Shoot and perennial organ yields of lucerne genotypes of three fall dormancy levels over five years

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Abstract
This study evaluated productivity and persistence of a dormant (FD2), semi-dormant (FD5) and non-dormant (10) lucerne genotype over five years. The experiment at Iversen Field, Lincoln University, Canterbury, New Zealand, was sown on 4th October, 2014. Measurements of shoot, perennial organ (roots + crown) and weed yields were made from destructive samples of shoots and roots (30 cm of depth) harvested each 42 days from spring to autumn of 2015, 2016, 2017, 2018 and 2019. During the establishment phase, the FD10 had the greatest shoot yield, followed by the FD5 (9.5 and 6.3 t DM ha^{-1}, respectively). The lucerne shoot yield increased from year 1 to year 2, with no difference until year 5, when FD10 showed a decrease of more than 2 t DM ha^{-1} compared with the same season in year 4. There was no difference in perennial organs in the early stages of the experiment with a maximum of 8.9 t DM ha^{-1} for FD5 in March of 2017. In year 5 FD10 had the lowest accumulated shoot and perennial organ yields. A reduction in FD10 canopy cover allowed an infestation of weeds (white clover, Californian thistles, dandelion and docks). The FD2 genotype had the highest yield below ground, while FD5 was the most productive above ground. The use of more fall dormant cultivars is recommended if persistence of the pastures is an important management factor.

Key Words
Alfalfa, dry matter production, fall dormancy (FD), legume forage, *Medicago sativa* L.

Introduction

Lucerne (*Medicago sativa* L.) is the legume forage most cultivated around the world due to its high genetic variability that allows it to adapt to different temperature and rainfall regimes. Cultivars of lucerne were classified by Barnes et al. (1979) according to their capacity to produce shoots during very low temperatures and short day-lengths, which generated a scale of fall-dormancy (FD). This ranges from the very dormant plants (FD1) to very active plants (FD11). They are physically identified by shoot production during the autumn/winter, and also by their and root reserve patterns. Plants that are more dormant usually have lower height and shoot yield, but deposit more assimilates in their roots which increases their survival during winter conditions (Cunningham et al., 2001).

Some studies have shown no difference in productivity of different genotypes with lucerne FD levels after two years of cultivation (Ventroni et al., 2010), but there are few datasets that refer to subsequent years. Harvey et al. (2014) showed a more rapid loss in productivity for an FD10 genotype in Canterbury after four years of hard grazing, but offered no physiological basis for the differences. Therefore, the purpose of this research was to compare the shoot accumulated yield, perennial (crown + roots) yield and weed yield of lucerne genotypes of three different fall dormancy ratings over five years.

Methods

The experiment was at the Field Research Centre (FRC), Lincoln University, Canterbury, New Zealand. The mean annual rainfall during the five years was 500 mm, and the air temperature extremes during the experiment were -6.2 º C in July of 2015 and 20 º C in January of 2018. An irrigated split-plot completely randomized block design with four replicates (20 m x 4.2 m) was established. The main plot was cutting frequency (28, 42 or 84 days) while fall dormancy was the sub-plot. This paper reports data from the most agronomically aligned (42-day regrowth) treatment. The sub-plots (genotypes comprised a dormant (cv. AgR Palatable, FD 2), a semi-dormant (cv. Kaituna, FD 5) and a very non-dormant (cv. SARDI 10, FD 10) genotype sown on 4th October 2014. Seeds were inoculated with Nodule® and sown at 15.1, 11.8 and 11.1 kg ha^{-1}, based on germination tests to result in a final germination of ~ 10 kg of germinated seeds ha^{-1}. In January of 2015 a common seedling cut was taken, that ended the establishment phase. Measurements were initiated during the germination phase and destructive harvests started in November 2014, and lasted until June 2015 for year 1. During years 2 to 5, destructive harvests carried from each July to June.

In August of 2016, based on test results, 350 kg ha^{-1} of extra superphosphate was applied. Weed control was done as required, with applications of Chlorimuron ethyl (sulphonylurea) (30 g a.i ha^{-1}) to control white clover (*Trifolium repens* L.) (on 11/12/2017, 7/5/2018, 26/10/2018, 4/12/2018). On 4th July 2016 an Atrazine (648 g a.i ha^{-1}) was applied to control ryegrass (*Lolium perenne* L., *Lolium multiflorum* Lam.) and annual Poa (*Poa annual* L.), and on 30th October, 2018 to control docks (*Rumex obtusifolius* L.). The experiment was irrigated as required with a traveling gun sprinkler irrigator.

A destructive sample was taken every 42 days, with the shoots cut inside a 0.2 m^2 frame, across four rows. The remaining crowns and roots to a depth of 30 cm were than manually excavated. The shoots were sorted to lucerne shoots and weeds, the total roots of lucerne were gently washed to remove the soil, and the number of plants was counted. All samples were dried in a forced-air oven at 65ºC for 72 h to determine shoot, weed and perennial organ dry weights (t DM ha^{-1}). After quadrats were taken the plots were grazed or mown to 50 mm above ground to remove remaining herbage. The total shoot yield represents the accumulated for the year (spring-autumn), weeds and perennial organs are shown as the average of each regrowth cycle. The final values were compared by ANOVA and when significant (P<0.05), the averages were compared with Tukey's honestly significant difference tests. Statistical analyses were performed by SAS® University Edition.

Results

During the establishment year, FD10 produced the highest (P=0.001) accumulated shoot yield of 9.5 t DM ha^{-1}, more than 3 t DM ha^{-1} higher than FD5 which was 1.75 t DM ha^{-1} higher (P=0.02) than FD2 (Figure 1). From the second to the fourth year there were no differences between the genotypes in shoot yield, with a maximum of 16.6 t of DM ha^{-1} in the second year (FD10) and a minimum of 12.8 t DM ha^{-1} in the fourth year (FD10). All genotypes had a similar behaviour until year 4, with an increase in shoot yield from year 1 to year 2 (P<0.05), and no differences for the two subsequent years. By January of 2019, the FD10 showed a significant decrease of ~ 6 t DM ha^{-1} compared to the same period of 2018. The final accumulated shoot yield for FD10 was 5.5 t DM ha^{-1} compared with 9.0 and 12.6 t DM ha^{-1} for the FD2 and FD5 genotypes. The total accumulated lucerne shoot yields over five years was 61.7; 68.1 and 63.2 t DM ha^{-1} for FD2, FD5 and FD10, respectively (P=0.09).

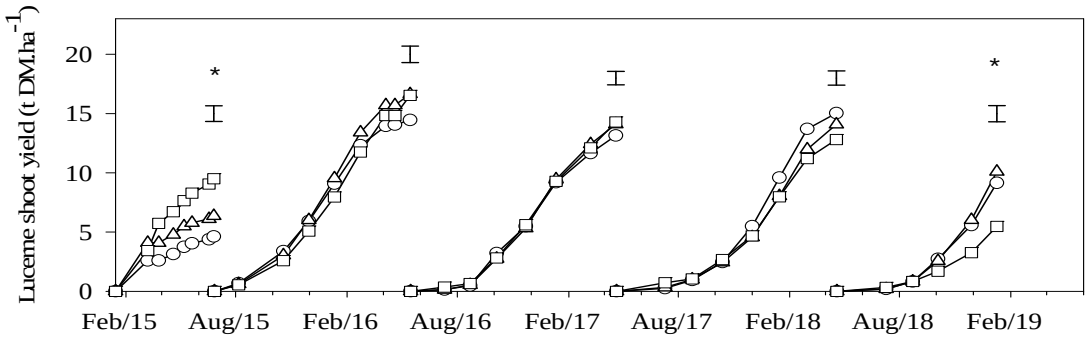

Figure 1. Accumulated shoot yield (t DM ha^{-1}) of an FD2 (○), an FD5 (Δ) and an FD10 (□) lucerne genotype over five years in Canterbury, New Zealand. Error bars represent the standard deviation. *represents significant differences (α=0.05).

The perennial organs showed a seasonal fluctuation in all genotypes over the first four years, with an increase in biomass yield in summer/autumn and decrease in winter/spring. During the early autumn of year 3 all genotypes had ~ 8 t DM ha^{-1} in perennial organs with a reduction to less than 5 t DM ha^{-1} in October. In year 5, the FD10 had lower values during the growth season and a final below-ground yield of only 1.6 t DM ha^{-1}, almost 3 t DM ha^{-1} lower than FD2 (P=0.022).

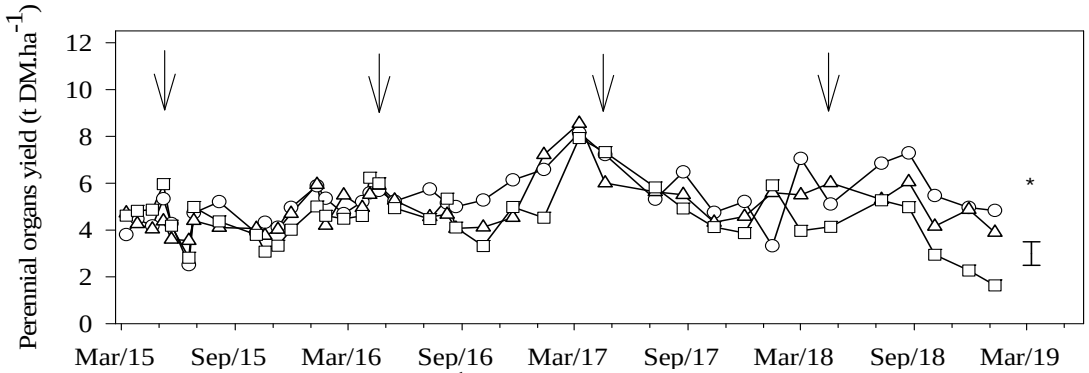

Figure 2. Perennial organs yield (t DM ha^{-1}) of an FD2 (○), an FD5 (Δ) and an FD10 (□) Lucerne genotype over five years in Canterbury, New Zealand. Error bars represent the standard deviation. *represents significant differences (α=0.05). Arrows indicate the beginning of winter.

The differences in genotypes along the five years were also reflected in weed yield (Figure 3), with greater (P<0.05) values for FD2 during the first year compared with FD10. But during the summer of years 4 and 5 the FD10 increased (P<0.05) the weeds yield compared to FD2, even with the application of herbicides. The main weeds were white clover, docks, dandelion (*Taraxacum officinale* L.) and Californian thistles (*Cirsium arvense* L.). In the last regrowth cycle the weed yield of FD10 was 1.12 t DM ha^{-1}. The only genotype that kept a similar plant population from 2015 to 2019 was the FD2, with an average of 142 plants.m^{-2}, while FD5 reduced (P=0.0003) from 279 plants m^{-2} to 62 plants m^{-2} (22% survival) and FD10 reduced (P=0.001) from 240 plants m^{-2} to 24 plants m^{-2} (10% survival).

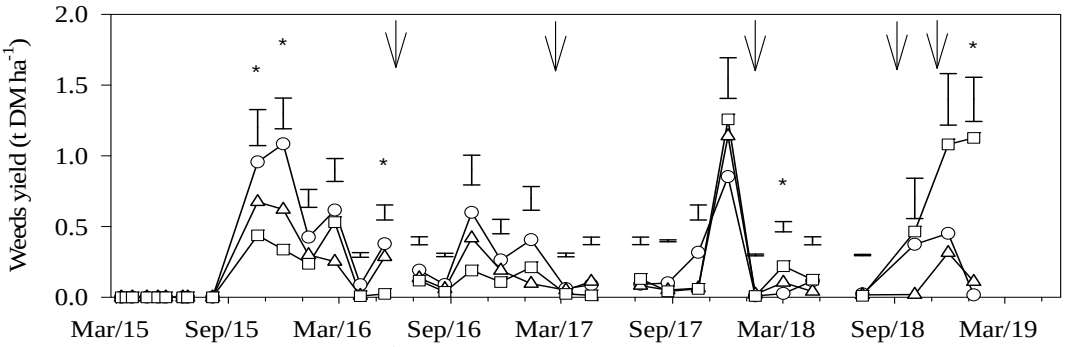

Figure 3. Mean weed yield (t DM ha^{-1}) of an FD2 (○), an FD5 (Δ) and an FD10 (□) lucerne genotype over five years in Canterbury, New Zealand. Error bars represent the standard deviation. *represents significant differences (α=0.05). Arrows indicate herbicide application dates.

Discussion

In the establishment year the FD10 genotype was the most productive, as a result of higher shoot height (Ventroni et al., 2010) and leaf area index (Ta et al., 2017). The initial superiority in yield compared with more dormant genotypes was consistent with results from Cunningham et al. (2001) and Ventroni et al. (2010), who noted this as a benefit for farmers. However, after establishment, yields of all genotypes were not different until the collapse of FD10 in the fifth year, a behaviour consistent with the patterns found by Harvey et al. (2014), who accelerated crop decline by intensive grazing. The loss of lucerne shoot yield was replaced by weeds in FD10 and commercially this crop now requires renovation. In contrast, the chemical weed control has maintained virtually pure monocultures of lucerne in the FD2 and FD5 crops.

The perennial weeds, such as Californian thistles and dandelions, are a sign of a canopy in decline. They were initially controlled by lucerne suppression but as the stands age chemical control has been necessary. The reduction in lucerne shoot yield and plant population, of FD10 has led to this infestation. The frequent irrigation also encouraged weed growth in lucerne, and in this experiment white clover has thrived from the frequent soil wetting. White clover has been adequately controlled chemically and FD2 and FD5 crops remain vigorous and productive.

During the first four years of the experiment it was possible to observe some patterns in perennial organ development. There was a consistent decrease during the winter/spring with a minimum of 2.52 t DM ha^{-1}

(FD2) and a maximum of 8.55 t DM ha^{-1} in autumn (FD5). This was consistent with the pattern reported by Teixeira et al. (2009). However, from March of 2018, FD2 and FD5 continued to follow their pattern and their yield increased to be ~ 3 t DM ha^{-1} higher than FD10. From this moment FD10 maintained cyclic pattern with the other genotypes, but with lower below ground yield. According to Moot et al. (2003) the cold season is a moment for plants to store assimilates in their roots and prepare themselves for spring with a higher energy requirement for regrowth. The absence of this storage process was reflected in the last winter (2018) for FD10 with reduced perennial organ yield, while FD2 and FD5 increased theirs. Thus, by the end of year 5, FD10 had a lower accumulated shoot yield (~ 5.5 t DM ha^{-1}), increased weed yield (~ 1.12 t DM ha^{-1}) and, consequently, a reduction on final perennial organs yield (~ 1.6 t DM ha^{-1}), which document the collapse of this genotype.

Conclusions

Both dormant and semi-dormant lucerne genotypes had a greater longevity than the FD10 genotype over the five years of this experiment, based on higher shoot accumulation, with lower weed infestation at the end of the fifth year. Under the conditions of the experimental environment and management, the FD10 cultivar has shown a collapse after five years and commercially these stands are no longer viable. Thus, the initial yield advantage of FD10 was not consistent over time and this lack of persistence represents a need for earlier stand replacement.

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