Biomass accumulation and recovery of dual-purpose crops in a dryland environment

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Abstract

In the Canterbury region feed deficits occur during summer and winter. Dual-purpose crops (used for forage and grain) such as wheat and oilseed rape, can supply forage during the autumn and winter feed deficit periods and also provide harvestable grain from the mature crop. It may be possible to sow winter type annual crops that require vernalisation very early (> four months early), graze as forage in summer and winter and still harvest grain from the mature crop. A field experiment was conducted to investigate the dry matter production of wheat and oilseed rape under dryland conditions from a range of sowing dates: 15 November 2012, and 23 January, 12 March and 26 March in 2013. Grazing by sheep occurred whenever significant biomass was available and measurements taken included biomass accumulation, recovery and crop development. Oilseed rape produced more biomass in total than wheat, with earlier sowing dates producing greater biomass than later times of sowing. The earliest sowing date (15 November 2012) produced 7342-9749 kg/ha of biomass for grazing, providing 5616-6692 kg/ha of consumed forage. In comparison the latest grazed sowing date (12 March 2013) accumulated 1238-1484 kg/ha of forage in total consumed for both crops. For wheat, grain yields were not significantly different between time of sowing 2 to 4, ranging from 5300 to 5700 kg/ha but time of sowing 1 grain yield was greatly reduced to 2500 kg/ha. Total biomass for oilseed rape was low for all times of sowing in response to grazing. Under dry summer conditions both crops accumulated biomass that enabled grazing to occur and both species did not flower until spring. Therefore forage could be grazed from summer to winter under dryland conditions. There is a significant opportunity for both wheat and oilseed rape to be sown up to four months earlier than grain-only crops in a dryland environment and be grazed throughout the summer and winter period to reduce the impact of feed deficits.

Additional keywords: *Brassica napus*, canola, feed deficit, forage, oilseed rape, rapeseed grazing, *Triticum aestivum*, wheat

Introduction

Dual-purpose (DP) crops are cereals and oilseed brassicas grown for the production of both livestock forage and grain in the same season. The purpose of DP crops is to provide forage for stock at a time when the production of pasture species is low and not meeting stock requirements. The practice of growing cereal crops for grazing by livestock during the early vegetative growth stages and harvesting grain at maturity, has been practiced around the world for decades in many temperate and Mediterranean regions (Harrison *et al.*, 2011a). There is a long history of cereals being grazed for forage from the 1930s, when many wheat (*Triticum aestivum* L.) varieties with a long vegetative growth phase were grazed up until flower initiation, with no impact on yield (Winter and Thompson, 1987; Virgona *et al.*, 2006). DP cereals and oilseeds are particularly suited to regions with mild to high rainfall environments e.g., the United States, Australia, New Zealand and South Africa, which favour the growth and grain yield potential of long-season winter-type cultivars (Kelman and Dove, 2009).

Traditionally oats (*Avena sativa* L.), triticale (*x Triticosecale* Wittm.), barley (*Hordeum vulgare* L.), and wheat are the main crops that have been grown in mixed farming systems to provide winter forage while still producing income from grain yield (Bonachela *et al.*, 1995; Kelman and Dove, 2009). Recently oilseed rape (*Brassica napus* L. spp *napus*) has been used as a DP crop (Kirkegaard *et al.*, 2008). Oilseed rape is a high-value, broad-leaf brassica species that can also be used to provide a disease break in cereal-based farming systems (McCormick *et al.*, 2012; Seymour *et al.*, 2012). The practice of grazing oilseed rape before seed production has only been recently developed in southern Australia, with experiments conducted by Kirkegaard *et al.* (2012a; 2012b) and McCormick *et al.* (2012), demonstrating that long season winter and spring oilseed rape varieties can be grazed without grain yield penalty. Cultivars with a strong winter-type characteristic have a vernalistaion requirement that allows for sowing 1-2 months earlier than the Australian recommended sowing period in May. This results in high biomass production for grazing without the risk of early flowering and associated frost damage, when compared with spring-type cultivars (McMullen and Virgona, 2009).

DP crops can be both a valuable resource and an attractive management option to farmers if managed correctly. Both cereals and oilseed brassicas grown as DP crops represent a unique and economically important resource for growers, as income from the crop is derived from both the grain and the value that is added to stock that graze the crop (Nicholls, 2005; Harrison *et al.*, 2011a). However, success in particular seasons depends on management decisions including the choice of species, time of sowing, duration of grazing, and sufficient recovery time between the end of grazing and flowering to allow for biomass accumulation and yield recovery (Kelman and Dove, 2009; McCormick *et al.*, 2013). The objective of this experiment was to determine the amount of biomass that could be accumulated under dryland conditions and whether final yield could be retained for early sown crops.

Materials and Methods

Experimental site

The experiment was conducted at Lincoln University Field Research Centre, Canterbury, New Zealand (43° 38’ S, 172° 28’ E, 11 m.a.s.l.) on a Wakanui silt loam (Cox, 1978). The experimental site was sown in 2006 with an endophyte ryegrass trial which continued until 2010 and was then sprayed out and left fallow. In February 2012, Caucasian clover (*Trifolium ambiguum* M. Bieb) was sown but failed due to excess weeds and was sprayed out in October 2012. Site preparation involved the entire area being rotary hoed, dutch-harrowed and rolled in October 2012. The experiment was a split-plot design with three blocked replicates. Experimental treatments included four sowing dates (main plots) and four cultivars (sub-plots) resulting in 48 plots in total. The first time of sowing (TOS1) was 15 November 2012, with the subsequent three sowings on 23 January 2013 (TOS2), 12 March 2013 (TOS3), and 26 March 2013 (TOS4) respectively; the March 26 sowing was the control (i.e. usual sowing date). The sub-plots consisted of two winter wheat (*Triticum aestivum* L.) cultivars 'Richmond' and 'Empress' and two oilseed rape (*Brassica napus* L.) cultivars 'Taurus' and 'Flash'. All cultivars were selected for their strong winter characteristic, allowing them to be grazed during the long vegetative growth phases up to flowering (anthesis) in the spring. Each plot was 10 m by 2.1 m and was sown with an Oyjoord cone seeder with 0.15 m row spacings. All plots were rolled immediately after sowing.

The target population of oilseed rape and wheat plots was 60 and 150 plants/m^2 respectively, and to achieve these populations sowing rates were as follows: 'Empress' 97 kg/ha; 'Richmond' 81 kg/ha; 'Taurus' 6.7 kg/ha and 'Flash' 5.1 kg/ha. Superphosphate (9% P, 11% S) and urea (46% N) was spread by hand onto each sub-plot immediately prior to sowing at a rate of 250 kg/ha and 100 kg/ha respectively; these were applied to ensure no nutrients were limiting. Due to extremely dry soil conditions and low rainfall during the period December 2012 to March 2013, the TOS2, TOS3 and TOS4 plots were irrigated post sowing to promote germination and emergence; water was applied at an amount of 12 mm, 11 mm and 19 mm respectively to these plots. The TOS4 oilseed rape plots had very poor establishment which limited biomass for the duration of the crop.

Mean monthly air temperature and total monthly rainfall data were collected (Figure 1) from Broadfields meteorological station, located approximately 2 km north of the experimental site (43° 62' S, 172° 47' E). The long-term average annual rainfall for this site is 631 mm. Rainfall for 2013 was 120 mm higher than the 35 year average, with 751 mm recorded. Total rainfall received for the period of the experiment (November 2012 to January 2014) was 848 mm. The summer period (December 2012 to March 2013) received 70 mm less rainfall than the 35 year average. The highest period of rainfall occurred during May and June 2013, with the area receiving approximately 50 mm and 144 mm higher, respectively, than the long term average.

Plots were subjected to 'crash grazing' treatments of differing durations. Temporary electric fences were erected around each of the four main plots in order to prevent stock grazing crops from later sowing dates. Crash grazing involved ewe hoggets grazing to a residual of 2-3 cm across all grazed plots, before being removed from the area. The residual was determined by a visual evaluation; however, it was intended that all of the leaf matter from both plant species was consumed before stock were removed. Grazing period one (17 January 2013) and two (5 March 2013) was only conducted on TOS1. Grazing period three (17 April 2013) included TOS1 and TOS2 while grazing period four (12 to 13 June 2013) included TOS1, TOS2 and TOS3. Grazing period five (1 August 2013) was conducted on TOS1, TOS2 and TOS3 but for wheat plots only.

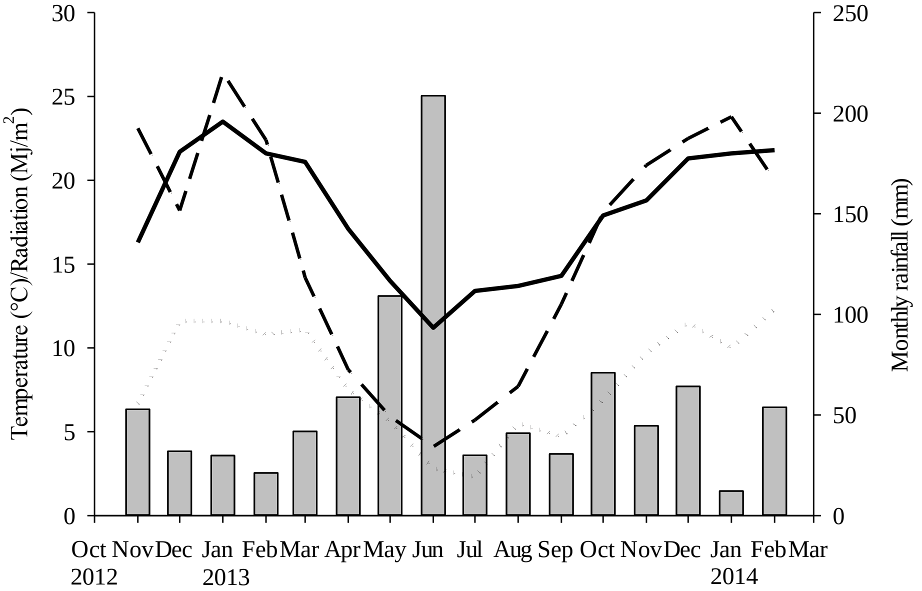

Figure 1: Climate data for Lincoln from November 2012 to February 2014 including monthly rainfall (bars), average monthly maximum temperature (solid line), average monthly minimum temperature (dotted line) and solar radiation (dashed line).

Weeds were controlled by hand on 14 December 2012, 26 March 2013 and 25 May 2013, although a high proportion were removed at the time of each grazing. High temperatures and low rainfall during the December 2012 to March 2013 period prevented nitrogen from being applied after the first two grazing dates, but urea (46% N) was spread by hand onto each sub-plot within TOS1 and TOS2 following grazing on 19 April 2013 with 120 kg/ha N applied to TOS1 and 40 kg/ha N applied to TOS2. On 13 July 2013, 40 kg/ha N (urea) was applied to TOS1, TOS2 and TOS3. All plots were sprayed with insecticide and fungicide once at the end of October.

Measurements

Samples (0.5 m lengths from four rows) were collected from each sub-plot pre- and post-grazing. Above-ground biomass was removed with clippers at ground level. The fresh weight (leaves and stems) of each sample was determined before a sub-sample (50 g fresh weight for wheat, five average plants for oilseed rape) was separated and sorted into leaves and stems. These leaves and stems of post-graze samples were then washed by hand to remove all soil particles and foreign matter. Following washing, the material was dried in a forced air oven at 70°C for a minimum period of 48 hours.

On the 17 April 2013 shoot apices from three representative plants were sampled from each of the 48 plots to determine apical development. The developmental stage of the meristem from the largest/most developed stem (oilseed rape) and tiller (wheat) of each plant was determined by destructive dissection under a microscope. The stages of each wheat plant was scored as described by Kirby (2002), while the oilseed rape score was as described by

Tommey and Evans (1989). The scoring process was repeated on 16 May, 12 June, 4 July and 20 July 2013; however only plants from replicate 1 were sampled at each of these dates due to time constraints.

Statistical analysis

All analyses were conducted using Genstat (Version 14, VSN International Ltd, UK). The experiment was analysed for main effects (Crop, TOS) and interactions using the general analysis of variance model. Fitted and residual values were approximately normal. For comparisons of means, all least significant differences (LSD) were calculated at the P< 0.05 level.

Results

Pre-grazing dry matter on 17 January (grazing 1) and 5 March 2013 (grazing 2) was different (P<0.05) between crops for TOS1. Oilseed rape produced approximately 1500-1900 kg/ha greater than wheat prior to grazing 1 and 2 (Figure 2). Accumulated dry matter prior to grazing 3 was affected by the interaction between time of sowing (TOS) and crop (P<0.001). Oilseed rape TOS2 accumulated 3814 kg/ha compared with 1511 kg/ha for wheat TOS2 and 1685 kg/ha for oilseed rape TOS1, which had already been grazed twice prior to this date. There was no interaction between TOS and crop for pre-grazing dry matter on 12 June 2013 prior to grazing 4. However both crop (P<0.008) and TOS (P<0.014) were significant as main effects. TOS2 and TOS3 oilseed rape accumulated 430-900 kg/ha higher pre-grazing dry matter than TOS1 oilseed rape. Within sowing dates, oilseed rape accumulated higher dry matter than wheat for TOS2 (2508 versus 1509 kg/ha) and TOS3 (2043 versus 1191 kg/ha). Pre-grazing dry matter did not differ between time of sowing for all wheat plots on 12 June and 1 August 2013. On 1 August, oilseed rape plots had not accumulated sufficient dry matter to be grazed.

The early sowing date of TOS1 crops (15 November 2012), allowed them to have an additional two to three grazings compared with crops from TOS2 and TOS3. Overall, sheep consumed the greatest amount of accumulated dry matter from TOS1 oilseed rape (6692 kg/ha) and TOS1 wheat (5612 kg/ha) plots compared with later sowing dates during the grazing period (17 January to 1 August 2013). TOS2 crops had 4560 kg/ha and 3447 kg/ha for oilseed rape and wheat consumed, respectively, while TOS3 crops had 1239 kg DM ha and 1485 kg/ha for oilseed rape and wheat consumed, respectively.

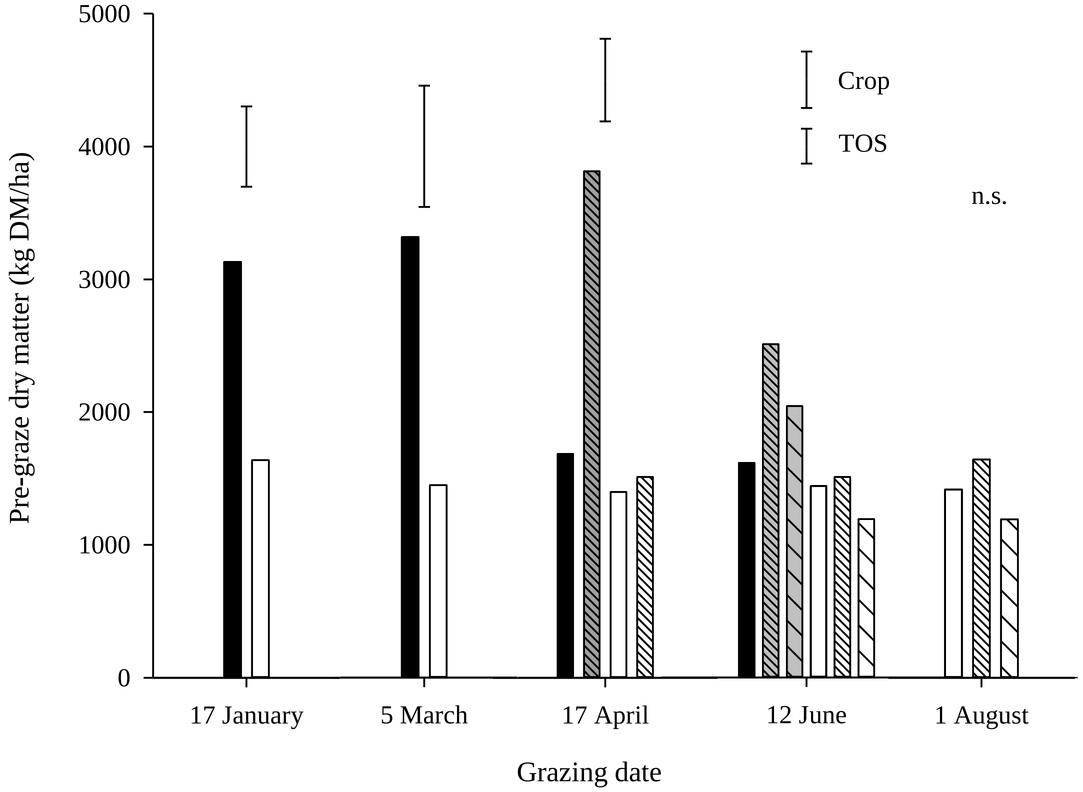

Figure 2: Total dry matter production of time of sowing (TOS)1 oilseed rape (▬), TOS1 wheat (▭), TOS2 oilseed rape (▨), TOS2 wheat (▨), TOS3 oilseed rape (▨) and TOS3 wheat (▨) plots immediately prior to each grazing (Grazing 1: 17 January; Grazing 2: 5 March; Grazing 3: 17 April; Grazing 4: 12 June; Grazing 5: 1 August), at Lincoln University, Canterbury. Error bars show least significant differences between means at each measurement date, where significant interactions exist ($P<0.05$) between Crop and TOS, unless otherwise stated.

All wheat tillers from the grazed plots had reached the double ridge stage by 12 June 2013, with TOS1 wheat at the glume primordial stage prior to grazing. Wheat apex development for the first three sowing dates was significantly delayed compared with the ungrazed control (TOS4), when plants were sampled on 4 July 2013 following grazing period four. Stock selectively removed advanced tillers from the wheat, by grazing these plots to a residual that resulted in the removal of the apical meristem from the main tillers of each plant. Subsequently, the removal of the growing points from the main stems and tillers resulted in secondary tillers from the grazed plants becoming the dominant ones. However, the development stage across all grazed plots reverted back to the double ridge stage compared with approaching terminal spikelet stage for the ungrazed control. Prior to grazing on 12 June 2013 the developmental stage of oilseed rape for TOS1 had a number of initial leaves whereas the final three sowing dates still had a dominant apical dome. Unlike wheat, grazing did not significantly delay apical meristem development, with plants from each sowing date reaching the developmental stage of first flower initial in unison by 4 July 2013. Where grazing removed the main stem (and growing point) from oilseed rape plants, leaves regrew from existing secondary meristems. The secondary meristems rapidly developed to reach the same stage (first flower initial) as the consumed main stems, resulting in no developmental delays. All four sowing dates from both crops reached terminal spikelet (wheat) and flower initial (oilseed rape) by 29 July 2013. Despite differences in time of sowing and grazing treatments, all plots for each crop flowered at similar times. Flowering had begun in all plots of oilseed rape by the first week in September and finished by the last week in October. Flowering occurred in the wheat plots in the first week of November.

Final biomass for TOS1 for both wheat cultivars decreased compared with the other times of sowing (Table 1). There was no difference in biomass yield between wheat cultivars. Grain yields were not significantly different between TOS2 to TOS4 for wheat, ranging from 5300 to 5700 kg/ha. The grain yield for TOS1 was greatly reduced to 2500 kg/ha. Grain yield was not different between wheat cultivars. Oilseed rape generally had low final biomass as a result of over-grazing for TOS1, TOS2 and TOS3 while TOS 4 had very poor establishment. Oilseed rape cultivar 'Flash' at TOS 4 was the only instance in which oilseed rape biomass reached high levels (14717 kg/ha). No grain was harvested from the oilseed rape due to bird damage.

Table 1: Final dry matter (kg/ha) at harvest for wheat and oilseed rape cultivars for four times of sowing.

		Final dry matter (kg/ha)			
		Time of sowing (TOS)			
Crop	Cultivar	1	2	3	4
Wheat	Empress	11510	15579	17547	17244
	Richmond	6922	14141	16181	16318
Oilseed rape	Flash	643	4862	4632	14717
	Taurus	413	2210	3923	3269
LSD TOS x cultivar		3845			

Discussion

Winter cultivars of wheat and oilseed rape were sown into a dryland environment with the aim of producing dry matter during the mid-summer to winter months (January to August; a time of scarce forage supply in the area) for the purpose of grazing by sheep. Time of sowing (TOS) and species of crop influenced the level of biomass available at each grazing. The 2012-2013 summer was extremely dry with total rainfall 70 mm less than the 35 year average for the period December 2012 to March 2013. Despite lower than average rainfall throughout the summer period, crops sown on 14 November 2012 produced greater pregrazing biomass in total, compared with crops from later sowing dates by the end of the grazing period. Sowing on 14 November 2012 meant that crops were sown approximately 14 months before the expected harvest date (mid- to late January

2014). TOS1 wheat and oilseed rape crops were therefore sown approximately 4 months earlier than they would normally have been. The November sowing of TOS1 oilseed rape produced similar amounts of dry matter accumulated by forage rape and kale (7410-8860 kg/ha) grown under similar conditions in Canterbury by Adams (2005), where forage brassicas were sown on 14 January, although it should be noted that the sowing date is later than ideal for Canterbury.

When comparing crops within sowing dates, oilseed rape produced greater dry matter than wheat at each grazing date, with the exception of grazing 5 on 1 August 2013, when oilseed rape crops did not accumulate sufficient biomass to be grazed. There were no differences between cultivars for each crop in terms of the amount of biomass produced for grazing. Despite the lack of differences between cultivars, the fact that wheat crops accumulated an additional 1192 to 1643 kg/ha for grazing on August 1 was important, as it showed that wheat can be grazed later in the growing season closer to the time of anthesis. This could be important for farmers aiming to provide forage for stock up to this date.

Dry matter production of oilseed rape sown on 23 January (TOS2) and 12 March (TOS3) prior to grazing, was in the 2000 to 4000 kg/ha range that has been previously reported for crops grown under dryland environments in Australia (Kirkegaard *et al.*, 2008; Kirkegaard *et al.*, 2012b; McCormick *et al.*, 2012) and reflects the biomass accumulation expected under dryland conditions for this species. In comparison, the dry matter production of wheat sown on the same dates prior to each of the five grazings ranged from 1200 to 1650 kg/ha, which was similar to that reported previously by Bonachela *et al.* (1995) (in Spain), Kelman and Dove (2009) (in Australia) and Nicholls (2005) (in New Zealand).

When introduced to the oilseed rape and wheat plots, sheep preferentially grazed the oilseed rape first, rapidly consuming the leaf laminae and petioles; this resulted in 90% of the available above-ground biomass being removed from the plants. After TOS1 oilseed rape had been grazed twice, sheep did not graze the thicker petioles of the older plants, but removed only leaves, leaving residuals of 568 to 893 kg/ha. By comparison, sheep grazed the wheat plots more heavily to lower residuals (279 to 424 kg/ha), choosing to eat the most advanced wheat tillers first. McCormick *et al.* (2012) found that sheep grazed oilseed rape to similar levels (<700 kg/ha), while Harrison *et al.* (2011b) and Virgona *et al.* (2006) found that lower biomass levels (100-500 kg/ha) can be safely reached when grazing cereals, which was also reflected in this experiment.

Agronomic and grazing strategies that resulted in excessive stem removal by sheep rather than leaf removal caused ‘over-grazing’ effects of TOS1 oilseed rape after multiple grazings. Prior to grazing 1 and 2, oilseed rape TOS1 produced 3132 to 3317 kg/ha, compared with 1685 to 1615 kg/ha from the same plots prior to grazing 3 and 4.

By comparison, TOS2 oilseed rape produced 3814 and 2508 kg/ha prior to grazings 3 and 4, suggesting that low biomass accumulation from TOS1 oilseed rape at later grazings was due to over-grazing effects, as opposed to environmental factors limiting growth. Furthermore, TOS1 wheat consistently recovered from each grazing to produce 1200 to 1650 kg/ha prior to each of the five grazing dates. This demonstrated that the ability of TOS1 oilseed rape to recover during mid-late autumn was reduced when compared to TOS1 wheat, even when moisture was non-limiting.

Had this experiment been designed so that grazing of each crop could have been managed independently of each other, the wheat plots could have been grazed more frequently than oilseed rape throughout the grazing period. Due to the slow recovery of oilseed rape during autumn, later grazing dates of this experiment were delayed until the crop had accumulated sufficient biomass to be grazed. It is likely that wheat plots from each TOS would therefore have had greater biomass consumed in total.

As stated earlier, grazing of crops in this experiment was conducted when oilseed rape was at vegetative growth stages. Consequently, grazing had no impact on either crop and/or apical meristem development. The apical meristem of the wheat plants were removed at later stages of development, but this did not seem to impact on recovery, with the secondary tillers reaching terminal spikelet stage at the same time as oilseed rape.

Total biomass for TOS1 was affected by grazing in both wheat and oilseed rape. Grain yield for TOS1 wheat was reduced and it could be predicted that grain yield for oilseed rape would have been reduced as well. The oilseed rape was heavily grazed and this resulted in very slow regrowth and weed infestation in the TOS1 plots; aphids also infested these early sown crops. However, the reasons for poor TOS1 wheat regrowth was more difficult to determine. As the crop had already changed to reproductive growth there was a limit in the number of leaves remaining that the crop could produce following the grazing. It is surmised that the TOS1 wheat crops simply ran out of leaves following the last grazing. Further work needs to be carried out on very early sown crops to determine if regrowth can be increased with improved agronomic management, or whether there is a physiological limitation on these very early sown crops. Grain yield in this experiment was lower than industry averages, with ‘Empress’ and ‘Richmond’ achieving 9.0 and 8.3 t/ha respectively at Chertsey in 2013 (FAR, 2014). Leaf disease, particularly for the wheat, was present but due to difficulties with experimental design only one application of a fungicide was used. Agronomic management of these crops needs to be refined further as early sowing does lead to increased disease and pest pressures.

Applying prices to dual-purpose crops it can be demonstrated that consumed biomass of 4000 kg/ha at $0.24/kg provides $960/ha. Adding the value of a grain yield of 5.5 t/ha at $380/t adds $2090/ha to give a gross value of $3050/ha for the experimental data. A gross margin of $1550/ha can be derived using an expenditure cost of $1500/ha. This is similar gross margins estimated for a wheat crop ($1736/ha for 10 t/ha) or dryland kale ($1328/ha) (Askin and Askin, 2012). With improved management strategies for dual-purpose wheat leading to comparative grain yields to dryland wheat (10 t/ha), this would result in a gross margin of $3260/ha.

Conclusions

Oilseed rape and wheat have potential as dual-purpose crops in dryland environments, with these crops producing forage during the summer to autumn period for grazing by stock. Earlier sowing dates produced greater biomass in total than later sowing times. Oilseed rape produced greater total accumulated pregrazing biomass than wheat for each sowing date;

however, wheat was grazed later into the season. Yield was reduced in TOS1 crops but maintained in other TOS treatments. The reason for yield decline in TOS1 may have been due to over-grazing and pest effects, although in wheat, the crop may not have had sufficient leaves following grazing to maximize its yield potential.

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