# Manipulation of the Tillering Dynamics in a Perennial Ryegrass Seed Crop as a Response to Sowing Date, Sowing Rate and Grazing

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Perennial ryegrass (*Lolium perenne* L.) seed crop is a profitable option for arable farmers in Canterbury. To achieve optimal yields there is a requirement of the crop to produce 2000 + seed heads/$m^2$ which is the result of >2000 reproductive tillers/$m^2$.

The aim of this experiment is to quantify the effects of manipulating the tillering dynamics of a perennial ryegrass seed crop through the change in sowing date, sowing rate and grazing. Four sowing dates at 3 week successive intervals from the 27th of March with 4 target population densities of 200, 600, 1000 and 1400 plants/$m^2$ were sown. Times of sowing one through three with the population density of 200 – 1000 plants/$m^2$ reached the target of 2000+ fertile reproductive tillers/$m^2$ required for maximum seed yield. As sowing rate increased the number of vegetative tillers/$m^2$ also increased while the number or reproductive tillers/$m^2$ remained constant, therefore decreasing the proportion of reproductive tillers/$m^2$ as sowing rate increased. A reduction in the proportion of reproductive tillers was also seen with later sowings, along with individual reproductive tiller weight.

A target population of 1400 plants/$m^2$ was impractical as increased self- thinning occurred and resulted in many of the plants dying before reproductive development. Sowing a Perennial ryegrass seed crop as late as 28th of May regardless of population density, tillering could not compensate for lost thermal time in regards to the production of reproductive tillers.

**Keywords:** Perennial Ryegeass, Samson, *Lolium perenne*, tillering dynamics,  reproductive tiller, vegetative tiller, tiller weights, grazing

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# 1 Introduction

Perennial ryegrass (*Lolium perenne* L.) seed crop is an option for arable in Canterbury. It provides income from three components, including grazing before reproductive growth, the harvested seed and being able to baleing the straw after harvest. There are four main species of herbage seed produced in New Zealand, perennial ryegrass (Lolium perenne), Italian ryegrass (*Lolium multiflorum*), tall fesuce (*Festuca arundinacea*) and white clover (*Trifolium repens*). These four account for over 98% of all the herbage seed grown in New Zealand (Pyke, Rolston, & Woodfield, 2004). In 2004, annual production averaged 22,000 t, of which 70-80% was perennial ryegrass seed with exports being worth around $60 million annually. New Zealand contributes to 4% of global herbage seed production but is a major exporter of perennial ryegrass.

A tiller is the primary growth unit of a perennial ryegrass plant, it is a mechanism for both vegetative and sexual reproduction. Tillers are grown from tiller bud formed at the axil of the main stem. Tillers have varying degrees of lifespans. There is constant birth and death equilibrium, with young vegetative tillers replacing those that were grazed off, died or switched to reproductive. This ensures the plants survival and perenniality. Tillers are initiated by the increased ratio of red to far red (R:FR) light interception at the base of the stem where the tiller buds are located on the axil. The plants tiller very close to the ground and there is very little internode elongation from vegetative tillers and the stem stays below cutting or grazing height These tiller buds are shaded from light by the leaves, it is only after an increased ratio of R:FR light reaching these buds do they initiate. Events that can increase the light reaching these buds include but is not limited to defoliation or cutting of the leaves, lodging or rolling.

Intra plant and inter plant competition are both factors that affect seed yield. Publications have eluded to the fact that in low sowing rates, such as below 5 kg/ha plants experience intra-plant competition resulting in poor seed yields due to poor seed head production. While inter-plant competition is known to have an effect under high sowing rates on plant survival with self-thinning occurring within the sward. Having 2000 – 4000 fertile reproductive tillers/$m^2$ at anthesis is important for ensuring enough seeds heads as to not to impede yield.

There is very little literature on the tillering dynamics of a perennial ryegrass seed crop and how sowing rate, sowing date and grazing have an effect on the number of reproductive tillers that extend to produce a fertile seed head, and how this affects the yield of the seed crop. The aim of this experiment is to quantify the effects of manipulating the tillering dynamics of a perennial ryegrass seed crop through the change in sowing date, sowing rate and grazing and to see what effects they have on the number of reproductive tillers they produce that have potential of contributing to a seed yield.

# 2 Review of the Literature

## 2.1 Introduction

The objective of this review is to gain an insight into how tillers initiate and how management and establishment techniques for perennial ryegrass seed crops effect tiller dynamics. There is limited literature on tiller population dynamics due to the very time consuming nature of taking their measurements, which means published examples are uncommon. Many of the same principles researched apply for pasture forages and perennial ryegrass seed crops grown both globally and domestically, providing an adjustment for seasons and climate is made.

## 2.2 Tiller Dynamics

A tiller is the primary growth unit of a mature grass plant and has the same terminal apex structure as the main stem. Tiller buds are formed in the axil of the main stem leaves and grow out to produce tillers. Tillers have varying degrees of lifespans, with the constant birth of new tillers replacing those that have died or gone reproductive ensures the plants survival and perenniality (Hunt & Field, 1976; Matthew et al., 2013). It was noted by Hunt and Field (1976) that when tiller densities are sufficient to induce competition between tillers, differences in tiller density tend to be compensated by differences in tiller growth. The plants tiller very close to the ground and there is very little internode elongation from vegetative tillers and the stem stays below cutting or grazing height allowing new tillers to be produced from the tiller buds after defoliation or cutting. Tillers are turned reproductive by vernalisation (Williamson, 2008). The purpose of a reproductive tiller is to reproduce sexually. Reproductive tillers are unable to produce any more leaves once head emergence has happened, due to leaves being initiated from the apical meristem which develops into the seed head. Daughter tillers that are produced from the main tillers develop their own root systems and become independent of the plant they were formed from as a means of vegetative reproduction, this leaf and tiller production continues until specific environmental cues shift the plant to become reproductive (Williamson, 2008), such as the process of vernalisation.

Birth of replacement tillers are either vegetative or reproductive (Matthew et al., 2013), these reproductive tillers produce a seed head and then die at the seed ripening and are then replaced. Therefore there is a constant shift in the amount of vegetative and reproductive tillers amongst a sward throughout a season. With this tiller death and initiation follows the same seasonal rhythm, with tiller numbers increasing in spring before and after reproductive development. Death is also high at this time, turnover of tillers is accelerated by nitrogen (Hunt & Mortimer, 1982). Due to the very time consuming nature of measuring tiller densities over time there is a very limited number of papers published on the change of tillers over time (Matthew et al., 2013) as well as the tiller densities and ratios of vegetative to reproductive tillers from establishment to seed set in a perennial ryegrass seed crop.

Typically the birth and death of tillers is the main contribution to pasture persistence as this directly influences the tiller population density. It is well known that defoliation is experienced by most forage crops. The ratio of red to far red light has an influence on the amount of tillers produced per plant (Gautier, Varlet-Grancher, & Hazard, 1999). The ratio of red to far red light has known to cause an increase in tillering in many dicot species (Deregibus, Sanchez, & Casal, 1983). Deregibus et al. (1983) found that with an increase in the R:FR, without significantly modifying the photosynthetically active radiation, increased the amount of tillers produced per plant. Their results demonstrated that the phytochrome mechanism widely recognized as the determinant of branching in dicotyledonous plants also controls tiller production in grasses such as perennial ryegrass (*Lolium perenne*) (Deregibus et al., 1983). Gautier et al. (1999) found the same result that by decreasing the ratio of red to far red light there was a decrease in the amount of tillers produced in perennial ryegrass. The decrease in the red to far red ratio which occurs with increasing plant density reduces the amount of tiller buds which develop into tillers in a dense canopy therefore reducing the amount of tillering that occurs with the decreased growing space (Gautier et al., 1999) and therefore light interception at the base of the plant where the tiller buds are located. Therefore the R:FR ratio is clearly involved in regulation of tillering. It was also found that a decrease in the R:FR ratio that a decrease in tillers site filling was triggered.

In this experiment by Gautier et al. (1999) there was a lower tillering rate after defoliation, which could have resulted from the reduced resource availability and that the decrease in R:FR is the major environmental signal that needs to be taken into account in tillering studies, this was a result that was not expected. Heavy rolling the crop after establishment also promotes tillering by allowing more light into the base of the canopy. It also buries rocks, levels the soil and squashes grass grubs if they were present (Brown et al., 1990).

Korte, Watkin, and Harris (1985) looked at the effect of cutting treatments on tiller appearance and longevity, relationship between tiller age and weight and herbage production. They used different 6 different cutting treatments including different first times of cutting and different frequencies. First cutting after 3 weeks of the experiment commencing (T1), when meristems were above cutting height (T2) and first cutting when inflorescence emerged (T3). The frequencies were every 3 weeks (F1), subsequent cuts at 95% light interception and subsequent cuts at 8 weeks (F3) (Table 2.1)

For the purposes of a seed crop the T1 treatment could be used to simulate grazing while T2 and T3 gives a good indication of the tiller numbers that would produce seed as this experiment is looking at tillering dynamics of a ryegrass sward for pasture.

Table 2.1 Changes in tiller number (tillers/m-) ± SEM, tiller weight (mg) ± SEM, and ryegrass herbage mass (kg DM/ha) ± SEM during uninterrupted reproductive growth after mowing on 5 September 1977. Data were obtained before the first mowing of each treatment. Tiller numbers have been adjusted by covariance for the number of tillers marked in each frame on 5 September 1977. (Korte et al., 1985)

| | 26 September | 19 October | 11 November |
|---|---|---|---|
| Treatments | T1F1, T1F2 | T2F1, T2F2, T2F3 | T3F2 |
| Days regrowth | 21 | 44 | 67 |
| Tillers/m² | | | |
| Vegetative | 12900 ± 410 | 10600 ± 230 | 8100 ± 730 |
| Reproductive | 100 ± 50 | 1600 ± 160 | 2200 ± 300 |
| Total | 13000 ± 410 | 12200 ± 280 | 10300 ± 690 |
| Tiller weight (mg) | | | |
| Vegetative | 12 ± 1 | 21 ± 1 | 27 ± 1 |
| Reproductive | 56 ± 12 | 93 ± 4 | 211 ± 24 |
| Herbage mass (kg DM/ha) | | | |
| Vegetative | 1210 ± 80 | 1770 ± 140 | 1380 ± 190 |
| Reproductive | 40 ± 20 | 1250 ± 160 | 3780 ± 740 |

When the swards were left uninterrupted by defoliation from the 5th of September when the final cutting the number of reproductive tillers increased and the weight of vegetative tillers was considerably smaller than the reproductive tillers present (Table 2.1). It was found that the reproductive tillers only represented a small proportion of tillers by number with the T3F2 treatment on the 11th of November showing the highest proportion with 21% (Table 2.1). Due to the reproductive tillers being larger than the vegetative tillers in weight they made up 73% of the sward by weight. The importance of the number of vegetative tillers that are carried during the reproductive phase of perennial ryegrass is important for the plants persistence through the summer period as more tillers are needed to maintain the plants survival (Matthew & Sackville-Hamilton, 2011).

Earlier interruption of swards resulted in greater survival of age category 1 tillers (tillers present at the beginning of the experiment) (Korte et al., 1985). , which were tagged at the start of the experiment (Table 2.2) with the T3F2 treatment having the lowest number of original tillers (5231 tillers). A better indication of the number of tillers that survive from the start of the experiment is treatment T2F2 for the purposes of a seed crop.  This is due to the measurement being taken on the 11th of November before the meristems are removed. The measurement of T3F2 is on the 8th of December, sometime after the defoliation of the reproductive meristems (8 – 28 November).

The T3F2 treatment had 2200 ± 300 reproductive tillers on the 11th of November which is in the recommended range of reproductive tillers needed to produce a high yielding seed crop (Hampton & Hebblethwaite, 2000).

Table 2.2 Total number or ryegrass tillers/$m^2$, and surviving number of tillers/$m^2$ marked at the start of the experiment (age category 1) or during the experiment (age categories 2-8). Measurements were taken during early summer and at the end of the experiment. Data have been adjusted by covariance for the number of ryegrass tillers marked at the start of the experiment. (Korte et al., 1985)

| | | Age category | | |
|---|---|---|---|---|
| Treatment | Date | 1 | 2–8 | Total |
| **Early summer** | | | | |
| T1F1 | 28 Nov 1977 | 6 272 | 6 292 | 12 564 |
| T1F2 | 5 Dec 1977 | 6 171 | 7 092 | 13 263 |
| T2F1 | 30 Nov 1977 | 6 313 | 7 993 | 14 306 |
| T2F2[1] | 26 Nov 1977 | 7 756 | 5 318 | 13 074 |
| T3F2 | 8 Dec 1977 | 5 251 | 9 253 | 14 504 |
| SED | | 433*** | 780** | 622* |
| **End of experiment** | | | | |
| T1F1 | 23 Jan 1978 | 671 | 9 630 | 10 301 |
| T1F2 | 23 Jan 1978 | 824 | 10 855 | 11 679 |
| T2F1 | 23 Jan 1978 | 732 | 12 114 | 12 846 |
| T2F2 | 23 Jan 1978 | 876 | 12 215 | 13 091 |
| T2F3 | 23 Jan 1978 | 2 478 | 10 274 | 12 752 |
| T3F2 | 23 Jan 1978 | 1 085 | 11 113 | 12 191 |
| SED | | 245*** | 1 129NS | 1 013NS |

[1] T2F2 and T2F3 both received the same cuttings on 26 November 1977.

Populations of tillers are dynamic with the birth of new tillers and the death of others creating a balance in tiller population densities (Korte et al., 1985; Matthew & Sackville-Hamilton, 2011). The expansion in growth of tiller numbers is usually in spring and after reproductive growth.

## 2.3 Biophysical factors on Ryegrass

### 2.3.1 Temperature

Vernalisation is the cold requirement needed by some plants to switch from vegetative to reproductive. This environmental influence is activated through winter with low temperatures (1-7°C) (Langer, 1990). It was documented by Evans (1964) that tillers are induced to flower by low winter temperatures followed by increasing day length with about 6 weeks of below 10°C weather to fully vernalize perennial ryegrass. Cooper (1960) reported that vernalisation is achieved by several weeks of short photoperiods (with temperatures below 17°C), low temperatures or a combination of both however photosensitivity becomes irrelevant below 6°C.

Temperature is also a main driver for plant growth and the rate of leaf extension is sensitive to temperature. The growth rate of perennial ryegrass is determined by temperature, which influences both the frequency at which leaves and tillers appear and the rate at which they expand (Peacock, 1975b). The study by Peacock (1975b) looked at the site of temperature perception. A variety of methods were used to determine which part of the plant was used to drive growth, whether it be roots, leaf or stem apex. It was concluded that both spring and autumn leaf extension was determined by the temperature of a discrete zone at the level of the stem apex rather than the general soil or air temperature therefore influencing development. As temperature is perceived by the apex cold periods need to be experience at the stem apex to switch to reproductive.

The temperature that the plants experience is influenced by the pattern of interception of radiation from the sun, which is affected by the density of the canopy and the leaf area distribution. Therefore the leaves meristems and roots will experience different temperatures and as the crop develops these influences will have a stronger effect on the temperature experienced. In canopies of different structures, temperatures experienced by the plants will be different even though the weather is the same (Peacock, 1975a). Different management techniques such as the use of defoliation, the application of fertilisers and irrigation can influence crop density and influence the temperature experienced by the plants.

The effect of temperature on photosynthesis is often overlooked and might be more important for crop growth than originally thought. Woledge and Dennis (1982) showed that there was a great effect of temperature on the net photosynthesis rate, especially at high light intensities. It was found that ryegrass leaves that experienced temperatures of 15$^{o}$C had almost double the photosynthetic rate as at 5$^{o}$C (Figure 2.1) when exposed to 250 W m$^{-2}$. The photosynthesis rate was a lot lower at the lower light intensity (50 W m$^{-2}$). The optimum temperature was said to be below 20$^{o}$C, above this the plant develops stress. The increase of photosynthesis with temperature is mainly due to the increase of enzyme activity and is more pronounced with higher levels or irradiation (Woledge & Dennis, 1982).

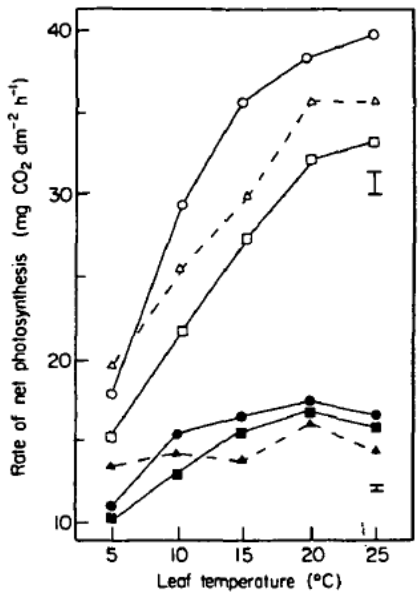


Figure 2.1 Net photosynthesis of ryegrass leaves. (□, ■), November; (Δ, ▲), January; (○, ●), April. Open symbols represent photosynthesis at 250 W $m^{-2}$, solid symbols photosynthesis at 50 W $m^{-2}$. Vertical bars represent standard errors of means, (Woledge & Dennis, 1982).

Woledge and Dennis (1982) discussed that there was not much effect on photosynthesis of growing the plants at different temperatures during low light intensities, the example given was that ryegrass leaves that expanded during the low temperatures and light intensities of mid-winter were capable of photosynthetic rates nearly as high as the leaves in the better spring conditions, suggesting that the very low photosynthetic capacities of ryegrass leaves from swards in mid-winter were due less to low temperatures than to the shading of the leaves experienced by the canopy (Woledge & Dennis, 1982) as even at higher temperatures the rate of photosynthesis is still low. There is still room for further work to be done on the extensive measurements of how temperature effects photosynthesis as it is difficult to measure due to individual leaves experiencing different light intensities throughout the canopy as well as many other environmental factors effecting photosynthesis.

### 2.3.2 Moisture and Nitrogen

Limitations of water are common in semi-arid parts of the world due to the variation and timing of rainfall. This affects plant growth, nutrient uptake and supply to crops, particularly nitrogen, which is the most important nutrient applied as a fertiliser (Akmal & Janssens, 2004). Increasing biomass and leaf expansion can be aided with the application of nitrogen. This is also dependant on the quantity of water available for uptake. Therefore the plant is reliant on both moisture and nitrogen availability. How moisture affects the productivity and light use efficiency of perennial ryegrass along with differing nitrogen supply has been looked at by a number of people and more recently by Akmal and Janssens (2004). They found that insufficient water supply was more critical than insufficient nitrogen supply (Figure 2.2). This agrees with Mills, Moot, and McKenzie (2006) comment that there will be no growth if there is no water available. Also mentioned by Akmal and Janssens (2004) was that nitrogen fertiliser with sufficient water brings a dramatic increase in herbage productivity.

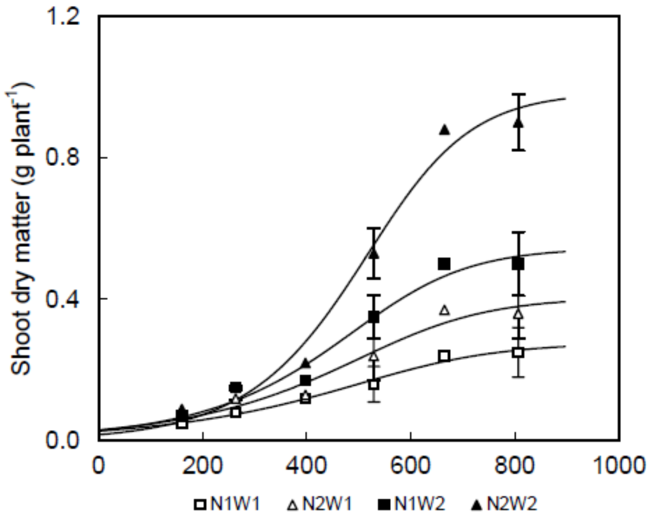


Figure 2.2 Dry matter of a ryegrass plant influenced by sufficient vs. insufficient water and N rates against growing degree days $N_1$ and $N_2$, 5 g N $m^{-2}$ and 10 g N $m^{-2}$ and $W_1$ and $W_2$ being the insufficient and sufficient water treatments, respectively (Akmal & Janssens, 2004).

The objective of the study by Akmal and Janssens (2004) was to look at the contrasting effect of water and N supplies and to determine if an increase in nitrogen to perennial ryegrass can subsidise an insufficient water supply to the crop, and its light use efficiency. They reported on two experiments, one a pot trial, the other a field trial, in this review the focus will be on the results found in the field trial. The four treatments were $N_1$ and $N_2$, 5 g N $m^{-2}$ and 10 g N $m^{-2}$ and $W_1$ and $W_2$ being the insufficient and sufficient water treatments, respectively. As with Mills et al. (2006) the data was analysed against thermal time to accommodate for different growing conditions.

They found that plants that had been treated with sufficient water showed an increase in shoot growth by 54.6% and a 37.4% increase in root growth, with sufficient N treatments showing an increase of shoot DM of 12%. Across the literature reviewed there was a constant result in all experiments. With non-limiting moisture and nitrogen, grass plants out yield the other treatments. This can be seen in Figure 2.2which shows the shoot DM of plants in the experiment by Akmal and Janssens (2004). There was a reduction in root growth of 16% (Figure 2.3) in the plot trial under the sufficient water treatment compared to the insufficient water treatment. The reasoning behind this is that under field conditions, plants with insufficient water partitioned more growth into the roots than shoots which increased root activity and therefore resulted in a higher DM of roots.

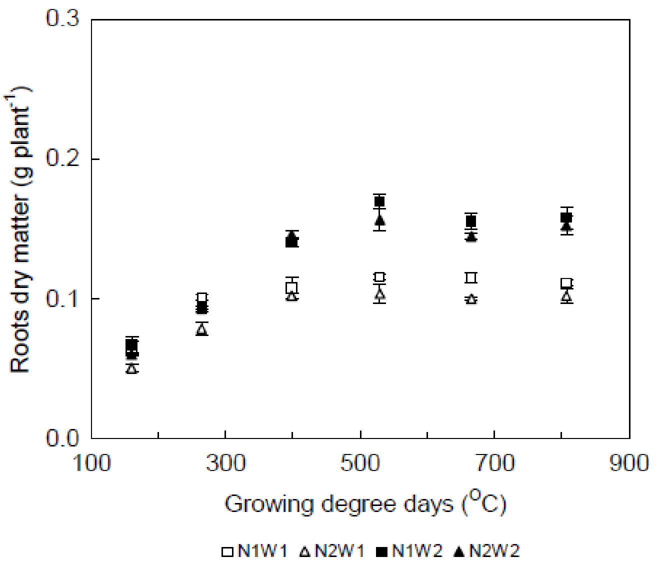


Figure 2.3 Root dry matter of a ryegrass plant influenced by sufficient vs. insufficient water and N rates against GDD (Akmal & Janssens, 2004)

As tiller number (TN) and leaf number (LN) are the major contributors to DM production they were measured closely by Akmal and Janssens (2004). They found, as expected, that they both increased in number as thermal time accumulated. There was an increase ($P<0.05$) in tiller numbers with sufficient water and nitrogen also increased ($P<0.05$) the number of tillers produced (Figure 2.4a). On average TN per plant increased 25.3% with sufficient water and 13.6% with sufficient nitrogen treatments. Leaf number followed a similar trend to tiller numbers (Figure 2.4b) with an average increase per plant was estimated at 32.7% under sufficient water and 13.2 under sufficient nitrogen. Showing that the response to water was greater than the response to nitrogen in relation to TN and LN, although tiller production is still dependant on light at the base of the plant and leaf production is directly related to the rate of tiller production (Akmal & Janssens, 2004).

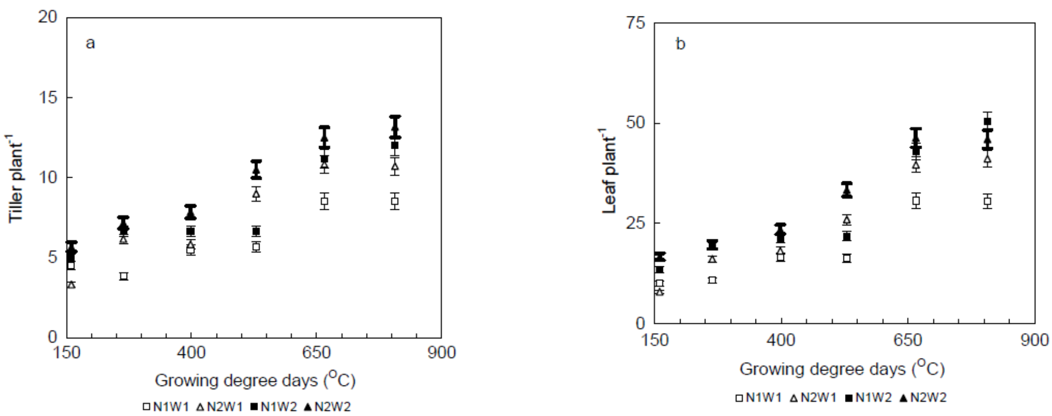


Figure 2.4 Tiller number (a) and leaf number (b) of a ryegrass plant influenced by sufficient vs. insufficient water and N rates against GDD (Akmal & Janssens, 2004)

Hunt and Mortimer (1982) found that tiller and leaf appearance rates were sensitive to nitrogen. It was noted to some extent that leaf and tiller appearance was limited more by nitrogen stress than leaf and tiller initiation. The application of nitrogen increased the size and number of tillers but in doing so it increased inter-tiller stress. This experiment looked at perennial ryegrass swards for grazing, it was noted that unless the sward was grazed the increased production from nitrogen would be realized as increased leaf and tiller death. As sexual reproduction and the increased production of seed occurs, applying excess nitrogen resulting in tillers death and increased leaf would not be beneficial in terms of management as a seed crop.

Nitrogen must not be limiting at any part of the growth as it will severely affect the seed yield of the crop. As the growing season progresses, nitrogen in the soil will deplete therefore nitrogen needs to be applied in the form of fertiliser. By avoiding nitrogen stress productivity and seed yield are maximised (Hill, Hampton, & Rowarth, 1999). Hill et al. (1999) also noted that if irrigation is available it should be used. There has not been a lot of research conducted on the timing of application of water. It was noted that as nitrogen application increased water demand is also increased due to the increase of leaf area per plant. Increases in yield of 25% are common with the correct use of nitrogen fertilisers. The best gross margins have come from applications of 50 kg N/ha in both autumn and late winter and 150 kg N/ha in the spring. This application regime also resulted in the best water use efficiency and nitrogen yield efficiency (Cookson, Rowarth, Cornforth, & Cameron, 1999).

## 2.4 Sowing Date

Ryegrass seed crops are successfully sown from February to April depending on climatic conditions to initiate flowering of tillers which is induced by vernalisation. Early March is the recommended time for sowing when the soil temperatures are still at 14$^{o}$C (Hill et al., 1999). Pastures that are sown specifically for seed crops are never sown earlier than this, as they produce excess amounts of vegetative growth in the form of many tillers. If too much dry matter accumulates, paddocks may be grazed quickly and lightly before spikelet initiation in early September when the soil temperatures warm to 8$^{o}$C at a depth of 10 cm. Moot, Scott, Roy, and Nicholls (2000) also showed that germination was optimised at 15$^{o}$C with 99% germination of a ryegrass seed ‘Embassy’. Low temperatures (5 and 10$^{o}$C) showed a decreased germination however it was still over 80% emergence. It was noted that there was a delay in germination.

The age of the tiller determines the size of the grass seed head. The earlier the plant is sown in autumn, the more time it has to develop more spikelets, as a result of this larger seed head more seeds per tiller are produced (Table 2.3) (Hill et al., 1999). This larger seed head is due to the increased photosynthetic capacity of the plant over the plants that were sown at a later date, as it has had more tile to grow it has developed more leaves to intercept light.

Table 2.3 Effect of autumn sowing date on the number of spikelets per tiller in perennial ryegrass (Hill et al., 1999).

| Sowing Date | Spikelets per tiller |
|---|---|
| mid-March | 20.3 |
| early-April | 17.9 |
| mid-April | 15.8 |
| Early-May | 14.1 |

## 2.5 Sowing Rate

Lee et al. (2013) examined how seeding rates alters plant morphology and size in a ryegrass pasture. The Waikato site plants in the 6 and 12 kg/ha sowing treatment were of a similar height to those in the 18 – 30 kg/ha treatments after one month as plants were not yet limited on light, however the lower sowing rate treatments had a higher number of tillers per plant. Eight months post sowing at the Canterbury site, the plants in the 6 and 12 kg/ha treatments were larger than the plants in the 18-30 kg/ha treatments in terms of both tiller number and total dry weight per plant (Table 2.4). There was an average of 24 tillers per plant on the 6 kg/ha sowing treatment whereas there was only 10 tillers per plant on the higher seeding rate (30 kg/ha). There was no significant difference in plant survival among the sowing rate treatments at the Canterbury site, however it was expected they would due to the plants known to self-thin in times of high competition for resources (Lee et al., 2013).

Table 2.4 Average tillers per plant and total mass per plant of perennial ryegrass in Canterbury 8 months after sowing (Lee et al., 2013).

| | Seeding Rate (kg/ha) | | | | | | |
|---|---|---|---|---|---|---|---|
| Eight months post-drilling | 6 | 12 | 18 | 24 | 30 | SED | *P* value |
| Tillers per Plant | 24 | 18 | 13 | 13 | 10 | 1.3 | <0.001 |
| Total mass per plant (mg (DM/plant) | 1094 | 780 | 598 | 569 | 444 | 68.1 | <0.001 |

Brown et al. (1990) reported that ryegrass seed crops are generally grown at 10 – 12 kg/ha with some specialist growers using rates as high as 20 kg/ha. However ryegrass seed crops sown at 5, 10, 15 and 20 kg/ha have the ability to produce the same seed yield. At low sowing rates such as below 5 kg/ha, plants have displayed intra-plant competition resulting in poor seed yields due to poor seed head production due to the amount of resources required to fill a seed head with its potential maximum. However at high sowing rates above 20 kg/ha there is inter-plant competition which also results in poor tiller and seed head production.

Acikgoz and Karagoz (1989) examined the effect of row spacing, seeding rate and nitrogen fertilization on the seed yield of perennial ryegrass under dryland conditions. Three sowing rates, three row spacing's and four different rates of nitrogen fertiliser were used. Seeding rates of 10, 20 or 30 kg $ha^{-1}$ did not significantly affect the seed yield. This may have been due to their row spacing's of 45, 60 and 75 cm, with row spacing's this wide there would be no competition from plants in different rows and there would have been plenty of room to allow them to tiller out. This experiment was conducted in Turkey but they have a rainfall similar to Canterbury dryland farmers on a dry year with an annual rainfall of 500 mm, however many Canterbury farms now have irrigation. Application of nitrogen at higher rates were shown to significantly increase seed yields. It was also found that plants that had wider row spacing's and higher N applications were also more prone to lodging.

## 2.6 Grazing Management

Poff, Balocchi, and López (2011) researched sward and tiller growth dynamics as a response to defoliation in autumn. Plants that were defoliated at 3.5 leaves per plant had a higher herbage production and a higher tillering output than those that were defoliated at 1.5 leaves. There was also a direct linear relationship between the mean daily temperature and accumulated leaf. Tiller number showed a significant linear relationship with thermal time expressed as growing degree days. Due to plants showing a higher number of tillers and increased herbage output when defoliated at 3.5 leaves, this was the recommended time to graze. The rate of leaf extension was decreased in plants that were defoliated at 1.5 leaves per plant to those that has 3.5 leaves at defoliation during the first 11 days after defoliation. Overall the leaf extension rate was not affected by the defoliation. There was also a close positive relationship between the tiller appearance rate and the defoliation interval in this study. This has also been found in other studies (Donaghy & Fulkerson, 1998; Hume, 1991).

There is an allocation hierarchy for the available water soluble carbohydrates after defoliation as reported by Donaghy and Fulkerson (1998). Plants allocate the available water soluble carbohydrates first to support the current tillers up until the leaf area is fully recovered. This is when the generation of carbohydrates from photosynthesis is equal to the utilisation and the plant growth is positive. After this the plant stores the excess carbohydrates as a resource. In the study by Poff et al. (2011) plants reached their maximum tiller appearance rate at 2.5 leaves however water soluble carbohydrate accumulation continued up until an average of 3.5 leaves per plant. As studied by Donaghy and Fulkerson (1998) after the lost leaf area has been recovered from the remobilisation of the stored water-soluble carbohydrates the second concern for the plant was to replace the carbohydrates that were taken from the roots to re-establish the leaf area. Thirdly the water soluble carbohydrates are used to develop daughter tillers.

The use of grazing in a ryegrass seed crop where high seed crops are expected should only be used as a tool to encourage autumn tillering (Brown et al., 1990) with tiller density being greatest under frequent cutting or grazing than under a lax regime (Hunt & Easton, 1989)The aim of grazing is to aid in producing strong autumn and winter tillers as these are the most productive when it comes to seed yield Brown et al. (1990). Brown et al. (1990) suggested using grazing in early winter to encourage these tillers with any further grazing of the crop to be light. The use of grazing in winter to reduce the bulk of the crop for harvest was another good use of grazing, with winter grazing to a height of 4cm recommended under large scale production. However it is known that perennial ryegrass seed yield is not effected by defoliation or cutting up to spikelet initiation (Young, Chilcote, & Youngberg, 1996). However it is also noted by Young et al. (1996) that the growers priority is seed production and any effect of grazing on seed yield is unacceptable.

In New Zealand there are a lot of farms that grow ryegrass seed crops and also graze pastures by stock. By growing a ryegrass seed crop these mixed cropping farms have the ability to use the ryegrass as a dual purpose crop, by grazing the leaf before the plant goes reproductive around the end of September. Closing date is referred to as the time in which stock are removed from the crop to allow it to flower and set seed. Closing date is important to maximise the number of spikelets and potentially the overall yield of the crop.

Crops should be closed before the initiation of reproductive growth. This prevents damage to, or removal of, the reproductive heads (Brown et al., 1990). Closing dates vary depending on the cultivar sown however seed yields decline rapidly with closing dates that are later than optimum (Foundation For Arable Research, 2007).

Table 2.5 Effect closing date on the number of spikelets per tiller in perennial ryegrass (Hill et al., 1999).

| Defoliation date | Spikelets per tiller |
|---|---|
| autumn | 20.4 |
| mid-September (floret initiation) | 17.8 |
| mid-October (head emergence) | 15.3 |

## 2.7 Seed Yield Components

Trethewey, Rolston, McGill, and Rowarth (2010) found that the seed yield of a perennial ryegrass crop showed no reduction in yield when the flag leaf and stem were covered preventing photosynthetically active radiation intercepting these parts of the plant. It was believed that the flag leaf and stem were the main sources for carbohydrates for seed filling as they are in cereal varieties. However it was found that when the seed head was covered and did not receive any light there was a decrease in yield by 16% the study concluded that it was the head photosynthesis that contributes to seed fill and the head itself may be more important than the flag leaf in contributing to seed weight and determining tiller seed yield.

A main component of perennial ryegrass seed production is the number of fertile tillers that are available for seed production, Hampton and Hebblethwaite (2000) recommends between 2000-4000 per $m^2$, while Hill et al. (1999) recommends 2000 - 3000 tillers per $m^2$ to be sufficient for a high seed yield. To try and prevent lodging too early a product that chemically alters the plant to produce a shorter straw length “Moddus” has been developed which helps increase the seed yield of ryegrass seed crops (Chynoweth, 2012).

Seed yield was more correlated with the number of seeds per unit of area that the weight of each seed (Elgersma, 1990) which is increased by increased spikelets/head, however seed size has more of an effect on yield than the number of seed heads/$m^2$ (Brown, 1980). Therefore the number of seeds that are filled to a threshold weight per unit area is a larger component to seed yield than the actual weight of each seed.

## 2.8 Conclusion

- R:FR ratio determines tiller initiation.
- Sufficient sowing rate of a minimum of 5 kg/ha is important for reducing the inter tiller competition within the same plant. Sowing rates of 10, 20 or 30 kg/ha do not have a significant influence on seed yield however higher sowing rates are known to self-thin plants due to interplant competition.
- Vernalisation, a period of cold temperatures is important to turn the early vegetative tillers into the reproductive state which contribute to the largest proportion of reproductive tillers.
- Achieving an optimum reproductive, fertile tiller population that produces 2000-4000 seed heads/$m^2$ is important for not limiting seed yield.

- Seed head photosynthesis has the greatest contribution to seed filling and the head itself may be more important than the flag leaf in contributing to seed weight and determining tiller seed yield therefore it is important to achieve optimum seed head number

- Seed yield is determined by the number of reproductive tillers/m$^2$. The number of reproductive tillers/m$^2$ is determined by sowing rate, sowing date and grazing. The purpose of this experiment is to quantify these effects on the number of reproductive tillers/m$^2$.

# 3 Materials and Methods

## 3.1 Experimental Design

The experiment was conducted on a Wakanui silt loam in the Field Research Centres Iverson field, paddock 3. The previous crop was wheat. The paddock was sprayed off with glyphosate and mulched. Irrigation was then applied with a Precision Irrigation Mini Boom which applied a gentle rain at a rate of 60 mm. The field was then rotary hoed and rolled with a Cambridge roller. It was then ploughed and top-worked, which consisted of a power harrow pass with roller, then a pass with the Dutch harrower and roller.

A randomised split block design was set up with four sowing dates, three weeks apart from the 27$^{th}$ of March 2015 with Samson (seed line -SMT324AA) perennial ryegrass seed with a germination of 95%. The seed was treated with Gaucho insecticide/ fungicide. The four target plant populations were 200, 600, 1000, 1400 plants/m$^2$. The calculated thousand seed weight (TSW) for the seed sown was 2.6 grams. The sowing rate was calculated using equation 1.

Equation 1 Sowing rate calculation used to determine the sowing rate from target population.

$$Sowing\ rate(kg/ha) = \frac{Target\ population\ \ (p/m^2) \times TSW(g) \times 100}{\%\ germination\ \times\ \%\ emergence}$$

The values in Table 3.1 were used to calculate sowing rates in kg/ha for the plots, which were 2.1m wide and 10 m long.

Table 3.1 Germination and emergence percentage (%) used to calculate sowing rates (kg/ha) along with the calculated seed weight used per hectare to sow each plot.

| TOS | Germination % | Emergence% | | Sowing Rate(kg/ha) | | | |
|---|---|---|---|---|---|---|---|
| | | 200/600 | 1000/1400 | 200 | 600 | 1000 | 1400 |
| 27th March | 95% | 95% | 95% | 5.76 | 17.28 | 28.8 | 40.33 |
| 17th April | 95% | 95% | 95% | 5.76 | 17.28 | 28.8 | 40.33 |
| 8th May | 95% | 90% | 87% | 6.08 | 18.25 | 30.41 | 42.57 |
| 28th May | 95% | 88% | 85% | 6.29 | 18.87 | 31.46 | 44.04 |

The trial was sown using a flexi-seeder precision plot drill to a depth of 15 – 20mm.

Electric flexi net was set up around each of the grazing treatments for grazing. Plots were grazed at canopy closure and were grazed to an even residual of 1500 t DM/ha

Table 3.2 Table of grazing treatments to times of sowing (TOS) and dates of when grazing occurred.

| Grazing | | | | | |
|---|---|---|---|---|---|
| 1 | 13th July | TOS1 | | | |
| 2 | 1st September | TOS1 | TOS 2 | | |
| 3 | 8th October | TOS1 | TOS 2 | TOS 3 | TOS 4 |

## 3.2 Measurements

Four sampling strips of row measured out with wooden sticks for the un-grazed and metal pegs for the grazed plots. The sticks/pegs defined a 30cm strip of plants on rows 5, 7, 9 and 11, with each sampling area being located greater than 2 metres from the end of each plot.

Plant numbers were counted when the majority of the plant had their 3rd leaf appear, to allow for later seeds to germinate. A tiller count of TOS 1 was taken on the 30th of May and a tiller count for TOS 2 was taken on the 30th of July. A tiller count of all pots was conducted on the 14th of august and again on the 15th of September. A quadrat cut was taken at each grazing to measure the dry matter accumulation and the amount of feed taken off by the sheep.

A final harvest of plots were taken after at GS32, a single 30 cm sampling strip was harvested with roots intact, plants were then washed and separated to achieve individual plant numbers. Individual reproductive tiller and vegetative tiller numbers were counted for each plant tillers were cut from the root at ground height. Vegetative and reproductive tillers from each plot were dried and weighed. All dried samples were dried in the ovens at the Field Research Centre at Lincoln University for 48 hours at 60°C until no change in the materials weight.

Due to the criteria of the final harvest of tiller numbers for quantitative analysis with a destructive sample being when plants reached a minimum of 50% growth stage 32, only the un-grazed plots could be harvested for this dissertation as there was a delay in growth stages by the grazed treatment plots.

## 3.3 Statistical analysis

Data was statistically analysed using GenStat (16th edition). Data was tested for normality. Significance was calculated with ANOVA, differences were determined at the 0.05 probability. Treatment differences were determined by LSD calculated at the 0.05 probability.

# 4 Results

## 4.1 Plant Establishment

There was a main effect of time of sowing on the amount of plants that established per sowing (Table 4.1). There was no significant difference in the number of plants that established between time of sowing 1 and 2. The number of plants that established after time of sowing 2 showed a negative response ($P<0.001$) to later times of sowing. There was also a main effect of rate on the number of plants that established per sowing rate as expected. There was a decrease in the number of plants that established as the sowing rate increased with none of the plant population target reaching the desired plant density for each sowing rate.

Table 4.1 Average of the number of plants/m$^2$ that established 3 weeks after sowing over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 in and of different plant populations 200, 600, 1000, and 1400 plants/m2 shown in plants/m$^2$of Samson Perennial ryegrass, of both grazed and un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 634 | 645 | 518 | 374 |
| l.s.d. (TOS) | | 97.2 | | |
| TOS P<0.001 | | | | |
| | | | | |
| Sowing Rate | 200 | 600 | 1000 | 1400 |
| | 169 | 412 | 678 | 911 |
| l.s.d. (Rate) | | 59.5 | | |
| Rate P<0.001 | | | | |

There was an interaction effect (TOS*Rate, $P=0.007$) on the establishment percentage of the number of seeds sown. Only the target population of 200 plants/m$^2$ in time of sowing 1 and 2 reached their target population. As sowing rate increased during the same time of sowing there was a sowing rate had a negative effect on the amount of seeds that emerged. There was no significant difference between the percentage of plants that emerged across all target populations for times of sowing 3 and 4.

Table 4.2 Establishment percentage (%) of the number of seeds sown to establish a target population of 200, 600, 1000, and 1400 plants/m2 over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 of Samson Perennial ryegrass, of both grazed and un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| | Target population (Plants/$m^2$) | | | |
|---|---|---|---|---|
| TOS | 200 | 600 | 1000 | 1400 |
| 1 | 102% | 75% | 68% | 68% |
| 2 | 106% | 76% | 74% | 66% |
| 3 | 45% | 54% | 57% | 53% |
| 4 | 45% | 36% | 36% | 39% |
| l.s.d. (TOS.Rate) | | 19% | | |

TOS*Rate (P=0.007)

## 4.2 Tillers Trends

For time of sowing 1 on the first sampling date, 20th of May, there was a main effect of rate (P<0.001, l.s.d. = 260.1) on the number of tillers/$m^2$ (Figure 4.1a). On 30th of July for the first sampling date of tillers/$m^2$ on time of sowing 2 there was also a significant main effect of rate (P<0.001, l.s.d.= 378.3) on the tiller numbers by rate (Figure 4.1b).

On 14th of August, there was a significant time of sowing by rate interaction (P<0.001) for all treatments for tiller density. There was a grazing by date interaction (P=0.006, l.s.d.= 450.7) but only time of sowing one decreased from 4413 tillers/$m^2$ in the un-grazed treatment to 3158 tillers/$m^2$ on the grazed treatment. Other sowing dates not receiving grazing treatment before this sampling date (Figure 4.1). Time of sowing one had significantly higher tiller number than the other times of sowings on the 14th of August. There were also very small differences in tiller numbers between time of sowings 3 and four.

There is a time of sowing by rate interaction for the sampling date 15th of September for the number of tillers/$m^2$ (P=0.011, l.s.d = 579.1). There was no main effect by grazing (P=0.417) on the number of tillers on the sampling date 15th of September for any time of sowing. The only significant difference between time of sowing one and time of sowing two across all sowing rates was in the lowest sowing rate, 200 plants/$m^2$ with 3251 tillers/$m^2$ for time of sowing one and 2526 tillers/$m^2$ for time of sowing two. There were 705 and 192 tillers/$m^2$ for time of sowing three and four respectively at the 200 plants/$m^2$ sowing rate . There was a decrease in the number of tillers across sowing rates between time of sowing two and three, with the sowing rate of 1000 plants/$m^2$ showing the largest difference in the number of tillers of 1826/$m^2$. The highest sowing rate of 1400 plants/$m^2$ showed the lowest differece in tiller numbers between times of sowing 2 and 3 with a difference of 1245 tillers/$m^2$. Sowing rate 1400 plants/$m^2$ in time of sowing four had a lowest tiller/$m^2$ population than any other time of sowing four sowing rate with 1678 tillers/$m^2$. Time of sowing four displayed the least amount of tillers at sowing populations 600 and 1000 plants/m$^2$ with 646 and 1020 tillers/m$^2$ respectively which was significantly less than time of sowing three at the same sowing rates.

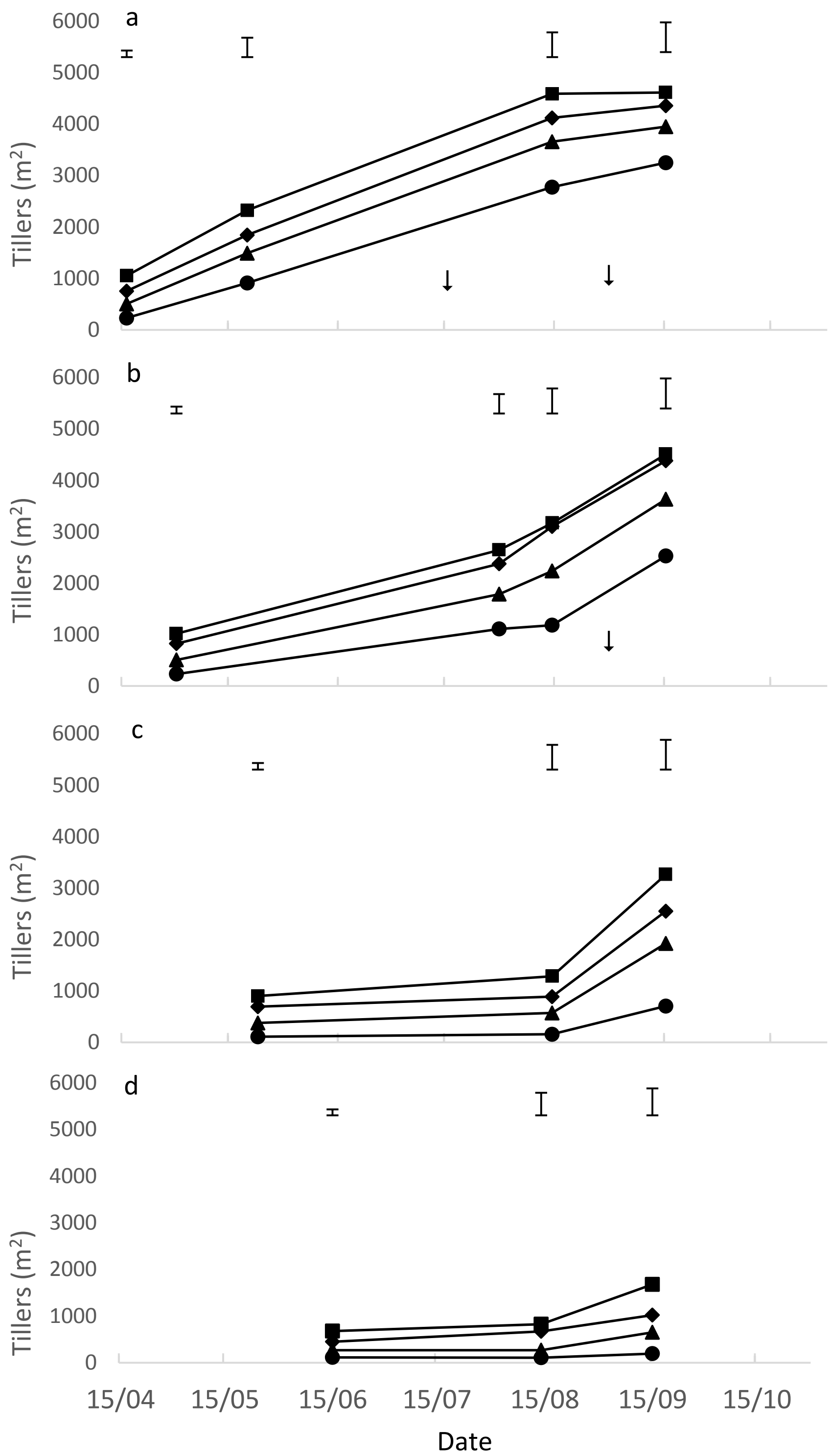


Figure 4.1 Average number of tillers per m$^2$ over the 4 target population of 1400 (■), 1000 (◆), 600 (▲), 200 (●) plants/m$^2$ over different times of sowing (TOS), 27th March (a, TOS 1), 17th April (b, TOS 2), 8th May (c, TOS 3) and 28th May (d, TOS 4) 2015 of Samson Perennial ryegrass, mean of both grazed and un-grazed plots in Iverson 3, (↓ indicates grazing) Field Research Centre, Lincoln University.

## 4.3 Final Harvest

Destructive samplings of the un-grazed plots occurred from the 16th of October with time of sowing one, then time of sowing two on the 19th of October, time of sowing three on the 23rd of October and finally time of sowing four on the 6th of November 2015.

The time of sowing decreased (P=0.027) the number of plants that were present at the final harvest (Table 4.3).There was no difference between times of sowing one and two for the number of plants at the final harvest. There was a decrease between times of sowing two to three from 661 plant /m$^2$ to 485 plants/m$^2$, respectively. There was also a decrease in plants/m$^2$ from time of sowing two (661 plants/m$^2$) to time of sowing four (410 plants/m$^2$). There was no significant difference between time of sowing one, three and four. The sowing rate had increased (P<0.001) on the number of plants per sowing rate at the final harvest (.

Table 4.3).

Table 4.3 Plants/m$^2$ at the final harvest over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 in and of different plant populations 200, 600, 1000, and 1400 plants/m$^2$ shown in plants/m$^2$of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 518 | 661 | 485 | 410 |
| l.s.d. (TOS) | | 152.1 | | |
| TOS P=0.027 | | | | |
| | | | | |
| Sowing Rate | 200 | 600 | 1000 | 1400 |
| | 203 | 439 | 626 | 809 |
| l.s.d. (Rate) | | 85.1 | | |
| Rate P<0.001 | | | | |

A change in plant survival interaction (P=0.041) was seen between time of sowing and sowing rate (Table 4.4). The lowest sowing densities seen the least amount of change in the number of plants/m$^2$ and the highest sowing rates has the largest change along with the earliest sowings. There was an increase in plant number during the latest time of sowing. Each time of sowing showed no significant difference in the number of plants from the different sowing rates 1000 and 1400 plants/m$^2$. There was no significant change in the number of plants for time of sowing four across all sowing rates. The largest change in plant numbers was seen between sowing rates 1000 and 1400 plants/m$^2$.

Table 4.4 Change in plant numbers/m$^2$ at the final harvest from initial plant numbers, at sowing rates of 200, 600, 1000, and 1400 plants/m2 over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 of Samson Perennial ryegrass, of the un-grazed plots in Iverson 3, Field Research Centre, Lincoln University

| | Sowing Rate (Plants/m$^2$) | | | |
|---|---|---|---|---|
| TOS | 200 | 600 | 1000 | 1400 |
| 1 | -17 | -183 | -228 | -283 |
| 2 | 11 | 39 | -72 | -111 |
| 3 | 17 | -50 | -144 | -39 |
| 4 | 33 | 33 | 106 | 40 |
| l.s.d. (TOS.Rate) | | 135.8 | | |
| TOS P=0.041 | | | | |

There was main effects by both time of sowing (P=0.025) and sowing rate (P<0.001) on the total number of tillers/m$^2$ (Table 4.5). There was no difference between the total number of tillers/m$^2$ from time of sowing one and time of sowing two. Time of sowing three had more tillers/m$^2$ than time of sowing one. There no difference between time of sowing two and three. There was also no difference between the total number of tillers/m$^2$ from time of sowing one and four. Time of sowing four had significantly less tillers/m$^2$ than time of sowing three.

Less tillers/m$^2$ formed in the 200 plants/m$^2$ than any other sowing rate. There was no difference in the total number tillers in in the 1000 and 1400 plant/m$^2$ sowing rates. There was however more tillers in the 1000 plant/m$^2$ sowing rate than in the 600 plants/m$^2$ sowing rate.

Table 4.5 Total number of tillers/m$^2$ at the final harvest over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 in and of different plant populations 200, 600, 1000, and 1400 plants/m$^2$ shown in plants/m$^2$of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 4117 | 4842 | 5154 | 3567 |
| l.s.d. (TOS) | | 1018.2 | | |
| TOS P=0.025 | | | | |

| Sowing Rate | 200 | 600 | 1000 | 1400 |
|---|---|---|---|---|
| | 3497 | 4286 | 5012 | 4884 |
| l.s.d. (Rate) | | 643.6 | | |
| Rate P<0.001 | | | | |

Different times of sowing had a significant effect (P=0.002) on the number of reproductive tillers/m$^2$ at the final harvest (Table 4.6). There was no significant difference in the number of reproductive tillers/m$^2$ from time of sowing one through to time of sowing three. Time of sowing four had significantly less reproductive tillers/$m^2$ than any of the other times of sowing with only 1220 reproductive tillers/$m^2$. There was no main effect of sowing rate on the number on reproductive tiller/$m^2$ however sowing rate of 1000 plants/$m^2$ had the highest number of reproductive tillers and the only rate to reach over 2000 reproductive tillers/$m^2$ with 2038/$m^2$, sowing rate of 200 plants had the lowest with 1599 reproductive tillers/$m^2$ however these differences were not significant.

Table 4.6 Reproductive tillers/$m^2$ at the final harvest over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 2086 | 2110 | 2057 | 1220 |
| l.s.d. (TOS) | | 402.5 | | |
| TOS P=0.002 | | | | |

The sowing rate had an effect (P<0.001) on the number of vegetative tillers/$m^2$ (Table 4.7) with increased vegetative tillers as the sowing rate increased. There was no significant difference in the number of vegetative tillers/$m^2$ from the sowing rates of 1000 and 1400 plants/$m^2$. There was a significant difference between each of the sowing rates of 200, 600 and 1000 plants/$m^2$ with 1899 vegetative tillers/$m^2$ in the 200 plants/$m^2$ sowing rate.

Table 4.7 Vegetative tillers/$m^2$ at the final harvest over different plant populations 200, 600, 1000, and 1400 plants/$m^2$ shown in tillers/plant of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Sowing Rate | 200 | 600 | 1000 | 1400 |
|---|---|---|---|---|
| | 1899 | 2376 | 2975 | 2957 |
| l.s.d. (TOS) | | 408.4 | | |
| TOS P<0.001 | | | | |

Time of sowing had a significant effect on the proportion of reproductive tillers per plant with the earlier time of sowing having a higher proportion of reproductive tillers than any other time of sowing with a proportion of 0.5 and an LSD of 0.076. No significant differences were found between times of sowing three and four, for the proportion of reproductive tillers present per plant. There was no significant difference between time of sowing two (0.41) and three (0.37) however there was a significantly lower proportion of reproductive tillers produced in the time of sowing four treatments (0.31). Sowing rate had a significant effect (P=0.018) on the proportion of reproductive tillers produced per plant (Table 4.8) with sowing rates 1000 and 1400 plants/$m^2$ producing a significantly less proportion of reproductive tillers/plant. There was no significant in the proportion of reproductive tillers/$m^2$ between sowing rates 200, 600 and 1000 plants/$m^2$.

Table 4.8 Proportion of reproductive tillers per plant over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 in and of different plant populations 200, 600, 1000, and 1400 plants/m$^2$ shown in plants/m$^2$of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 0.51 | 0.41 | 0.37 | 0.31 |
| l.s.d. (TOS) | | 0.076 | | |
| TOS P=0.002 | | | | |

| Sowing Rate | 200 | 600 | 1000 | 1400 |
|---|---|---|---|---|
| | 0.43 | 0.42 | 0.38 | 0.36 |
| l.s.d. (Rate) | | 0.047 | | |
| Rate P=0.018 | | | | |

The number of reproductive tillers per plant decreased (P<0.001) due a main effect of sowing rate increasing (Table 4.9). There was no difference in the number of reproductive tillers per plant in the highest sowing treatments 1000 and 1400 plants/m$^2$. The lowest sowing rate 200 plants/m$^2$ had the highest number of reproductive tillers per plant with an average of 8.78 reproductive tillers per plant.

Table 4.9 Reproductive tillers/plant at the final harvest over different plant populations 200, 600, 1000, and 1400 plants/m$^2$ shown in tillers/plant of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Sowing Rate | 200 | 600 | 1000 | 1400 |
|---|---|---|---|---|
| | 8.8 | 4.5 | 3.4 | 2.4 |
| l.s.d. (TOS) | | | 1.75 | |
| TOS P<0.001 | | | | |

There was a decreasing effect (P=0.017) of time of sowing on the number of vegetative tillers per plant (Table 4.10). Time of sowing one produced significantly less tillers that time of sowing three. There was no difference between the two latest sowings, time of sowing three (8.32 tillers/plant) and four (6.85 tillers/plant). There was also no difference between the earliest sowing treatments time of sowing one (4.89 tillers/plant) and two (5.13 tillers per plant). There were less (P<0.001) vegetative tillers as sowing rate increased (Table 4.10). Sowing rate of 200 plants/m$^2$ had significantly more vegetative tillers per plant than any other sowing rate. There was no significant difference in the number of vegetative tillers produced per plant between the sowing rates 600 and 1000 plants/m$^2$ or between the highest two sowing rates 1000 and 1400 plants/m$^2$. However the sowing rate 1400 plants/m$^2$ had significantly less vegetative tillers per plant than the 600 plants/m$^2$ treatment.

Table 4.10 Number of vegetative tillers/plant at the final harvest over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 in and of different plant populations 200, 600, 1000, and 1400 plants/m$^2$ shown in tillers/plants of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 4.9 | 5.1 | 8.3 | 6.9 |
| l.s.d. (TOS) | | 2.1 | | |
| TOS P=0.017 | | | | |
| | | | | |
| Sowing Rate | 200 | 600 | 1000 | 1400 |
| | 10.9 | 5.7 | 4.8 | 3.7 |
| l.s.d. (Rate) | | 1.79 | | |
| Rate P<0.001 | | | | |

The amount of tillers per plant decreased (P<0.001) as the sowing increased (Table 4.11). The lowest sowing rate had the most tillers per plant (19.7) while the two highest sowing rates had the lowest number of tillers per plant with no significant difference in tiller number per plant between their sowing rate of 1000 and 1400 plants/m$^2$. The sowing rate 600 plants/m$^2$ had less tillers per plant than the 200 plant/m$^2$ sowing rate and significantly more tillers per plant than the 1400 plants/m$^2$ sowing rate.

Table 4.11 Average number of tillers/plant at the final harvest over different plant populations 200, 600, 1000, and 1400 plants/m$^2$ of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Sowing Rate | 200 | 600 | 1000 | 1400 |
|---|---|---|---|---|
| | 19.7 | 10.21 | 8.29 | 6.12 |
| l.s.d. (TOS) | | | 3.417 | |
| TOS P<0.001 | | | | |

Individual vegetative tiller weight was decreased with later times of sowing (P<0.001). There was a difference between all times of sowing with time of sowing one having the largest individual tiller weight of 64.3mg per tiller (Table 4.12). Individual reproductive tiller weight showed very little difference across all treatments however it was still significant (P=0.017) with a trend of larger reproductive tillers during earlier time of sowing and at lower sowing rates except for time of sowing four which displayed the opposite, however there was no significant difference between any of sowing rates within each time of sowing.

Table 4.12 Mean weight of individual vegetative tillers (mg) at the final harvest over different times of sowing (TOS), 27th March (1), 17th April (2), 8th May (3) and 28th May (4) 2015 and reproductive tillers at sowing rates of 200, 600, 1000, and 1400 plants/m2 over different times of sowing (TOS) 1, 2, 3, 4 of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

Vegetative Tiller Weight

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 64.3 | 44.5 | 37.0 | 31.6 |
| l.s.d. (TOS) | | 7.3 | | |
| TOS P<0.001 | | | | |

Reproductive Tiller Weight

| | Sowing Rate (Plants/m$^2$) | | | |
|---|---|---|---|---|
| TOS | 200 | 600 | 1000 | 1400 |
| 1 | 255.3 | 227.2 | 224.6 | 213.6 |
| 2 | 216.8 | 231.5 | 202.1 | 149.6 |
| 3 | 203.4 | 173.8 | 184.7 | 175.0 |
| 4 | 190.5 | 198.3 | 207.9 | 235.7 |
| l.s.d. (TOS.Rate) | | 55.6 | | |
| TOS P=0.017 | | | | |

Time of sowing decreased the weight of individual vegetative tillers (P=0.032). The Dry Weight of vegetative tillers/m$^2$ from time of sowing four were significantly less that vegetative tillers from any other time of sowing. There was no difference in the weight of individual tillers from time of sowing one, two or three, there was however an effect of sowing rate on their weight. As sowing densities increased the weight of the vegetative tillers increased, with the lowest sowing rate of 200 plants/m$^2$ having a lower dry weight than the other three sowing densities.

Table 4.13 Mean weight of vegetative tillers/m$^2$ (grams) at the final harvest over different times of sowing (TOS), 27$^{th}$ March (1), 17$^{th}$ April (2), 8$^{th}$ May (3) and 28$^{th}$ May (4) 2015 in and of different plant populations 200, 600, 1000, and 1400 plants/m$^2$ of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Time of Sowing (TOS) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | 133.3 | 123.1 | 113.9 | 76.5 |
| l.s.d. (TOS) | | 36.8 | | |
| TOS P=0.032 | | | | |

| Sowing Rate | 200 | 600 | 1000 | 1400 |
|---|---|---|---|---|
| | 81.5 | 101.1 | 132.6 | 131.5 |
| l.s.d. (Rate) | | 31.9 | | |
| Rate P=0.005 | | | | |

There was a time of sowing by sowing rate interaction that decreased the weight of reproductive tillers/$m^2$ as the sowing rate increased and as time of sowing got later (P=0.032). There was no difference between sowing rates for time of sowing one or three, or between times of sowing for the high sowing rates 1000 and 1400 plants/$m^2$. Time of sowing four at the sowing rate 200 plants/$m^2$ had the lowest total weight of reproductive tillers/$m^2$ at 133 g/$m^2$ while time of sowing one had the highest at 553 g/$m^2$.

Table 4.14 Mean weight of reproductive tillers/$m^2$ (grams) at the final harvest, at sowing rates of 200, 600, 1000, and 1400 plants/m2 over different times of sowing (TOS), 27$^{th}$ March (1), 17$^{th}$ April (2), 8$^{th}$ May (3) and 28$^{th}$ May (4) 2015 of Samson Perennial ryegrass, of the un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| | Sowing Rate (Plants/$m^2$) | | | |
|---|---|---|---|---|
| TOS | 200 | 600 | 1000 | 1400 |
| 1 | 553 | 490 | 435 | 437 |
| 2 | 420 | 500 | 464 | 307 |
| 3 | 303 | 397 | 450 | 372 |
| 4 | 133 | 224 | 339 | 358 |
| l.s.d. (TOS.Rate) | | 184.4 | | |

TOS P=0.031

There was a time of sowing by sowing rate interaction for the weight of all tillers/$m^2$ at the final harvest (P=0.03) where later time of sowing decreased the DM/$m^2$. While there was no significant differences between sowing rates for times of one, two or three, time of sowing four showed an increase in the total weight of tillers/$m^2$ in sowing rates 600, 1000 and 1400 plants/$m^2$ over sowing rate one which had 173 g/DM $m^{-1}$.

Table 4.15 Mean weight of total tillers/$m^2$ (grams) at the final harvest from initial plant numbers, at sowing rates of 200, 600, 1000, and 1400 plants/m2 over different times of sowing (TOS), 27$^{th}$ March (1), 17$^{th}$ April (2), 8$^{th}$ May (3) and 28$^{th}$ May (4) 2015 of Samson Perennial ryegrass, of the un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| | Sowing Rate (Plants/$m^2$) | | | |
|---|---|---|---|---|
| TOS | 200 | 600 | 1000 | 1400 |
| 1 | 676 | 606 | 571 | 596 |
| 2 | 504 | 636 | 608 | 436 |
| 3 | 382 | 500 | 584 | 512 |
| 4 | 173 | 274 | 456 | 457 |
| l.s.d. (TOS.Rate) | | 203.7 | | |

TOS P=0.03

Increased sowing rate decreased the proportion of reproductive tillers/$m^2$ by weight. There was no difference between sowing rates 200 and 600 plants/$m^2$, 600 and 1000 plants/$m^2$ or between 1000 and 1400 plants/$m^2$. There was a decreased proportion of reproductive tillers in 1000 and 1400 plant/$m^2$ compared to 200 plants/$m^2$.

Table 4.16 Proportion of reproductive tillers at the final harvest by weight over different plant populations 200, 600, 1000, and 1400 plants/$m^2$ of Samson Perennial ryegrass, of un-grazed plots in Iverson 3, Field Research Centre, Lincoln University.

| Sowing Rate | 200 | 600 | 1000 | 1400 |
|---|---|---|---|---|
| | 0.804 | 0.796 | 0.744 | 0.733 |
| l.s.d. (TOS) | | 0.0544 | | |

TOS P=0.023

# 5 Discussion

## 5.1 Plant Establishment

Germination and emergence of seeds in the field is dependent on temperature moisture and oxygen therefore it is important to sow the crop when conditions are at their optimum, with the soil temperature fluctuating on both a seasonal and daily basis (Moot et al., 2000), however conditions are rarely optimum therefore adjustments need to be made. Moot et al. (2000) found perennial ryegrass to have an optimum germination temperature of 15$^oC$ with a 99% germination rate. Hill et al. (1999) recommended sowing perennial ryegrass during early March when the soil temperature is still around 14$^oC$ to help maximise germination as well as planting it at the right time of year for the crop to receive its vernalisation requirement during winter for seed head production.

The average number of plants to emerge over all treatments showed a significant decrease (P<0.001) from 634 and 645 plants/m$^2$ on the first and second sowing dates on the 27$^{th}$ of March and 17$^{th}$ of April to 518 and 374 plants/m$^2$ on times of sowing 3 and 4, respectively (Table 4.1). This reduction in plant number is due to the later sowings occurring in the autumn when temperatures were colder although ground temperature at the sowing site was not measured. The decrease in temperature was expected as a part of seasonal fluctuations. As expected there was an increase in the amount of plants that established as sowing rate increased.

The Samson seed line used (SMT324AA) had excellent germination with a 95% germination rate 2 days prior to the first time of sowing, however there was a reduction in the seeds that emerged of the seeds sown as the sowing rates increased (Table 4.2). This trend was observed for the first two times of sowing with no differences in the establishment percentage of time of sowing four, with the plant numbers only reaching around 50% of the target population the target population.

As with the establishment percentage of plant populations the establishment percentage of the number of seeds sown showed the same interaction of sowing rate and time of sowing with as low as only 39% and as high as 102% with a grand mean of 62% of the seeds sown emerging (Table 4.2). Poorer germination was also experienced by Moot et al. (2000) with perennial ryegrass with around 80% of plants germinating at the lower temperatures of 5 and 10$^oC$ with it being noted that there was a delay in the number of days seeds took to germinate at these low temperatures. There was an increase in the number of plants in the latest time of sowing treatment with the 1000 plants/m$^2$ target reaching as high as 106 extra plants. These extra plants may have been the result of delayed germination from the low temperatures of winter following time of sowing four.

There was no literature to suggest that an emergence of only 36% of seeds sown. Such a low emergence will have an effect on the number of tillers/plant and tillers/$m^2$ that are produced. Wall (1982) as cited by Destro et al., (2001) identified that cultivars that do not have a high tillering capacity and the established plant population is low, the crop can have a reduction in seed yield as it cannot compensate adequately.

There also seemed to be some interplant competition during the first stages of emergence. As the sowing rate increased there was a drop ($P<0.001$) in the amount of plants that emerged. To ensure the correct target population is reached a calculation of the amount of seed needed to compensate those that do not germinate or emerge is used. To ensure the highest possible emergence the seed that is sown should be of the highest available planting value i.e. high purity freedom from undesirable weed species, and high germination (Charlton, Hampton, & Scott, 1986).

Germination test are used to measure the full potential of a seed lot in laboratory conditions, however these conditions often differ from those in the field where the seed will interact with its environment (Moot et al., 2000). Herbage seeds are often sown when temperature and moisture levels are less than ideal and these conditions may greatly affect seedling establishment and subsequent performance (Charlton et al., 1986). Soil temperatures that seeds are sown into are not a constant temperature as in the laboratory tests that determine germination potential. Seeds that are sown in soil experience for germination and emergence fluctuate on in temperature on both a daily and seasonal basis. Charlton et al. (1986) found that the germination rate for all species tested for germination length at different temperatures slowed as temperatures moved away from the optimum and was greater for ryegrass at all temperatures. This experiment demonstrates this result with the amount of plants that established during the trial.

If a May sowing was to be used in practice, according to this experiment, given the emergence that occurred, sowing rate would be adjusted accordingly. For time of sowing three, on the 8th of May, on average only 52% of seed sown emerged therefore seeding rates would need to be doubled to reach the target populations, although this allows for later sowing the cost of extra seed to reach target populations may be a factor to consider.

## 5.2 Tiller Trends Dynamics over time

The difference in the number of plants at sowing had an effect on the number of tillers that followed through to the 15th of September (Figure 4.1). Lower sowing rates had increased weed pressure which was corrected after establishment, there was many volunteer wheat plants from the previous crop that were removed by hand. Measuring tiller trends over time from the same sampling area can have implications (Arosteguy, 1982) with disturbing the erect habit of the canopy and allowing light to penetrate to the base of the canopy which could alter the number of tillers that are measured compared to the rest of the sward

There was a decrease (P=0.006) in the number of tillers from the un-grazed treatment to the grazed treatment on time of sowing one at the 14th of August, only time of sowing one showed a decrease, tiller numbers decreased from 4413 tillers/$m^2$ in the un-grazed treatment to 3158 tillers/$m^2$ on the grazed treatment. This was the only difference that grazing created. Arosteguy (1982) found that lax grazing or more severe grazing treatments had been observed to result in a lower population density, however the role of length of time between consecutive defoliation on tiller initiation is unclear (Poff et al., 2011). After this sampling date, on the 15th of September there was no difference in the number of tillers between grazed and un-grazed treatments. Any tillers that were grazed off would have been compensated with the birth of new tillers as the light would have increased at the base of the plant, initiating more tillers. This study did not find any significant increase in the number of tillers in a grazed treatment by the on the 15th of September over all treatments. Only time of sowing one and two had received grazing by this point in time due to the later sowings three and four not being of sufficient size or maturity to receive grazing

Vernalisation is an adaptation that ryegrass uses to prevent it from going reproductive in the late summer when seed production would be impractical due to shortening day length and colder temperatures with autumn and winter approaching (Williamson, 2008). Vernalisation is perceived by the apical meristem of each tiller which in vegetative plants is located at the base of the plant and is where leaves are initiated from. Only tillers that receive the cold treatment sufficient for vernalisation will become reproductive meaning that any tillers that are initiated after the chance of vernalisation in winter will not become reproductive, however in Canterbury the cool night time temperature in spring is sufficient to provide 12 hours per day of vernalisation (Rolston & Archie, 2005). Ensuring that there is sufficient (2000 – 4000) tillers available for this vernalisation prior to the time in which the plants receive their vernalisation treatment is important to reach the target of 2000+ fertile reproductive tillers at anthesis. Sowing rate 1400 plants/$m^2$ had the highest number of tillers at time of sowing four with 1678 tillers/$m^2$, on the 15th of September. Previous to this on the 14th of August it had a tiller population density of 824 tillers/$m^2$, therefore sowing rate four showed little potential of reaching 2000+ fertile reproductive tillers/$m^2$ at anthesis. All other sowing rates over times of sowing one through three had more than 2500 tiller/$m^2$ on the 15th of September showing good potential for reaching 2000+ fertile reproductive tillers at anthesis apart from sowing rates 200 and 600 plants/$m^2$ of time of sowing three with 705 and 1924 tillers/$m^2$ respectively. A study by Rolston and Archie (2005) has suggested that tillers that had not emerged in September may have been formed during winter and therefore receiving their vernalisation requirement before emerging. This was due to a result of reproductive tillers emerging to form a seed head after the September sampling of tiller numbers.

## 5.3 Final Harvest

### 5.3.1 Plants/m$^2$

Both time of sowing one and two had the same number of seeds sown for each treatment however there was an increase in the number of plants that made it to the final harvest for time of sowing two, even though it was sown three weeks following time of sowing one. There was no significant difference in the number of plants that established between time of sowing one and two however there is a difference the number of plants that made it to the final harvest. Time of sowing one showed higher plant death than time of sowing two due to self-thinning of the sward which meant earlier sowings at higher sowing populations caused high mortality of individual plants from establishment to the final harvest (Table 4.4). This was a result that was also found by Korte (1986), that there was a decrease in tiller numbers in the sward due to individual plants dying. This trend can also be seen in time of sowing one with the tiller numbers decreasing around September (Figure 4.1). Self-thinning of grass plants in usually occurs at high rates of sowing, which results in a high mortality of individual plants so that the sward consists of fewer but larger plants with time (Colvill & Marshall, 1984). Large variation in the number of tillers, both reproductive and vegetative was seed in all treatments resulting in a range of plants that had a wide range of tillers to some that were only a single vegetative tiller, which is caused by self-thinning and plant competition which resulted in a skewed distribution (Harris, 1971).

The sowing rate had increased ($P<0.001$) on the number of plants per sowing rate at the final harvest (Table 4.3) across all rates as it had with the number of plants that established at the start of the experiment (Table 4.1). As sowing rate increased, the number of plants at the final harvest increased as expected due to more seeds being sown in the higher sowing treatments.

### 5.3.2 Tillers

#### 5.3.2.1 Tillers/m$^2$

Target tiller population density for a perennial ryegrass seed crop is 2000 – 4000 fertile reproductive tillers/m$^2$ (Hampton & Hebblethwaite, 2000). This population density was shown to not limit seed yield. The total number of tillers/m$^2$ at the final harvest increased with time of sowing up until time of sowing 3 with time of sowing 4 showing a decrease in the amount of tillers produced (Table 4.5). The decrease in the total amount of tillers/m$^2$ in time of sowing four could have been due to its low number of reproductive tillers at the final harvest of only 1220 reproductive tillers/m2 (Table 4.6). As sowing rate increased so did the number of tillers per plant produced as well (Table 4.5) this increase was due to the increase in the number of vegetative tillers that were present as sowing rate increased (Table 4.7). Which is a similar finding to Hill and Watkin (1975) with tillers formed in spring making a major contribution to the vegetative growth of the plant.

The same number of reproductive tillers/m$^2$ was produced by times of sowing one through to three with all at least 2000/m$^2$ however the number of tillers/m$^2$ is not the only component to seed yield. The number of reproductive tillers per plant has a role to play in the amount of seed that is produced per reproductive tiller. Brown (1980) looked at seed production studies in Canterbury and found that in order of decreasing importance that seed head size, individual seed weight and the number of seed heads were the indicators of yield. Crops that produce a larger seed head (increased number of spikelets) with heavier seed have greater potential to yield higher than a crop with a high tiller number/m$^2$ with small seed heads or small seed size.

Hill and Watkin (1975) found that the primary tillers that first grew after sowing were highly persistent and almost exclusively became reproductive, as with this these tillers that are grown in the autumn tend to have larger seed heads than those that are initiated later in the season, with the minimum number of primary spikelet branches in the head occurring on tillers that have been vernalised, with the number of florets per spikelet being effected in the same way (Ryle, 1966). Under this reasoning it will the earlier time of sowing treatment which will produce the larger seed head however until the plots are harvested and measured this will not be known.

#### 5.3.2.2 Tillers per plant

There were decreased proportions of reproductive tillers per plant as the time of sowings increased (Table 4.8). The same effect was observed as sowing rate increased. The changes in the proportion of reproductive tillers are due to the number of reproductive tiller per plant decreasing at a greater rate as sowing rate increases (Table 4.9) than the number of tillers per plants decreases (Table 4.11). From this finding it is understood that each times of sowing had reduced thermal time to expand new leaves to the same size proportion as the time of sowing before it as is had less tillers per plant. Therefore in time of sowing three the 2057 reproductive tillers/m$^2$ is made up from 37% of the tillers present while time of sowing two the 2110 reproductive tillers/m$^2$ is made up of 41% of the tillers that are present. This is also shown by the increasing number of total tillers (Table 4.5) as time of sowing increased while the number of reproductive tillers remained constant over times of sowing one through to three (Table 4.6). These findings are similar to that of Young et al. (1996) where in 1978 the fertile tillers of an annual ryegrass sward made up 68 % of the total tiller numbers in an un-grazed seed crop. Although a higher proportion of reproductive tillers was found by Young et al. (1996) an important function of perennial ryegrass is to continue to produce vegetative tillers to ensure its perenniality. Tillering in winter was important to build up tiller numbers ready for the spring growth as part of its annual cycle for pasture growth (Korte, 1986). It was found by Korte (1986) that winter provided a time for doubling tiller growth, however it was found that few tillers produced in winter became reproductive with tillers grown in spring being dominated by tillers grown in winter such as those formed in May, June, July and August.

Time of sowing four displayed a positive change in all plant populations/m$^2$ from the initial plant count 3 weeks after sowing to the final harvest when the >50% of reproductive tillers were at growth stage 32 or greater. The greatest increase in plant numbers was in time of sowing four with a sowing rate of 1000 plants/m$^2$, however there was no significant difference across time of sowing four. Due to the cold temperatures of June and July due to seasonal temperature fluctuations seed may not have germinated immediately after sowing as germination and emergence is closely related to temperature (Moot et al., 2000). Late emergence of plants in time of sowing four under the sowing rate treatment of 1000 plants/m$^2$ may have contributed to a low number of reproductive tillers per plant. The higher sowing populations (1000 and 1400 plants/m$^2$) on the earliest time of sowing had the highest plant death from establishment to the final harvest as a result of competition for light.

#### 5.3.2.3 Tiller weights

Earlier sowing of perennial ryegrass allows for more vegetative growth prior to vernalisation and the switch to reproductive growth. Better establishment and more leaf growth allow for better intersection of light which is used for photosynthesis and the production of carbohydrates. As a result of earlier times of sowings, tillers had increased vegetative growth per tiller than later times of sowings. Reproductive tillers decreased in dry weight with later times of sowing however there was no difference in the weight of individual reproductive tillers across all sowing rates for each time of sowing apart from the reproductive tillers in the sowing rate 1400 plants/m$^2$ of time of sowing two. This decrease in dry weight is due to a significant increase in the number of vegetative tillers in this treatment (Table 4.5, Table 4.7).

Reproductive tillers represent a small proportion of the total number of tillers/m$^2$, for example sowing rate 1000 plants/m$^2$ had 2975 vegetative tillers and only 2037 reproductive tillers/m$^2$ making up only 38% of the total number of tillers. As reproductive tillers weigh more than vegetative tillers, as a whole reproductive tillers make up the majority of the dry matter in the swards. Reproductive tillers by weight make up from 73 – 80 % of the total dry weight in each of the sowing rates with reproductive tillers making up 78% of the total dry weight in the sowing rate of 1000 plants/m$^2$. This was a similar result to Korte (1986) where reproductive tillers made up a total of 73% of the sward in weight.

As there was more vegetative tillers/m$^2$ (Table 4.7) it would be expected that the weight of vegetative tillers would increase on a per metre basis as sowing rate increased (Table 4.13). The same interaction for the dry weight of the reproductive tillers/$m^2$ (Table 4.14) and the dry weight of the total tillers/$m^2$ (Table 4.15) is due to the proportion of reproductive tillers that make up the total tillers/$m^2$.

# 6 Conclusion

The aim on this experiment was to see how time of sowing, sowing rate and grazing had an effect on the number of reproductive tillers produced. Finding a sowing rate and date that would produce a sward with plants that had a low number of tillers per plant but of the tillers produced, a high proportion of these would be fertile and reproductive with a target of over 2000/$m^2$ as to not limit seed yield.

Sowing a population density of 200 – 1000 plants/$m^2$ between 27$^{th}$ of March and the 8$^{th}$ of May will result in > 2000 reproductive tillers/$m^2$ at growth stage 32, with no significant difference in the proportion for reproductive tillers/plant although earlier sowings produced larger reproductive tillers as measured by mean tiller weight. However as sowing rate increased the number of vegetative tillers/$m^2$ also increased which resulted in a reduction of the proportion of reproductive tillers produced. Reproductive tillering per plant also reduced with later sowings, along with individual reproductive tiller weight.

There would be no benefit of using a high sowing rate such as to achieve a target population of 1400 plants/$m^2$, as a population this high resulted in increased self- thinning and resulted in many of the plants dying before reproductive development. Sowing a Perennial ryegrass seed crop as late as 28$^{th}$ of May regardless of population density, tillering could not compensate for lost thermal time in regards to the production of reproductive tillers.

# Appendices

Treatment Map

**Block 1 (rep 1)**

| TOS | 3 | 1 | 4 | 2 |
|---|---|---|---|---|
| Grazed | 200 | 1000 | 600 | 1400 |
| | 1400 | 1400 | 1000 | 200 |
| | 600 | 600 | 1400 | 1000 |
| | 1000 | 200 | 200 | 600 |

| TOS | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Ungrazed | 1400 | 1400 | 600 | 600 |
| | 1000 | 600 | 1400 | 200 |
| | 600 | 1000 | 1000 | 1400 |
| | 200 | 200 | 200 | 1000 |

**Block 2 (rep 2)**

| TOS | 4 | 1 | 2 | 3 |
|---|---|---|---|---|
| Ungrazed | 1000 | 1400 | 200 | 600 |
| | 1400 | 1000 | 600 | 200 |
| | 600 | 200 | 1000 | 1400 |
| | 200 | 600 | 1400 | 1000 |

| TOS | 2 | 4 | 1 | 3 |
|---|---|---|---|---|
| Grazed | 1000 | 600 | 200 | 1400 |
| | 600 | 1000 | 1400 | 1000 |
| | 200 | 1400 | 1000 | 600 |
| | 1400 | 200 | 600 | 200 |

**Block 3 (rep 3)**

| TOS | 4 | 2 | 3 | 1 |
|---|---|---|---|---|
| Ungrazed | 600 | 600 | 1400 | 600 |
| | 1400 | 1000 | 1000 | 1000 |
| | 200 | 1400 | 600 | 200 |
| | 1000 | 200 | 200 | 1400 |

| TOS | 3 | 1 | 4 | 2 |
|---|---|---|---|---|
| Grazed | 1400 | 600 | 1000 | 200 |
| | 600 | 1000 | 200 | 1000 |
| | 200 | 200 | 1400 | 600 |
| | 1000 | 1400 | 600 | 1400 |

**Block 4 (rep 4)**

| TOS | 3 | 1 | 2 | 4 |
|---|---|---|---|---|
| Ungrazed | 1400 | 1000 | 1400 | 200 |
| | 600 | 1400 | 1000 | 1400 |
| | 1000 | 600 | 600 | 1000 |
| | 200 | 200 | 200 | 600 |

| TOS | 4 | 2 | 1 | 3 |
|---|---|---|---|---|
| Grazed | 200 | 600 | 600 | 1000 |
| | 1400 | 200 | 1400 | 600 |
| | 1000 | 1000 | 1000 | 200 |
| | 600 | 1400 | 200 | 1400 |

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