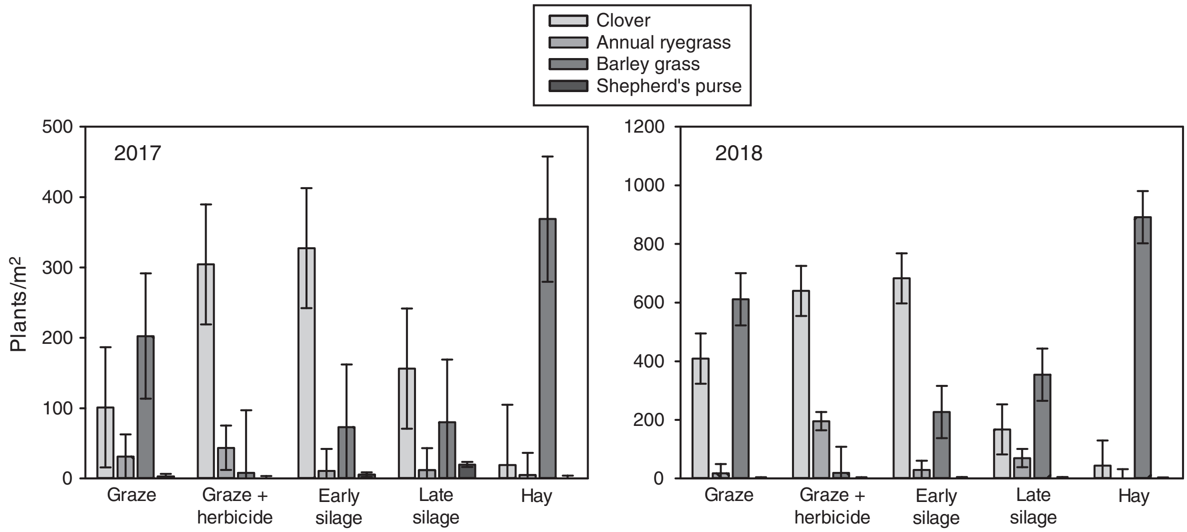

Fig. 2. The number of clover, annual ryegrass, barley grass and shepherd's purse plants on 23 June 2017 and 24 July 2018. Plant number varied ($P < 0.001$) with the interaction between treatment and year; l.s.d. ($P < 0.05$) values were clover = 169.1; annual ryegrass = 62.4; barley grass = 176.3; shepherd's purse = 7.0.

number of barley grass in 2017 (except for G) and 2018. Also in contrast with subterranean clover, barley grass numbers were higher ($P < 0.05$) for G compared with GH in both years. Shepherd's purse numbers were higher ($P < 0.05$) for LS in 2017 (20.0 plants/m^2) than all other treatments (average 1.6 plants/m^2), which did not differ from each other. Total broadleaf weed numbers were affected by treatment ($P = 0.02$: l.s.d.$_{0.05}$ = 4.214), being 4.38, 1.27, 0.63, 8.20 and 1.56 plant/m^2 for G, GH, ES, LS and H respectively.

Discussion

Forage harvesting significantly altered pasture composition in this experiment in contrast to grazing. In addition, timing of the harvest also affected pasture composition, suggesting that forage treatment differences, compared with grazing, were dependent on season and harvest time. When both years were considered together, the ES treatment reduced barley grass and increased clover content compared with H, with LS effect being intermediate; both ES and LS also increased clover and reduced barley grass content compared with G. This finding is consistent with that of Bowcher (2002) who reported that cutting perennial grass/subterranean clover pasture early in October increased subterranean clover compared with grazing. However, in contrast to this experiment, Bowcher (2002) found that the decline in subterranean clover content was not increased by a longer delay in cutting time. Also, in that experiment, cutting substantially reduced barley grass content compared with grazing, regardless of when the cutting occurred (average 0.2 vs 4.8%); which differed to our experimental results. Cutting of subterranean clover has been shown to increase seed set due to greater inflorescence numbers (Collins 1981); whereas early season cutting has been shown to increase seed yield of subterranean clover compared with later cutting (Dear *et al*. 2008). This is supported by our findings showing differences in subterranean clover content with cutting time.

Wild oats and soft brome were more likely to be present in the LS and H treatments during 2016 and 2017 than the G, GH or ES treatments, further evidence that later cutting was more likely to promote growth of certain grass weeds. In contrast, shepherd's purse seemed to benefit from ES and LS compared with H.

These data provide evidence that timing of the harvest was critical in affecting seed set and subsequent presence of species in the sward. In particular, critical time of harvest varied with species as reported by Bowcher (2002). Similarly Cocks *et al*. (1976) reported a range in flowering times and length of growing season within barley grass species and ecotypes, highlighting the importance of timing if a forage harvest is used as a control option for barley grass.

Pasture yield in spring has been reported to increase over time when the pasture is actively growing (Belton *et al*. 1989; Jacobs *et al*. 1998). In this experiment yield accumulation of the cut treatments occurred between ES and LS but declined thereafter in 2016 and remained unchanged between LS and H in 2017. This reduction in 2016 is attributed to 'slumping' or 'lodging' caused by the relatively high forage yields under favourable growing conditions which reduced yield below cutting height; whereas in 2017 the shorter spring meant that plants matured more quickly and presumably reached peak biomass earlier. There was no yield advantage in delaying harvest past late October, in either 2016 or 2017, furthermore the decline in forage quality that occurs as plants mature would have reduced production potential when fed to livestock (Jacobs *et al*. 1998).

Further analysis showed the reduction in total forage yield for GH compared with G at the first harvest in both years was entirely due to a reduction ($P < 0.05$) in barley grass yield (90 vs 969 and 38 vs 2063 kg DM/ha for GH and G in 2016 and 2017 respectively). This is consistent with other reports that have shown haloxyfop was a good barley grass control option; however, the prevalence of annual ryegrass resistance to haloxyfop is very high (Broster and Pratley 2006). Fortunately, as a grass herbicide haloxyfop does not reduce yield of other *Trifolium* species (Lockley and Wu 2008).

The lack of barley grass in GH showed the efficacy of the herbicide Verdict, and favoured the growth of annual ryegrass which contributed 70% of the total biomass in 2017. Such a result would be acceptable for a continuing pasture, but not desirable for a subsequent grain crop. Although Verdict is registered for the control of annual ryegrass, the incidence of resistance in NSW is very high (Broster and Pratley 2006) and may have influenced these results. The authors concluded that barley grass was more competitive than annual ryegrass, consistent with other reports that found barley grass was able to germinate and establish more rapidly than annual ryegrass (Smith 1968*a*; Cocks and Donald 1973), whereas annual ryegrass was more competitive than subterranean clover, and therefore dominated in the GH treatment. The authors attribute these differences to early seedling vigour. Similar findings have been reported by Moot *et al*. (2000) for Italian ryegrass (*Lolium multiflorum* Lam.) and by Turner *et al*. (2001) for annual ryegrass.

Seasonal conditions in 2016 were more favourable and there was sufficient regrowth for a second grazing of both G and GH treatments in mid-October, one month after the initial grazing, plus an additional harvest of the G, GH, ES and LS treatments in late November. However, the H treatment was not harvested in late November because only two weeks had elapsed since its previous harvest and insufficient biomass was available to justify another harvest at that time. Total yield over all harvests of LS exceeded ($P < 0.05$) that of ES, GH and G, with the lowest ($P < 0.05$) yield being the H treatment. As previously described, the authors believe that 'slumping' was a causative factor in the low yield of H in 2016. The impact of harvest or grazing timing on total pasture yield over the growth period in spring as reported by other authors has also been equivocal (Lee *et al*. 2007). However, in this case, we concluded that a forage harvest that occurs while plants are still vegetative and seasonal conditions are favourable will not compromise, and may increase, total forage yield. However, a single late harvest may result in reduced total yield.

Obvious differences in pasture composition occurred between years independent of grazing or cutting treatment. Specifically in 2017, the proportion of grass was greater and subterranean clover less compared with 2016. In 2017, barley grass was dominant in all treatments except GH, resulting in high infestation and less desirable pastures, and contributing to between 66 and 90% of the biomass present at harvest. Grass content was also greater for 2016 compared with 2015 during early spring (BOTANAL), but there was very little difference in clover content except for G, which had declined by 13%. In 2017, there was also an apparent effect of treatment on the increase in grass content in early spring compared with 2015: G+H (68.7%) < ES (80.3%) < LS (143.4%) < G (285.9%) < H (345.5%). It is not possible to determine whether the magnitude of these differences was solely due to the cumulative effects of individual treatments being imposed for two consecutive years, or it was exacerbated by interaction with season. However, it is likely that climate variability is an important contributing factor to pasture composition responses under different forage harvesting scenarios. These results support the conclusion that a later harvest will benefit early maturing species which have already shed viable seed, whereas early harvests promote later maturing species, provided adequate soil moisture is available for continued growth.

Conclusion

Strategic herbicide application was most effective at reducing barley grass, and produced pasture with high clover and reduced weed content. We found that pasture composition can be manipulated by cutting and, furthermore, the changes were dependent on the timing of that cut. Cutting in early October resulted in greatly reduced annual ryegrass, shepherd's purse and other broadleaf weed numbers, as well as a lower number of barley grass plants, and the highest number of subterranean clover plants. In contrast, cutting in early November, the traditional time for hay production in southern NSW, resulted in reduced subterranean clover and increased barley grass plant numbers, and consequently the least desirable pasture. These results confirm the potential for forage conservation to be used as a component of integrated weed management, and potentially reduce reliance on herbicides. However, it should be noted that these results relate to a specific pasture type containing barley grass as the single significant weed species, and a mixed clover sward. Further research is therefore recommended to elucidate the impact of forage conservation on different pasture types, and for the control of different weed species. Further research should also consider the impact of prevailing seasonal conditions and potential impacts of climate change.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

We acknowledge the support provided by Meat & Livestock Australia, NSW Department of Primary Industries, Charles Sturt University and the Graham Centre for Agricultural Innovation.

References

Belton JM, Michell PJ, Fulkerson WJ (1989) Effect of closing date and harvest date on yield and quality of a perennial ryegrass white clover sward in spring. *Australian Journal of Experimental Agriculture* **29**, 523–526. doi:10.1071/EA9890523

Bowcher AJ (2002) Competition between temperate perennial pasture species and annual weeds: the effect of pasture management on population dynamics and resource use. PhD Thesis, Charles Sturt University, Wagga Wagga, NSW, Australia.

Broster JC, Pratley JE (2006) A decade of monitoring herbicide resistance in *Lolium rigidum* in Australia. *Australian Journal of Experimental Agriculture* **46**, 1151–1160. doi:10.1071/EA04254

Burnett V, Enshaw T, Sutherland SU (2005) Advances in weed management for organic cereal production in southeast Australia. In 'Researching Sustainable Systems: Proceedings of the First Scientific Conference of the International Society of Organic Agriculture Research'. (Eds U Kopke, U Niggli, D Neuhoff, PS Cornish, W Lockeretz, H Miller) pp. 108–111. (International Society of Organic Agriculture Research: Bonn, Germany)

Burnett V, Enshaw T, Sutherland S (2006) Forage management effects on annual ryegrass density and cereal grain yields. In '15th Australian Weeds Conference. Managing Weeds in a Changing Climate'. pp. 339–342. Available at: http://www.weedinfo.com.au/bk_15awc.html (accessed 19 September 2019)

Cocks PS, Donald CM (1973) The germination and establishment of two annual pasture grasses (*Hordeum leporinum* Link and *Lolium rigidum* Gaud.). *Australian Journal of Agricultural Research* **24**, 1–10. doi:10.1071/AR9730001

Cocks PS, Boyce KG, Kloot PM (1976) The *Hordeum murinem* complex in Australia. *Australian Journal of Agricultural Research* **14**, 651–662.

Collins WJ (1981) The effects of length of growing season, with and without defoliation, on seed yield and hard-seededness in swards of subterranean clover. *Australian Journal of Agricultural Research* **32**, 783–792. doi:10.1071/AR9810783

Dear BS, Hackney BF, Dyce GM, Rodham CA (2008) Effect of timing of forage conservation on forage yield and quality, seed yield and seedling regeneration of four subterranean clover (*Trifolium subterraneum*) cultivars. *Australian Journal of Experimental Agriculture* **48**, 1133–1142. doi:10.1071/EA06264

Gill GS, Holmes JE (1997) Efficacy of cultural control methods for combating herbicide-resistant *Lolium rigidum*. *Pesticide Science* **51**, 352–358. doi:10.1002/(SICI)1096-9063(199711)51:3<352::AID-PS648>3.0.CO;2-M

Isbell R (1996) 'The Australian soil classification. Australian soil and land survey handbook. Vol. 4.' (CSIRO Publishing: Melbourne, Vic.)

Jacobs JL, Rigby SE, McKenzie FR, Ward GN, Kearney G (1998) Effect of lock up and harvest dates on dairy pasture dry matter yield and quality for silage in south-western Victoria. *Australian Journal of Experimental Agriculture* **38**, 131–138. doi:10.1071/EA97068

Kemp DR, King WM (2001) Plant competition in pastures. In 'Competition and succession in pastures'. (Eds P Tow, A Lazenby) pp. 85–102. (CAB International: Wallingford, UK)

Lee JM, Donaghy DJ, Roche JR (2007) The effect of grazing severity and fertiliser application during winter on herbage regrowth and quality of perennial ryegrass (*Lolium perenne* L.). *Australian Journal of Experimental Agriculture* **47**, 825–832. doi:10.1071/EA06037

Llewellyn R, Ronning D, Clarke M, Mayfield A, Walker S, Ouzman J (2016) Impact of weeds on Australian grain production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practises. Report for GRDC. CSIRO, Australia.

Lockley P, Wu H (2008) Herbicide tolerance in pasture legumes and herbs. In '16th Australian Weeds Conference Proceedings: Weed Management 2008 Hot Topics in the Tropics'. (Eds RDv Klinken, VA Osten, FD Panetta, JC Scanlan) pp. 319–322. (Queensland Weeds Society: Brisbane, Qld)

Moot DJ, Scott WR, Roy AM, Nicholls AC (2000) Base temperature and thermal time requirements for germination and emergence of temperate pasture species. *New Zealand Journal of Agricultural Research* **43**, 15–25. doi:10.1080/00288233.2000.9513404

Owen MJ, Martinez NJ, Powles SB (2014) Multiple herbicide-resistant *Lolium rigidum* (annual ryegrass) now dominates across the Western Australian grain belt. *Weed Research* **54**, 314–324. doi:10.1111/wre.12068

Peltzer SC, Matson PT (2002) How fast do the seedbanks of five annual cropping weeds deplete in the absence of weed seed input? In 'Proceedings of the 13th Australian Weeds Conference'. (Eds HS Jacob, J Dodd, JH Moore) pp. 553–555. (Plant Protection Society of WA: Perth, WA)

Powles SB (2008) Evolved glyphosate-resistant weeds around the world: lessons to be learnt. *Pest Management Science* **64**, 360–365. doi:10.1002/ps.1525

Robards GE, Leigh JH (1967) The effect of frequency and time of cutting on the production and quality of a barley grass (*Hordeum leporinum*) dominant pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* **7**, 528–532. doi:10.1071/EA9670528

Sheppard AWVC (1996) The interaction between natural enemies and interspecific plant competition in the control of invasive weeds. In 'Proceedings of the 9th International Symposium on Biological Control of Weeds'. (University of Cape Town: Cape Town, South Africa)

Smith DF (1968*a*) The growth of barley grass (*Hordeum leporinum*) in annual pasture. 1. Germination and establishment in comparison with other annual species. *Australian Journal of Experimental Agriculture and Animal Husbandry* **8**, 478–482. doi:10.1071/EA9680478

Smith DF (1968*b*) The growth of barley grass (*Hordeum leporinum*) in annual pasture. 4. The effect of some management practices on barley grass content. *Australian Journal of Experimental Agriculture and Animal Husbandry* **8**, 706–711. doi:10.1071/EA9680706

Tothill JC, Hargreaves JNG, Jones RM (1978) BOTANAL – a comprehensive sampling and computing procedure for estimating pasture yields and composition. 1. Field sampling. (CSIRO Division of Tropical Crops and Pastures: Brisbane, Qld)

Tozer KN, Minnee EMK, Greenfield RM, Cameron CA (2017) Effects of pasture base and species mix complexity on persistence and weed ingress in summer-dry dairy pastures. *Crop & Pasture Science* **68**, 561–573. doi:10.1071/CP17032

Turner NC, Thomson CJ, Rawson HM (2001) Effect of temperature on germination and early growth of subterranean clover, capeweed and Wimmera ryegrass. *Grass and Forage Science* **56**, 97–104. doi:10.1046/j.1365-2494.2001.00253.x

Walsh MJ, Powles SB (2007) Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. *Weed Technology* **21**, 332–338. doi:10.1614/WT-06-086.1

Webster TM, Cardina J, White AD (2003) Weed seed rain, soil seedbanks, and seedling recruitment in no-tillage crop rotations. *Weed Science* **51**, 569–575. doi:10.1614/0043-1745(2003)051[0569:WSRSSA]2.0.CO;2

Wolfe EC, Dear BS (2001) The population dynamics of pastures with particular reference to southern Australia. In 'Competition and succession in pastures'. (Eds P Tow, A Lazenby) pp. 119–148. (CAB International: Wallingford, UK)