The effects of basal frequency and nitrogen fertiliser application on *Phalaris aquatica* (cv. Grazier) dry matter production in the south-west slopes

A dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Agricultural Science with Honours

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21/09/2016
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Abstract

The high-rainfall temperate pasture zone of southern Australia is predominantly perennial grass based livestock production. Due to the high pasture establishment costs, management strategies increasing persistence is key to productive pastures. Phalaris (*Phalaris aquatica* cv. Grazier) is a cool-season, drought tolerant perennial grass commonly sown throughout these areas, known for its high production and persistence. Currently there are no benchmarks for basal frequency (% ground cover) of phalaris and the impact that it has on dry matter production in an established phalaris-based pasture.

A field experiment was conducted at Bringenbrong in the South-West Slopes of New South Wales in an established phalaris pasture. This study evaluated the effects of phalaris basal frequency and nitrogen fertiliser application on dry matter production. Four basal frequency treatments ranges (10-19%, 20-29%, 30-39% and 40-49%) and two nitrogen fertiliser treatments to simulate low and high fertility situations (3 applications of 46 kg N/ha at six-week intervals and a no nitrogen fertiliser control) were applied.

Basal frequency below 20% had a decreased phalaris yield whereas above 20% was within the optimum range for dry matter production. In swards below 20% basal cover where production has declined, it would be appropriate to consider resowing the pasture to improve pasture productivity. The accumulative yield of phalaris dry matter was 2.5 times higher under nitrogen fertilised conditions with an average of 9kg/ha of extra phalaris DM produced per kg of N/ha applied.

There was no response by clover and broad-leaf weeds to basal frequency treatments or nitrogen fertiliser application. However, the annual grass component had a significant response to fertiliser application with the accumulative dry matter yield of all species 3.1 times higher under nitrogen fertilised conditions, producing an additional 21 kg DM/ha for every kg of applied N/ha.

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1 Introduction

Successful pasture management in temperate areas requires an integrated approach of fertiliser inputs, grazing management, weed control and species selection. The components of a pasture are grouped into four main classifications, annual grasses, perennial grasses, legumes and other broadleaf species. A survey was conducted by Bowcher (2004) that identifies annual grasses to be a dominant species group throughout pastures in southern New South Wales. It was also identified that there were low incidences of perennial species and although subterranean clover (*Trifolium subterranean*) was commonly present, the majority of cultivars that were identified are no longer commercially available. This factor, combined with observations of low soil P levels, suggests low levels of pasture investments occurring through this region.

Although, annual species quite often dominate pastures throughout this region, perennial pastures would have positive benefits into these farming systems. Perennial species can assist in alleviating issues associated with land degradation, including soil acidity, salinity, erosion and also weed invasion. The increased ground cover, either green or residual, offered by perennial species helps protect the soil from both water and wind erosion (Bowcher, 2004), whilst limiting the bare ground exposed for weed invasion (Kemp & Dowling, 2000).

The higher rainfall (annual rainfall >600mm) perennial pasture zone in southern Australia is a major area for livestock production, with the majority of livestock being produced primarily on pastures (Kemp & Dowling, 2000). With high pasture establishment costs around $200/ha or more depending on soil fertility and weed burdens (Kemp & Dowling, 2000), producers are looking for more integrated management strategies to extend the productive lifetime of their perennial pastures. Weeds are defined as plants that occupy space that could be used by more beneficial pasture species (Michael, 1970). Weeds are a major economic problem in Australian agriculture and are estimated to cost $4.2 billion annually by a combination of reduced quality and yield of pasture, chemical control and resowing desired species (Jones, 2000). By understanding the effects that management has on pasture population dynamics, better decisions will be able to be made to help achieve more sustainable pasture systems.

This dissertation investigates the effects of phalaris basal frequency and nitrogen fertiliser use on the sward population characteristics and dry matter production at Bringenbrong in the south-west slopes of New South Wales.

2 Literature Review

2.1. Introduction

Pastures are the main feed source for livestock throughout southern Australia. Sown pastures are a significant component of Australian Agriculture, covering approximately 72 million hectares or 9.4% of Australia (Lesslie & Mewett, 2013). A combination of temperate perennial grasses, combined with legumes, can provide a sustainable grazing system for temperate (Figure 2.1) regions of south-eastern Australia (Anderson, et al., 1999). Unlike annuals, perennials are present after the growing season, which can increase both the quality and the amount of dry matter on offer, ultimately enhancing livestock production (Hill, 1985). Since the root systems are present all year round, perennials have the ability to respond faster to the autumn rain than annuals and in some species (depending on the dormancy level) dry matter out of season can be produced in response to sporadic rain events. Their deep-rooted systems enable more water to be utilised, aiding production gains, access to more nutrients for growth and reducing groundwater recharge and nitrate leaching (Reed, et al., 2008; Dear & Ewing, 2008; Dear, et al., 2009); whilst their continuous ground cover helps prevent environmental concerns like erosion and runoff (Cullen, et al., 2005b; Anderson, et al., 1999).

Figure 2.1. Map of Australia outlining the south-eastern temperate climate zone (shaded area) of Australia that typically experiences cool, wet winters and hot, dry summers. Source: (Bowcher, 2004).

Nitrate leaching decreases the pH of surface soil profiles, providing significant contribution to soil acidification and consequently also decreases the nitrogen (N) availability for the following season (Anderson, et al., 1998). One of the major benefits of reducing nitrate leaching in soils is slowing the soil acidification process (Dear, et al., 2009). Further, the established root systems of perennials are better able to utilise N at the break of season when mineral N levels are high and annual species are only beginning to germinate, having root systems incapable of capturing N (Ridley, et al., 1999). In a comparative study between the influence of perennial and annual species on nitrate leaching, Ridley et al. (1990) observed that nitrate leaching in phalaris pastures was lower than in annual pastures, further identifying the positive attributes of perennial grasses.

Studies have identified a perennials ability to aid prevention of dryland salinity by reducing the levels of groundwater recharge (Dear & Ewing, 2008; Dear, et al., 2009; Reed, et al., 2008). Dear & Ewing (2008) suggested that deep rooted perennials are able to dry the subsoil during the spring/summer dry period, creating a buffer of dry soil. This buffer is able to minimise leakage by absorbing unused water during winter when rainfall exceeds both plant demand and evaporation levels. However, traditionally many perennial cultivars haven't been able to survive the extended summer drought periods typical of many lower rainfall areas (<600mm/year) and consequently this has limited their use to pasture-crop rotations where they can be of particular benefit (Dear & Ewing, 2008).

The most widely used perennial grass species in the high rainfall region (>600mm annual rainfall) of southern Australia are phalaris (*Phalaris aquatica* L.), perennial ryegrass (*Lolium perenne* L.), cocksfoot (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea*), with the commonly sown perennial legumes being Lucerne (*Medicago sativa*) and white clover (*Trifolium repens*) (Reed, et al., 2008; Anderson, et al., 1999). All of these perennial species, have the ability to improve the productivity and sustainability of grazing systems in temperate regions. The levels of productivity from each species varies between studies depending upon the suitability of the species to the observed area, season present and soil fertility of the site. In comparison, studies have shown phalaris to be superior than other perennial species in terms of total herbage yield (Reed, et al., 2008). Ridley and Simpson (1994) identified that at the break of season in autumn, phalaris roots are more active when compared to those of other perennial grasses and consequently capture N more effectively.

2.2. Phalaris

Phalaris (*Phalaris aquatica* L.) is a cool-season, drought tolerant perennial grass species, utilised widely in temperate Australian pastures (Culvenor, et al., 2009; Cullen, et al., 2005a). It has a deep root system which enables more water and nutrients to be utilised for growth and also assists in reducing recharge and nitrate leaching (Reed, et al., 2008; Dear & Ewing, 2008; Dear, et al., 2009); whilst the continuous ground cover helps prevent environmental concerns like erosion and runoff (Cullen, et al., 2005b; Anderson, et al., 1999). More recently developed winter-active cultivars of phalaris have been able to consistently produce double the winter dry matter than the traditional Australian cultivar, helping to reduce feed gaps (Anderson, et al., 1999).

High growth rates and persistence are two of the most desirable characteristics driving phalaris popularity in sown pastures throughout south-eastern Australia (Virgona, et al., 2000). Another positive attribute for producers, is the ability of the deep rooted species to reduce deep water drainage and minimise nitrate leaching in soils (Ridley, et al., 1997; Ridley, et al., 1999), consequently improving the sustainability of the production system (Virgona, et al., 2000).

Phalaris has seasonal production, growing from autumn to spring, then becoming dormant over summer, however some growth in response to sporadic summer rainfall is possible. Population survival is predominantly by clonal spread and while limited, seedling recruitment can occur (Kelman & Culvenor, 2007). Seedling recruitment is the ability of the number of viable seeds to become established as seedlings.

2.2.1. Phalaris biology

Large quantities of phalaris plant material is sustained under the soil surface and can be divided into four components (Figure 2.2): old crown material, old reproductive tiller bases, rhizomes and roots (Cullen, et al., 2005a). Each component has a significant role in phalaris production and persistence.

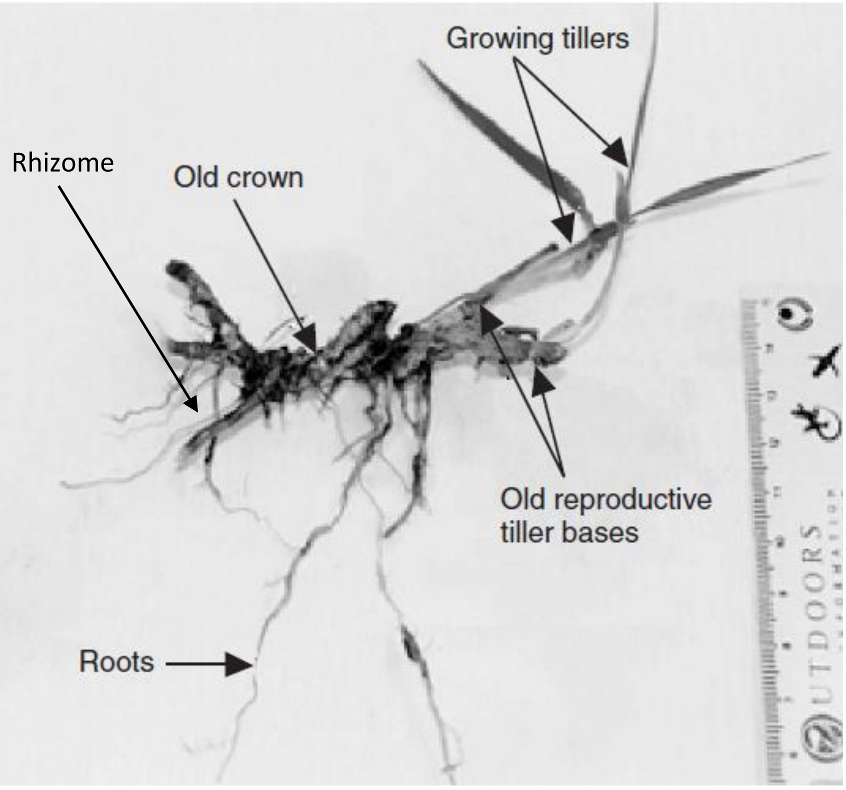

Figure 2.2: demonstrates some of the structural components of a phalaris plant. Source: (Cullen, et al., 2005a)

The reproductive tiller bases account for 26% of total underground phalaris mass (Cullen, et al., 2005a) and play an important role in plant regeneration after the autumn break. Reproductive tiller bases maintain the dormant buds over summer and provide a carbohydrate source for early stages of bud growth (McWilliam, 1968). These dormant buds develop leaf axils below the soil surface and can remain dormant for many months, even though the plant components above the soil surface have died from desiccation (Oram & Freebairn, 1984). Although, Lodge (2004) suggested that continuously grazed phalaris pastures are at risk of crown exposure over the dry summer period and consequently plant death can occur. The old crown material, found at the base of the old reproductive tiller, will not support new season growth but in previous seasons, these were responsible for sustaining growing tillers (Cullen, et al., 2005a). These old crowns account for 60% of the underground mass of phalaris components (Cullen, et al., 2005a).

Regenerative buds that survive the summer period grow out to form a primary tiller. Secondary tillers and new rhizomes both develop from axillary bud growth in the leaf axils of a primary tiller (Cullen, et al., 2005a). Cullen, et al., (2005a) identified that most of the axillary buds that grow out will form a new secondary tiller, however, some that exhibit downward growth will form a new rhizome instead. Culvenor & Oram (1993) described phalaris to be a weakly rhizomatous species. Furthermore, Cullen et al. (2005a) identified that only 8% of primary tillers produced a rhizome, accounting for only 3% of the total underground plant mass. It was also identified that grazing management had no influence on rhizome production.

Defoliation is a production constraint that is compensated for by multi-tillering, soluble carbohydrate reserves and low crowns (Virgona & Bowcher, 2000). Carbohydrate reserves within the tiller bases are used to support plant regrowth following defoliation or grazing and levels are only replenished after photosynthetic gains exceed plant utilisation (Lodge, 2004b). Whilst these reserves predominantly aid bud regrowth, bud survival is dependent on the availability of some soil water within the plants root zone (Hoen, 1968; McWilliam & Kramer, 1968). A study by Donaghy and Fulkerson (1997) in perennial ryegrass identified that the maximum level of water-soluble carbohydrates occurred when two to three leaves were fully emerged. It was found that waiting for the plant to reach the two to three leaf stage before defoliating increased the dry matter production and persistence of the pasture. However, it is not currently understood if phalaris operates in the same way and further research is needed to quantify this.

Frequency and intensity of defoliation has the ability to alter reproductive development in Phalaris. Hill (1989) identified that frequent (2 weeks), low (2cm from the ground) defoliation will delay reproductive development as this promotes immature tillers and minimal, if any, mature tillers will be present. It was also noted that under infrequent (4 weeks), high (7cm from the ground) defoliation conditions, there was an increase in dormant bud numbers at the base of reproductive tillers, aiding plant persistence. The significance of these findings can assist producers with sward management to aid reproductive development under various grazing systems.

Similar to other clonal plants, Phalaris is composed of one or more tillers (ramets in broad leafed species) which are genetically identical and formed by vegetative reproduction (Cullen, et al., 2005a). It has been identified that mature tillers are physiologically independent of one another (Noble & Marshall, 1983), however, it is possible for resource sharing to occur between the tillers and is particularly apparent during plant establishment (Colvill & Marshall, 1981). The resource sharing between defoliated and undefoliated tillers, and from mother to daughter tillers, improves establishment success and also promotes recovery following grazing or defoliation (Cullen, et al., 2005a). For phalaris in particular, resource sharing between tiller groups is minimised by vascular connection decay (Derner & Briske, 1998) which minimises the extent of resource sharing that is possible.

Seedling recruitment is becoming an increasingly important component of improving the sustainability of perennial pastures in challenging seasons. Minimal recruitment within swards has been reported for Phalaris (Virgona & Bowcher, 2000; Lodge, 2004a). It is suggested that the reason for poor recruitment is due to the competitiveness of annual species for light, water and nutrient resources which prevent establishment of phalaris seedlings (Virgona & Bowcher, 2000; Kelman & Culvenor, 2007). Other contributing factors are the large proportion of seed harvested by ants (Kelman, et al., 2002) and the short lifespan of the seedbank (Kelman & Culvenor, 2007). Improvement of cultivars through selective breeding can help improve seedling recruitment in phalaris. A 3-year study by Kelman & Culvenor (2007) identified that phalaris dispersed an average of 4600 seeds/m^2, with up to 11000 seeds/m^2 dispersed in some instances. However, emerged seedlings only accounted for 1-2% of the seeds produced and of that, only 3-5% of seedlings became established plants. Seed retention and panicle (Figure 2.3a) shattering are both distinct factors that influence seed dispersal mechanisms in phalaris (Kelman & Culvenor, 2003). The seed dispersal mechanism is predominantly influenced by the intactness of the rachillas (Figure 2.3b) and also shattering of the panicle (Kelman & Culvenor, 2003). Development of seed retaining cultivars aims to both thicken the rachilla, keeping it intact and therefore retaining the seed, and also incorporate seed-retaining panicle fragments (Kelman, et al., 2002; Kelman & Culvenor, 2003). In varieties with seed-retaining panicle fragments, Kelman et al. (2002) found that ants were unable to remove the seed from the panicle, resulting in reduced seed waste caused by ants.

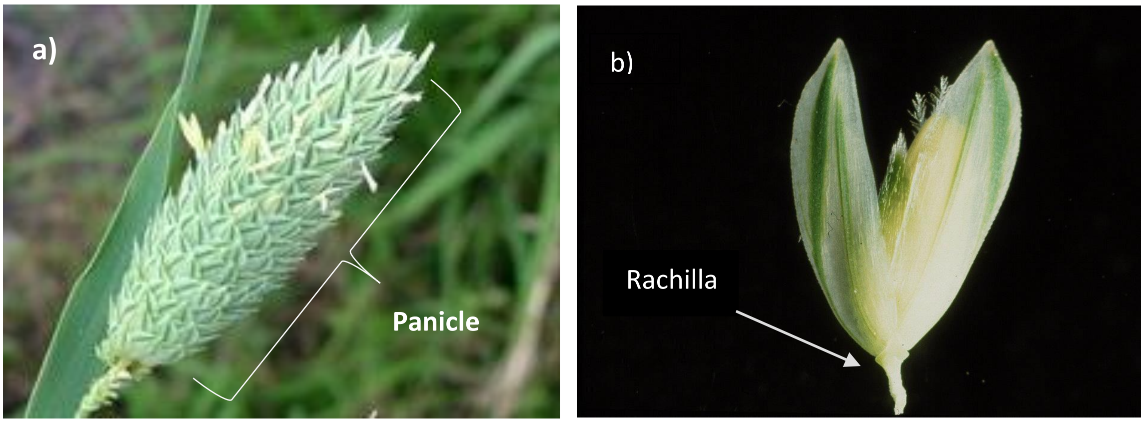

Figure 2.3.Diagrams identifying two components of phalaris seed head morphology. The panicle (a) and the rachilla (b). Modified from (Navie, 2016; Watson & Dallwitz, 2015).

2.2.2. Phalaris cultivars

Australian was the original phalaris cultivar sown in Australia and is known for its persistence under heavy grazing, particularly during drought seasons in regions where it is established (Culvenor, 1994; Culvenor, 1993; Culvenor & Oram, 1996). However, some of the disadvantages of the cultivar include poor seedling vigour and low growth rates during winter (Culvenor, 1993). More recently, winter-active cultivars (e.g. Sirosa, Landmaster, Holdfast, Sirolan) have been developed, with selection emphasis on faster seedling growth and more dry matter production during the cooler months (Culvenor, 1993; Oram & Culvenor, 1994). The newly developed cultivars vary morphologically when compared to the traditional Australian variety, having a growth habit that is more erect, has larger tillers and less spreading (Culvenor & Oram, 1996).

Studies confirm the winter-active cultivars, have approximately doubled the winter yield of Australian phalaris (Anderson, et al., 1999; Oram & Freebairn, 1984). These winter-active cultivars are more suited to areas that are hotter and drier as the earlier, more synchronous flowering of these cultivars will improve summer survival (Oram & Freebairn, 1984). However, a more synchronous flowering decreases grazing tolerance during reproductive development which can result in decreased persistence due to the removal of reproductive tillers (Culvenor, 1993).

Sirosa and Sirolan are similar cultivars in terms of total dry matter production, winter-activity, seedling vigour and persistence. However, Sirolan varies morphologically from Sirosa, having early synchronous flowering, larger seedlings and fewer, thicker and more erect vegetative tillers (Hill & Watson, 1989). Currently there is little research on the effects of tiller morphology on basal frequency. Anderson et al. (1999) observed that Sirosa had higher yields across all years and sites compared to the Australian variety. It was also noted that there was no difference in seedling vigour between the varieties, attributing the difference in growth to improved winter-activity. Haling et al. (2010) found that Sirosa had a higher seedling vigour than Australian in acidic soils, even though both cultivars have the same acid tolerance levels.

Cultivars such as Landmaster and Advanced AT are superior when compared to other varieties in acidic soils. These varieties have been observed to tolerate over 30% exchangeable Al and $CaCl_2$ pH of lower than 4.2 (Culvenor, et al., 2011). These findings indicate that these varieties would be more suited to acid soils than tall fescue, which is traditionally known to be more acid tolerant than phalaris.

Uneta is a variety that is similar to Australian with its high grazing tolerance, prostrate growth habit and high overall persistence. The main advantage of Uneta over Australian is its markedly improved seed retention capabilities. Seed retention will assist in seedling recruitment and consequently aid the improvement of the persistence and sustainability of the sown pasture.

Although the new cultivars have the ability to increase winter production, grazing management must also be altered to favour the growth and persistence of these cultivars. Under grazing systems that desire continuous heavy set stocking over winter, there will be no real benefits of sowing a winter active cultivar instead of the traditional Australian type variety (Hill, 1989).

2.3. Phalaris Production

2.3.1. Dry Matter Production

The carrying capacity of a sown pasture is calculated by the herbage production and seasonal growth (Anderson, et al., 1999). Regions with cool winters, have decreased stocking rates in the winter period due to the lack of pasture production; however, winter active cultivars of phalaris have been noted to help increase winter productivity (Anderson, et al., 1999). A field study by Anderson et al. (1999) observed winter active cultivars to produce between 1.5 - 3t DM/ha over winter and annual yields of 2.7 - 6.8t DM/ha, with winter growth accounting for approximately 40% of annual growth across experimental years. In the traditional cultivar, Australian, winter growth only accounts for approximately 26% of annual growth with annual yields for the experimental years ranging 2.4 - 5.2t DM/ha.

Biomass of phalaris can be expressed as a product of tiller dry weight and tiller density (tillers/m^2) (Cullen, et al., 2005b). An increase of either component would be expected to increase the overall biomass of the sward. However, Cullen et al. (2005b) found a negative linear correlation (slope= -0.71) between tiller density and tiller weight, highlighting that as tiller numbers increase, tiller weight will decrease. These observations are attributed to size density compensation which controls tiller density in accordance to the maximum level for light competition and subsequently maximises photosynthetic potential (Matthew, et al., 1995). A study by Hill & Watson (1989) identified that as defoliation interval increased, tiller number and dry matter yield also increased (Figure 2.4). Although individual tiller weights are not given, this data suggests that yield will increase as tiller numbers increase and therefore proposing the effects of size density compensation to be minimal. The reason for this is likely due to the sward canopy not being at the maximum level of light interception, therefore producing minimal shading. These contrasting results demonstrate the need for further study to identify the relationships between tiller characteristics and phalaris dry matter yields.

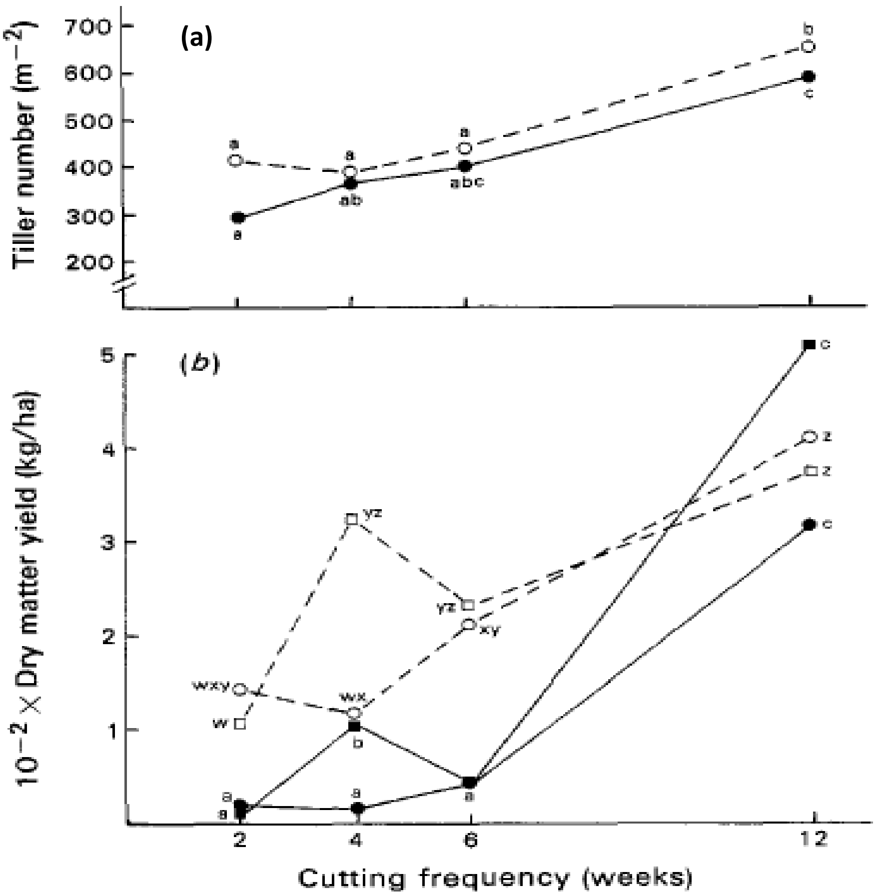

Figure.2.4: (a) The effect of cutting frequency on tiller numbers recorded for first (●) and second (○) regrowths in 1987. (b) Effect of cutting height and defoliation interval from first (solid lines) and second (broken lines) regrowth periods in 1987. Cutting heights are 2cm (●,○) and 7cm (□,■). Letters indicate significant differences at P=0.05. Source: (Hill & Watson, 1989).

2.3.2. Grazing Response

Defoliation is a physical constraint to growth and plant persistence. Pasture grasses have many adaptations to compensate grazing or defoliation, and these include: low crowns, multi-tillering and soluble carbohydrate reserves (Virgona & Bowcher, 2000). Interactions between defoliation and phenological development have identified that defoliation during the stem elongation and ear emergence growth stages may minimise dormant bud development. Therefore, this would reduce crown size, minimise both bud size and number and also reduce carbohydrate accumulation in stem bases (Culvenor, 1994; Kemp & Culvenor, 1994; Hill, 1989), ultimately reducing plant survival rates. Heavy grazing during spring can result in removal of the apex from elongating tillers. Proceeding this, further growth of those plants can only occur by new tiller growth from axillary buds.

Carbon resource sharing between tillers originating from the same regenerative bud enhances new tiller establishment and defoliation recovery at the expense of carbon allocated to the roots which is vital for summer survival (Cullen, et al., 2005a). For the first few days post-defoliation, regrowth is rapid utilising all of the available carbohydrate reserves. Once these reserves are depleted, the plant must rely on photosynthesis for growth, which is limited by the reduced leaf area available for light interception for photosynthesis (Cullen, et al., 2006). The primary tiller retains the highest percentage of carbon and supplies carbon resources to aid in establishment of secondary tillers and fed tiller roots (Cullen, et al., 2005a). As pasture mass increases, the photosynthetic capacity of the plant is increased, subsequently increasing growth and rebuilding the carbohydrate reserves.

Both frequency and height of defoliation impact production and persistence of phalaris. Culvenor et al. (1994) found that fortnightly defoliation throughout spring reduced autumn growth the following year. Since there was no increase in mortality, it is likely that the smaller plant size caused by frequent defoliation would reduce growth the following autumn growth. A smaller plant size would consequently reduce shading and competition which would enhance tiller survival (Langer, et al., 1964). Similarly, Hoen (1968) identified that under frequent cutting, those plants were still able to survive a 3-month summer drought, however, survival rates significantly decreased when the drought period was extended. In addition to high frequency, Hill (1989) documented that low (2cm) defoliations severely impacted leaf area and total dry matter production and crown size when compared to high (7cm) cutting.

Grazing type also has the ability to affect botanical composition. Chapman et al. (2003) found that rotational grazing favoured phalaris production and subsequently reduced clover growth. The reduction in clover presence is a product of the high competition of the established phalaris after the break of season when the clover is germinating. In comparison, set stocking favoured clover growth and phalaris presence was reduced. This is attributed to the high grazing tolerance of clover and low persistence of phalaris under heavy grazing pressure (Cullen, et al., 2005b). It was observed that under rotational grazing there was an additional 1000-3000 kg DM/ha of phalaris produced when compared to set stocked pastures. However, the set stocked pastures produced an additional 1000 kg DM/ha of clover due to the altered botanical composition of the pasture.

Grazing frequency in a rotational grazing system can influence the subsequent production of the plants. Culvenor (1994) found that defoliation at 2 week intervals during spring, reduced regenerative growth by up to 65%, however, minimal plant deaths were associated with frequent cutting. This study also suggested a long rotational grazing cycle has the potential for damage when swards are able to produce large amounts of dry matter leading to low tillering rates and death of small tillers due to shading and competition. The reduced range of tiller ages causes the sward to be more synchronous at stem elongation (first phase of reproductive development), increasing the risks of reducing regrowth ability and subsequent persistence. Grazing of young vegetative tillers during early spring can help combat this problem by encouraging multi-tillering, increasing tiller density and also increasing the range of tiller ages.

2.3.3. Phalaris Response to Nitrogen

Carbon and nutrient levels in plants produce common limitations for plant growth. Defoliation in pastures limits C supply through reduced leaf area, whereas nutrient supply is dictated by soil nutrient availability (Cullen, et al., 2006). Chapin et al. (1987) identified that in order for a plant to acquire nutrients, there is a carbon cost and vice versa. In conjunction with grazing management, both soil and climatic factors can play a role in phalaris production and persistence. Subsoil acidity has the potential to reduce root extension at 1-2m depths (Cullen, et al., 2005b), which will reduce phalaris survival in dry conditions. The loss of phalaris plants will have significant implications for sustainability of the pasture as it allows weed invasion.

Maintaining adequate soil nitrogen levels is required for high levels of pasture production in southern Australian soils. Phalaris production gains from improving soil fertility have been found to exceed production gains made from grazing management strategies (Chapman, et al., 2003). High inputs of fertiliser on phalaris pastures enables farm production to significantly increase through an increase of pasture growth, consequently aiding profitability from increased stocking rates in high-rainfall zones (Chapman, et al., 2003). However, increased fertiliser use and higher stocking rates are likely to favour introduced species over native species because pastures are typically responsive to improved soil fertility and are more grazing tolerant (Hill, et al., 2004).

The study by Hill & Watson (1989) identified the addition of nitrogen fertiliser can significantly improve dry matter yield (Figure 2.5). It can be identified that with the addition of N fertiliser under a 4-week defoliation interval, the maximum dry matter yield is approximately three times the yield of unfertilised plants. Under conditions with no nitrogen fertiliser, it can be expected to have a substantially reduced stocking rate due to the lack of herbage mass available for grazing. The advantage of higher cutting height allows more leaf area available for photosynthesis.

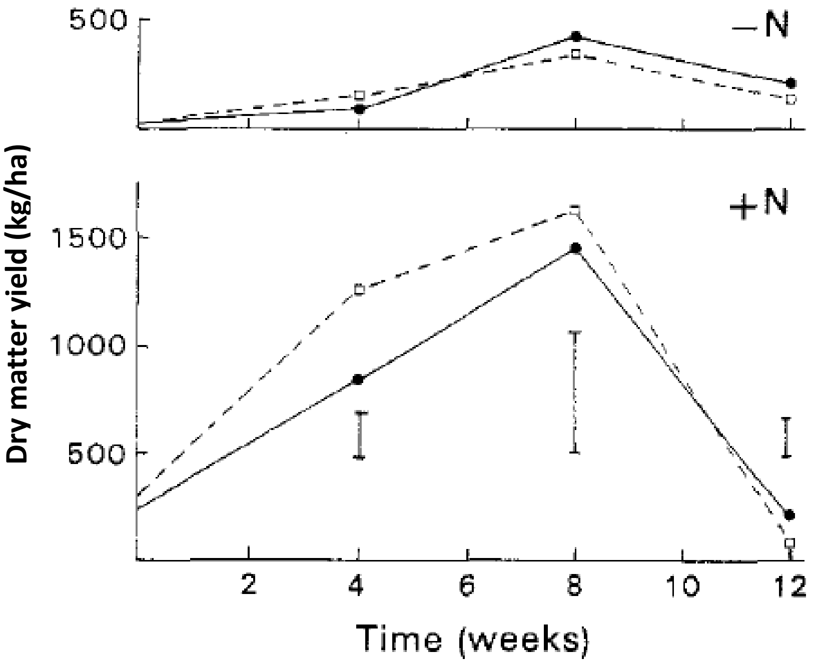

Figure.2.5: Dry matter production pattern for a 4-week defoliation interval during spring with (+N; 100 kg N/ha applied 12-weeks prior to each cutting cycle) and without N (-N) fertiliser application. Two different cutting heights were measured at Bunnan NSW; ● 2cm, □ 7cm. Bars indicate l.s.d. values at a 5% significance level. Source: (Hill & Watson, 1989).

The response of plants to phosphorus often depends on the amount of nitrogen present in the soil (Rossiter, 1964). Under low nitrogen conditions, clover is more responsive to the addition of phosphorus fertiliser due to the nitrogen fixation ability of the plant. Whereas, under high nitrogen conditions, grasses and broadleaf species are favoured.

2.3.4. Soil acidity

Perennial grasses such as cocksfoot and tall fescue are traditionally known to be more tolerant of acid soils than phalaris; However, the more recently developed acid tolerant cultivars of phalaris (Advanced AT and Landmaster) are found to be more acid tolerant than tall fescue varieties and similar in tolerance to cocksfoot (cv. Currie) (Haling, et al., 2010).

Soil acidity and the associated aluminium (Al) toxicity, is responsible for inhibiting root extension, consequently reducing water and nutrient uptake resulting in reduced plant growth (Culvenor, et al., 2011). Multiple studies have confirmed that phalaris is sensitive to the Al present in highly acidic soils (Ridley, et al., 1990; Ridley, et al., 2002; Li, et al., 2004; Ridley & Coventry, 1992; Coventry, et al., 1987). Ridley et al. (2002) identified soil acidity to be a major factor in relation to both poor emergence and persistence of phalaris throughout medium to high rainfall zones of southern Australia.

Earlier recommendations suggest phalaris is unsuitable for growth in soils where exchangeable Al exceeds 10% and pH in $CaCl_2$ is less than 4.9 (Culvenor, et al., 1986). Results from the study by

Culvenor et al. (2011) identified that previous advice is too conservative with all cultivars successfully tolerating 20% exchangeable Al and a $CaCl_2$ pH as low as 4.2. This study also concluded that newly developed cultivars have even greater acid and Al tolerance, tolerating around 30% exchangeable Al and $CaCl_2$ pH values below 4.2. Cultivars such as Landmaster and Advanced AT are superior to other varieties in acid soil (Culvenor, et al., 2011).

Lime application is effective at ameliorating acid soils, however, in an established pasture there are incorporation difficulties. The movement of lime into the soil beyond incorporation can take decades (Li, et al., 2006). Altering the soil pH with lime application affects a range of nutrient availabilities; not only will it reduce the amount of Al and manganese (Mn) available to levels that aren't toxic, but it will also increase available calcium (Ca), molybdenum (Mo) and phosphorus (P) (Ridley & Coventry, 1992). Pasture yield responses to lime have been measured up to a 20% increase in DM production (Scott & Cullis, 1992). For subterranean clover, which is commonly sown with phalaris in acidic soils, yield responses to lime are caused by alleviation of Mn toxicity and improved nodulation (Coventry, et al., 1987).

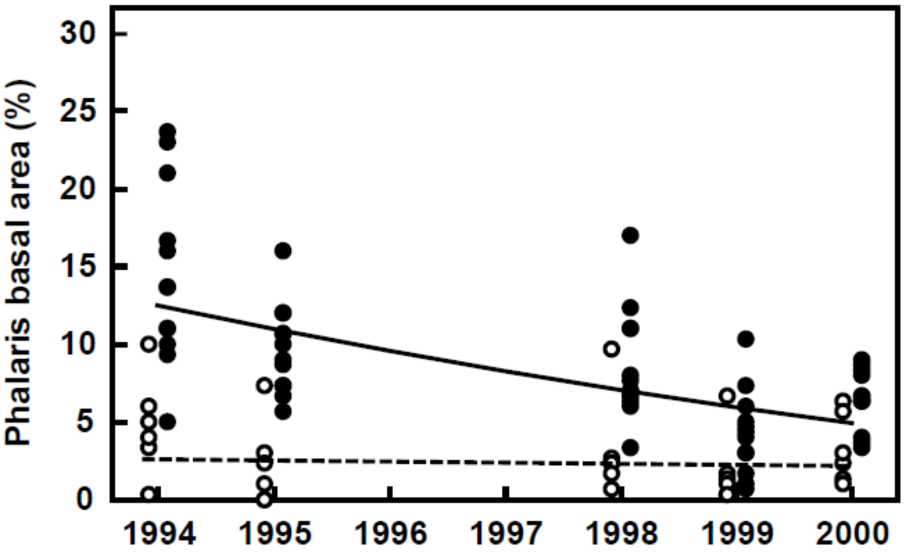

Figure 2.6: Phalaris basal area (%) in pastures from 1994 to 2000 under limed treatment (●) and unlimed (○) treatment. Cubic smooth splines represent the limed (solid line) treatment and unlimed (dashed line) treatments. Source: (Li, et al., 2003)

Studies have identified that lime application is beneficial for establishment and persistence of phalaris in an acidic soil, however, the subsoil acidity could limit long-term persistence and decrease basal area (% plants present in squares of a grid) over time, Figure 2.6 (Li, et al., 2004; Li, et al., 2003). A combination of lime application with improved cultivar tolerance has been recommended for acidity management in phalaris (Scott, et al., 2000).

2.3.5. Quality

The quality or composition of livestock diets is determined by the supply of energy and nutrients ingested and measured as digestibility (%), metabolisable energy (ME) (MJ/kg DM), crude protein (CP) (g/kg DM) and fibre (g/kg DM) content, with additional mineral and vitamin components. Digestibility is a major component of nutritive value as it influences livestock grazing (Anderson, et al., 1998; Cox, 2013). Digestibility measures the amount of feed retained and utilised by the animal. Digestibility decreases as fibre content increases, which is particularly apparent with plant maturation (Cox, 2013). Anderson et al. (1999) suggested that maintaining high digestibility for prolonged periods, especially during maturation, will improve the nutritive value of pasture species.

Phalaris nutritive values vary considerably throughout the year due to the varied structural composition and growth stages (Anderson, et al., 1999). Over summer during the dry period is when nutrition is the lowest due to the lack of new growth occurring and the senesced herbage available. Neutral detergent fibre (NDF) averages 58% of DM, metabolisable energy (ME) averages 9 MJ/kg DM and crude protein (CP) is 20% of DM on average (Greenwood, et al., 2006). Anderson et al. (1999) found that digestibility of phalaris was also the lowest during this period at 61.3%. The poor quality of feed on offer during this period affects livestock production and often supplementary feeding is required. In particular, young classes of livestock are unable to consume enough nutrition for sustained growth due to both the reduction of feed on offer and also the minimised capacity of their rumen to digest low quality fodder (Walsh & Birrell, 1987). After the break of season during vegetative growth stages, phalaris is of the highest nutritive quality. NDF averages 42% of DM, ME averages 12.3 MJ/kg DM and crude protein CP is 32% of DM on average (Greenwood, et al., 2006). Anderson et al. (1999) found phalaris to have the highest digestibility (85.7%) in September when compared to other perennial grass species. These increases in feed quality can improve grazing productions by improving the carrying capacity of the pasture and reducing the need for supplementary feeding. As the plant begins to mature and senesce toward the end of the growing season in late spring/early summer, the nutrition of these swards begin to decline.

Water-soluble carbohydrate content of plants is an important factor of diet selection by ruminants (Ciavarella, et al., 2000). Ruminants appear to select herbage with higher water soluble carbohydrate content and have higher intakes of the dry matter when compared with low water soluble carbohydrate vegetation (Leury, et al., 1999). Phalaris carbohydrate levels are low throughout both winter and summer (approximately 6%) and high in autumn and spring (approximately 8%) (Walsh & Birrell, 1987).

Variances in phalaris basal frequency in an established pasture resulted in a change in botanical composition (Culvenor & Oram, 1996). A study assessing phalaris basal frequency under grazing by Culvenor et al. (1996) identified that as phalaris dry matter (kg DM/ha) declined, both clover and other grass production increased. An increase in botanical composition of the pasture will consequently alter the quality of the feed on offer and implicate livestock production. Legumes are considered to be nutritionally superior for ruminants when compared to grasses (Walsh & Birrell, 1987). Subterranean clover is found to have less fibre and a higher proportion of water-soluble carbohydrates when compared to phalaris. Further, during late spring and summer clover is able to maintain a higher CP amount than grasses; however, during autumn and winter, the prostrate growth habit whilst establishing presents difficulties for grazing (Smith, et al., 1972). This evidence suggests there is potentially a quality trade-off that is able to occur as phalaris basal frequency is reduced and clover basal frequency increased. Further study would be necessary to quantify this relationship.

2.4. Persistence

Persistence is an important trait to ensure the longevity and profitability of a perennial pasture (Culvenor & Simpson, 2014). Persistence is described as the ability of a plant to survive and adapt to an area while tolerating grazing pressure, seasonal variation and possible pests and diseases (Anderson, et al., 1999). The shift toward more intensive and productive land use has caused increased pressure on persistence for common perennial grasses, such as phalaris, cocksfoot, perennial ryegrass and tall fescue. Often these species are failing to persist for enough years to provide producers a good return on their pasture establishment investments (Virgona & Bowcher, 2000). Degraded pastures can be resown, however, high pasture establishment costs suggest that extending the productive life of the pasture would be more economically viable (Culvenor & Simpson, 2014). Virgona et al. (2000) suggested that the major factor driving pasture profitability is increased stocking rate throughout the productive lifetime of a pasture.

In perennial grasses, the maintenance of a population requires that tillers be replaced in the subsequent growing season (Cullen, et al., 2005c). This predominantly requires dormant bud production or in some cases seed production prior to the end of the growing season. For phalaris, sensitivity to grazing will increase as the proportion of reproductive tillers increases (Culvenor, 1994). This is particularly apparent for cultivars that have synchronous reproductive development (Hill & Watson, 1989). When tillers are cut or grazed at early booting or anthesis, those plants are more prone to sprouting in summer during the dormant phase. If these new tillers die before the autumn break of season or before they form viable buds, this will cause a decline in persistence (Culvenor, 1994).

The high temperatures and low moisture availability innate to Australia during summer, are generally unsuitable for plant growth increasing the importance of summer survival mechanisms. After seed set or bud formation, persistence then will depend on the vigour of the seeds or buds the following season (Culvenor, 1994). Growth potential for the following season is calculated by the number of buds present at the beginning of the summer drought, however, sporadic rainfall events can cause tillers to form their own buds if sufficient growth occurs (Culvenor, 1993) subsequently increasing the growth potential. Evidence from the study by Cullen et al. (2005c) shows that from the bud sites that produce primary tillers, 71% of these tillers proceeded to produce higher order tillers, highlighting the importance of buds for tiller regeneration.

In an established phalaris pasture, direct counts of plant numbers per metre squared are an unreliable measurement as a result of the difficulties identifying boundaries between individual plants. Whereas, basal cover (percentage of ground cover occupied by a species) is more suitable as it accounts for a combination of number and size of plants, although these two factors cannot be separated (Virgona & Bowcher, 2000). The decline in phalaris populations is difficult to reverse due to the lack of seedling recruitment occurring within the species. Virgona et al. (2000) suggests that the phalaris population at establishment is at the maximum density and the rate of decline is the product of environment, management and genotype. In cases where an obvious decline in a phalaris population occurs, management strategies need to be adjusted to focus on favouring phalaris over other species (Virgona, et al., 2000). Such strategies often include spelling the pasture or destocking, which would result in a loss of livestock production.

The study by Virgona & Bowcher (2000) suggests that the ability for phalaris to maintain basal cover, increased with an increasing grazing interval. In treatments where grazing frequency was short and the plants had minimal recovery time, the basal cover was reduced to approximately 76% of the population present the previous spring. Similarly, Hill et al. (2004) found that lenient grazing regimes resulted in increases of phalaris basal area. Whilst it is understood that basal area declines under different grazing management regimes, further study is required to identify the effects of different basal areas on biomass production and also how this influences the quality of the pasture as a whole. Understanding this will assist management decisions to identify both the optimum basal frequency targets and also the level where pasture production is lost and rejuvenation is required by either over-sowing or re-sowing.

Recruitment is becoming an increasingly important factor for phalaris persistence since mechanisms for survival of existing plants are becoming reduced under certain environmental conditions. Many studies have suggested that seedling recruitment is infrequent within an existing phalaris sward and few new established plants were a product of this (Virgona & Bowcher, 2000; Lodge, 2002; Lodge, 2004a). Groves et al. (2003) identified that in cases where seedling recruitment occurred, the competitiveness of the seedlings were low when compared to annual species and this consequently impacted seedling survival. Seedling recruitment is determined by available seeds and suitable microsites, nutrients and climatic conditions; addressing these factors successfully would assist phalaris survival and consequently improve the sustainability of the system (Thapa, et al., 2012).

2.4.1. Dormancy

During summer, the phalaris plants are dormant while conditions are unfavourable for plant development. Summer survival is dependent on plants maintaining a deep root system providing a stable water supply (Cullen, et al., 2005c) and the development of dormant regenerative buds on the swollen bases of reproductive tillers (Culvenor, 1993; Hoen, 1968; McWilliam, 1968). The development of dormancy in these buds is a continuation of apical dominance, followed by suppression of bud growth caused by the environment (Hoen, 1968).

Defoliation or grazing during reproductive development can reduce the number of regenerative buds produced per tiller (Hill, 1985; Culvenor, 1994). Continual grazing (i.e. tiller decapitation) throughout reproductive development will decrease bud numbers per tiller (Figure 2.7). Whereas, ungrazed or intact vegetative tillers have more buds per tiller after a grazing occurrence during reproductive development. Under fortnightly defoliation during spring when reproduction was occurring, there was no significant difference between intact or decapitated tillers. The frequent defoliation of tillers meant that cutting occurred after only limited stem elongation. These decapitated tillers will still have buds developing at their base and they will react like ordinary axillary buds released from apical dominance and will grow out immediately, consequently reducing bud numbers (Hill & Watson, 1989). However, in contrast, Cullen et al., (2005c) found that grazing management had no significant impact on bud numbers and suggests that physical cutting protocols places more defoliation pressure on the plants compared to grazing. This is likely caused by grazing stock not consuming forage as closely to the crown as what cutting procedures do.

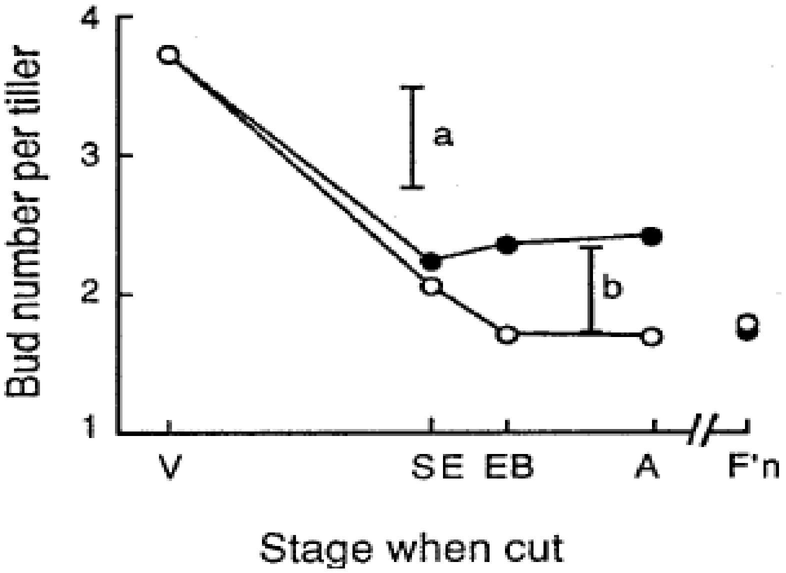

Figure 2.7. Number of buds per decapitated (○) and intact (●) tiller across averaged data from 5 phalaris cultivars. Each plant was cut once at four stages of development (V= vegetative, SE= stem elongation, EB= early boot, A= anthesis) and also fortnightly (F'n) during spring. Bar (a) shows l.s.d. for intact tillers only and bar (b) shows l.s.d. for comparison of intact and decapitated tillers at three reproductive stages (SE, EB and A). Source: (Culvenor, 1994).

Although buds can remain dormant for many months after the above ground plant components have desiccated (Hoen, 1968; McWilliam & Kramer, 1968), the essential factor for bud summer survival is water availability in the root zone. McWIlliam & Kramer (1968) found that buds on dormant plants died when roots were severed in the dry soil above the water source. Similarly, Hoen (1968) found that adding subsoil water doubled summer survival of the Australian cultivar, suggesting that drought resistance during the dormant period is more dependent on avoiding, opposed to tolerating bud desiccation. Once temperatures cool and water availability increases in autumn, the plant breaks dormancy and allocates resources to enable reestablishment of leaf area for photosynthesis (McWilliam, 1968). In spring, resources are then allocated for reproductive development prior to the summer dormancy phase (Cullen, et al., 2005a).

A proportion of buds (80% in controlled conditions and 50% in field conditions) were found in the study by Cullen, et al., (2005c) to remain dormant over the growing season. Approximately 20% of these dormant buds were still viable, as when placed under warmer conditions, they grew. The removal of growing tillers and buds in the study appeared to stimulate development of previously dormant buds. This evidence suggests that phalaris plants have a reserve mechanism in place for conditions such as false breaks. However, no regenerative buds survived over two summers during the study. Buds are typically only able to survive on tiller bases for 12 months after the reproductive tiller is formed and since buds form prior to commencement of reproductive tillers, their lifespan is approximately 18 months (Cullen, et al., 2005c).

The lifespan of buds is important for regeneration and consequently, extending the lifetime of bud viability may be beneficial for improved sustainability of the pasture. In cases where summer rainfall is sufficient enough for phalaris tillers to mature, these tillers will be smaller than those elongating in spring and will have lower carbohydrate reserves due to the elevated temperatures (Culvenor, 1993). Therefore, Culvenor (1993) suggests a high summer dormancy is also necessary for the persistence of phalaris.

2.4.2. Grazing effects on persistence

Grazing systems need to be constructed to favour phalaris persistence, avoiding grazing during sensitive periods. The critical period for grazing of phalaris is during reproductive development, predominantly between stem elongation and ear emergence (Kemp & Culvenor, 1994). However, the level of sensitivity to defoliation or grazing during this time is dependent on the cultivar and the environment (Virgona, et al., 2000; Culvenor, 1994). During early stem elongation, the tillering response to cutting was identified as a delay in new tiller appearances, and cutting during late stem elongation resulted in tillers appearing more rapidly across all cultivars (Culvenor, 1994). This is attributed to a suppression of axillary bud activity during the early stem elongation phase. Managing grazing to avoid slowing regenerative growth would be recommended to increase phalaris productivity and persistence.

Plant populations which survive periods of extended heavy grazing display morphological changes such as higher tiller number, more prostrate growth habits and often later flowering (Culvenor, et al., 2009; Hazard, et al., 2006; Smith, 1998), however in some cases, flowering was earlier (Liu, et al., 1999; Hacker, 1987). In a trial selecting phalaris plants for grazing tolerance, Culvenor et al. (2009) concluded that there was a 6-7% decline in individual plant yield per selection cycle as a result of grazing pressure and it was suggested that a higher original plant density could compensate for this yield loss.

Adaptation to higher grazing intensity is correlated with increased tiller numbers (Culvenor, et al., 2009). Furthermore, a higher proportion of vegetative tillers with apices below the ground will improve grazing tolerance as the tillers are able to maintain growth. This is mostly due to the synchronous reproductive development of winter active cultivars, which provide the opportunity for apex removal by grazing during spring (Culvenor, 1993). Culvenor (1993) observed that at anthesis, the traditional Australian cultivar has approximately 40% more tillers than Sirosa when subjected to the same defoliation regime. However, it has been observed that tillers from winter active phalaris cultivars have higher vigour than tillers from the Australian cultivar (Hill, 1989; Hill & Watson, 1989).

Different grazing systems will provide varied defoliation patterns on plants, potentially affecting bud numbers and regenerative ability (Cullen, et al., 2005c). When comparing rotational grazing to set stocking systems, there are many positive and negative factors to each system which influences managerial decisions. Rotational grazing is found to commonly benefit herbage mass opposed to basal frequency (Virgona, et al., 2000; Cullen, et al., 2005b). Studies have found that rotational grazing systems will favour perennial plant survival when compared to the same rate of set-stocking (Virgona, et al., 2000; Cullen, et al., 2005a). This is predominately due to the plants ability to regrow between grazing periods allowing for carbohydrate reserves to be replenished in preparation for summer dormancy. Due to the selective grazing nature of livestock, the vegetative tillers are selected prior to reproductive tillers in phalaris due to their increased palatability (Culvenor, et al., 1996). In comparison, Hill et al. (2004) identified that a low set-stocking rate can achieve the same outcome of perennial grass presence, but at the cost of decreasing animal production per hectare.

The different cultivars can also vary in tolerance to each grazing system. For example, phalaris cultivars with non-synchronous heading, such as Australian, will always have a portion of vegetative tillers on offer enabling these to be preferentially selected by stock and therefore allowing the reproductive tillers to avoid being grazed (Hill & Watson, 1989; Culvenor, 1994). This cultivar will therefore be better able to persist under set stocking regimes in comparison to a synchronous heading phalaris variety.

Fixed application of either grazing method can create many limitations for both animal and pasture production as each of the grazing methods cannot satisfy optimum production under all conditions and seasons (Chapman, et al., 2003). Using the two grazing methods interchangeably to suit both the pasture system and livestock production can help improve the productivity and sustainability of grazing systems.

2.5. Conclusion

Production and persistence are the two major factors concerning the use of phalaris throughout the high rainfall regions of south eastern Australia. A combination of improved cultivars, improved grazing management strategies, reduced soil acidity and the use of N fertilisers all contribute to the improvement of both persistence and production of phalaris.

Whilst there are many studies identifying that maintaining sward density is important for persistence, there has been little work done to identify what is considered a good density in an existing phalaris stand. From a management perspective, it is valuable to know what is considered to be a good sward density to maintain for optimum production and at what point plant production has declined to the point where rejuvenation or resowing is necessary. Evaluating the relationships between both basal frequency and nitrogen fertiliser application on phalaris dry matter production would assist in better management decisions.

3 Materials and Methods

3.1. Experimental site

The experimental site was located on the property of Tooma station at Bringenbrong (-36.157505 S, 148.050729 E; 920mm average annual rainfall; elevation 286m) in the South-West Slopes of NSW. The soil at the site is characterised as a yellow sodosol (Figure 3.1). These soil types are typically high in sodium content at depth and have an abrupt increase in clay.

Figure 3.1.The soil profile to 50cm depth at the Bringenbrong field trial site, April 2016.

The field site had a very low pH ($CaCl_2$) of 4.3 and also a high exchangeable aluminium percentage at 14% (Table 3.1).

Table.3.1. Soil test results from April 2016 at the Bringenbrong experimental site.

Soil test results		**Bringenbrong Site**
Depth (cm)		0-10
Soil texture		Clay Loam
pH ($CaCl_2$)		4.3
Colwell P (mg/kg)		33
Sulphate Sulphur (mg/kg)		4.1
Organic Carbon (%)		1.5
Nitrate Nitrogen (mg/kg)		4.1
Ammonium nitrogen (mg/kg)		3.5
Exchangeable cations (cmol(+)/kg)	Al	0.38
	Ca	1.9
	Mg	0.33
	K	0.14
	Na	0.0666
CEC (cmol(+)/kg)		2.79
Ca:Mg		5.8
Electrical conductivity (dS.m^{-1})		0.3
ESP (%)		2.4
Al (Exchangeable %)		14

An established perennial *Phalaris aquatica (cv. Grazier)* pasture, sown in 2011, with a high basal frequency between 40-48% was selected to study. Grazier has been developed by Upper Murray Seeds and is awaiting release. It is derived from a cross of Australian and Uneta cultivars with selection emphasis on increased winter production and drought tolerance. Features of the cultivar include a prostrate growth habit, semi winter dormancy, high seedling retention, and low summer dormancy.

There were also small amounts of volunteer broad and narrow-leafed species present throughout the phalaris pasture during the experimental period. Narrow-leaf components consisted of winter grass (*Poa annua*) and perennial ryegrass (*Lolium perenne*). Whilst the broad-leaf components were comprised of capeweed (*Arctotheca calendula*), sorrel (*Rumex acetosella*) and wireweed (*Polygonum aviculare*).

3.2. Experimental design and treatments

A randomised complete block design was used with four basal frequency treatments, two nitrogen fertiliser treatments and four replicates (Figure 3.2). Each plot was 0.84 m^2, totalling a treatment area of 26.9m^2. The entire experimental site was mown at a height of 4cm on the 15 of April to remove senesced growth from the previous season.

Basal frequency was measured twice (April 15 and May 10) at the beginning of the growing season by placing a 0.7 by 1.2 m quadrat of 0.1 by 0.1 m square mesh over the sampling area. The proportion of squares which were more than half occupied by a plant base were counted. In cases where plant density was too high for the allocated treatment, squares requiring removal were spray painted and then removed by a mattock. The four basal frequency ranges were: 40-50%, 30-39%, 20-29% and 10-19% and these treatments were assigned the letters A, B, C & D, respectively.

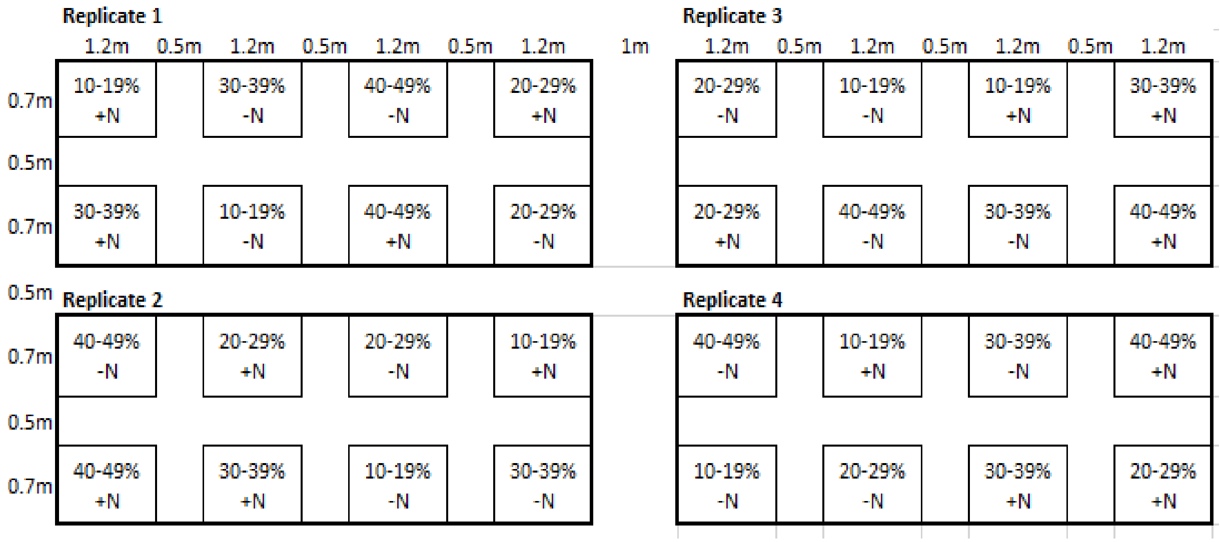

Figure 3.2: Layout of experimental site showing treatment locations and plot sizes. Basal frequency treatment ranges are 40-49%, 30-39%, 20-29% and 10-19%, which will be referred to as treatment A, B, C and D, respectively. +N indicates nitrogen fertiliser application and -N had no nitrogen fertiliser applied.

For each basal frequency treatment, two nitrogen applications consisting of zero and 46 kg N/ha were applied. The N fertiliser treatments were applied as urea (46% N) on April 19, June 17 and August 1. After all the basal frequency treatments were applied on April 15, the site received a uniform application of P fertiliser in the form of single superphosphate (9% P, 11% S) at the rate of 25 kg P/ha.

Subterranean clover (cv. Rosabrook) seed was sown on April 19 at a rate of 20 kg/ha. The space between phalaris planting rows was scarified and the seed spread by hand. Due to the lack of rain in April, the experimental area was hand irrigated with 20mm of water on the 19 of April to simulate a rainfall event and encourage autumn growth. 20L of water was evenly applied using a hand held watering can to each plot.

Due to presence of red-legged earth mites and also paddock history of African black beetles, Chlorpyrifos 500EC was applied at a rate of 900 mL/ha on June 1 and August 2 to prevent insect damage to both the clover and the phalaris.

3.3. Plant measurements

Dry matter was measured by harvesting the total plot herbage mass on three occasions at a six-week interval on: June 14, July 29 and September 9. Hand shears were used for cutting the herbage to a height of 2.5cm. The herbage from each plot was then sorted into four components: phalaris, clover, other grasses and other broad leaf species. Where herbage yield became too high, sub-sampling occurred. These components were then dried at 60°C for 48 hours and weighed.

3.3.1. Tiller numbers

Tiller numbers were estimated by counting the number of phalaris tillers in three 0.1m^2 grids on phalaris tufts within each 0.84m^2 plot on 13 June, 28 July and September 8 2016. These counts were used to determine the effects of nitrogen fertiliser and basal frequency on phalaris tiller numbers. Tillers per 1 m^2, individual plant tillers per 0.1m^2 and estimated tiller weights were calculated.

3.3.2. Leaf Area

A sub-sample of phalaris tillers were measured for leaf area (cm^2) using a Licor Li-3100 area meter (Lincoln, Nebraska). Leaf area per m^2 was calculated for each sample.

Leaf area index (LAI) is the total amount of one-sided leaf tissue per unit of ground surface area, measured in cm^2/cm^2. These leaf area values were used to calculate the total LAI per m^2 and used to determine the effects of nitrogen fertiliser application and basal frequency treatments on LAI.

3.4. Meteorological measurements

Mean monthly minimum and maximum air temperatures (Figure 3.3) were collected from the Khancoban bureau of meteorology weather station, approximately 10.5km south-east (-36.23 S, 148.14 E; elevation 339m) from the experimental site. April was 3°C warmer than the average maximum temperature, with the other months showing little variance from the long-term maximum temperature averages. The mean monthly minimum temperatures were above the long term averages for May, June, July and September, respectively being 2.5°C, 1.8°C, 3°C and 2°C warmer. Rainfall was collected on site and May, June, July, August and September were 44%, 40%, 51%, 23% and 131% above the average rainfall respectively (Figure 3.3). April received only 34% of the annual average monthly rainfall. The total rainfall for the duration of the experiment was 555mm.

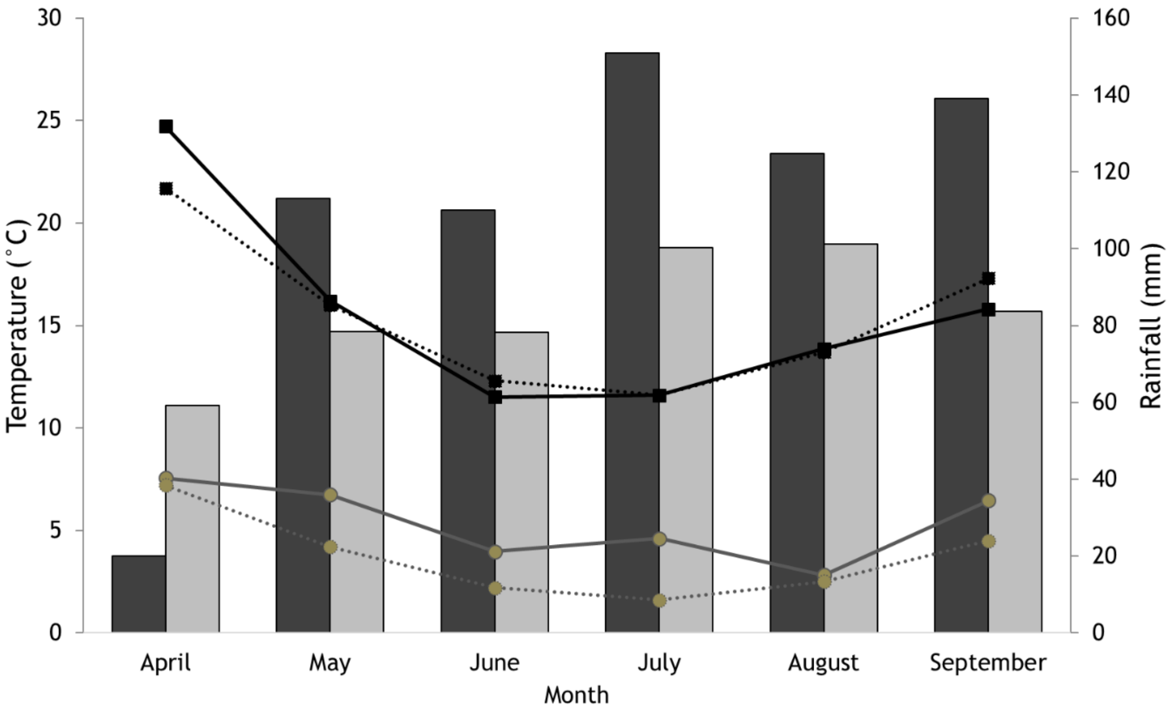

Figure 3.3: Mean monthly rainfall (■), long-term average monthly rainfall (▨), average monthly maximum temperature (■, solid line), long term average maximum temperature (■, broken line), average monthly minimum temperature (●, solid line), long-term average minimum temperature (●, broken line) for the April- September 2016 experimental period. Rainfall was collected on site at Bringenbrong and temperature data was collected from the Khancoban bureau of meteorology weather station, 10.5km south-east of the experimental site.

3.5. Statistical analysis

All statistical analyses were conducted using the software package GenStat 17 (version 17, VSN International Ltd, Hemel Hempstead, UK). The data was analysed for normality before being analysed using analysis of variance (ANOVA) and Fisher's Least Significance Difference (LSD) with a P value of 0.05.

Regression analysis and coefficients of determination (R^2) values were used to determine the relationships between phalaris accumulated dry matter yield and tillers/m^2, individual tiller weights and tillers/m^2.

4 Results

4.1. Basal Frequency

After plot establishment on May 10, phalaris basal frequency treatments were assessed and all treatments were significantly different ($P<0.05$) (Figure 4.1). Treatment A, B, C and D had basal frequencies of 44%, 37%, 26% and 13% of ground cover per m^2, respectively.

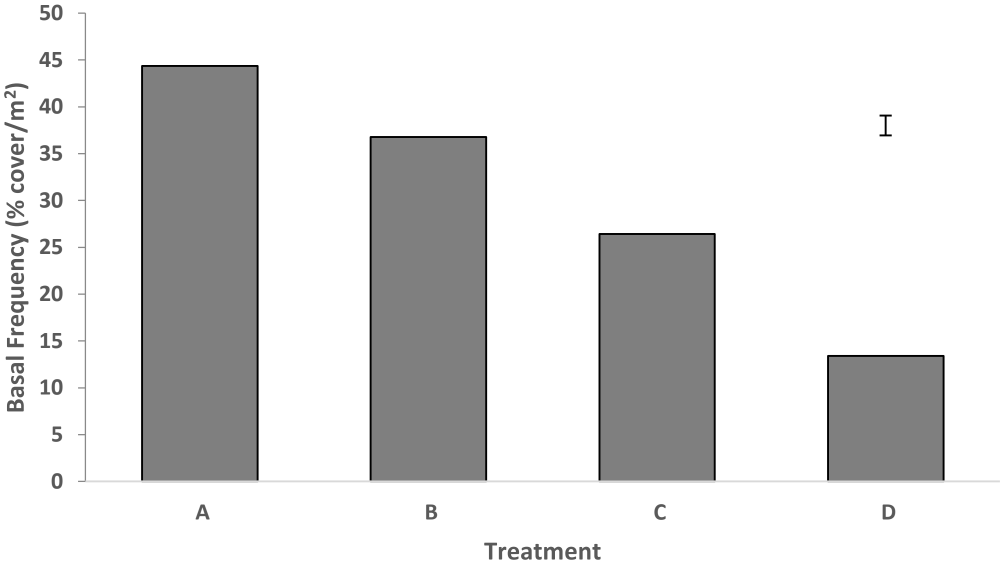

Figure 4.1: Basal frequency treatment following autumn rains (May 10) at the Bringenbrong field site in 2016. The bar indicates l.s.d. (P=0.05). Treatments A, B, C and D represent basal frequency ranges 40-50%, 30-39%, 20-29% and 10-19%, respectively.

There were no significant differences of clover establishment between plots. The plots were sown with subterranean clover (cv. Rosabrook) at a seed rate of 300 seeds/m^2, yet a mean of only 58 plants/m^2 became established.

The initial phalaris basal frequency (% phalaris cover) was measured on April 19 and again on May 10 to ensure correct establishment of treatment ranges. The final basal frequency was measured on September 9. Both the initial and final basal frequencies are expressed in Table 4.1, along with the relative change in basal frequency (RCBF). The RCBF are expressed as a ratio of final: initial basal frequency. There were significant effects ($P<0.01$) between the basal frequency treatments at the initial assessment and also between treatments at the final assessment. There was however, no significant difference between treatments for the RCBF.

Table 4.1. The relative change in phalaris basal frequency (RCBF) between the initial basal frequency measurement on April 19 and the final basal frequency measurement on September 8 2016. The LSDs are shown for each measurement.

	A	B	C	D	LSD (P = 0.05)
INITIAL BASAL FREQUENCY (%)	44.35	36.76	26.49	13.39	2.1
FINAL BASAL FREQUENCY (%)	44.79	37.35	26.94	13.99	2.3
RCBF	1.01	1.02	1.02	1.04	n.s.

4.2. Effect of basal frequency on production

Basal frequency and nitrogen fertiliser both had effects on dry matter production, however, there were no interactions found between the two treatments.

4.2.1. Basal frequency effects on phalaris dry matter production

Phalaris dry matter production was influenced by basal frequency treatments early in the season (Figure 4.2). At the first harvest (June 15), treatment A yielded 412 kg DM/ha. This was 69% higher ($P<0.01$) than the average yield of 244 kg DM/ha by treatment C and also 115% higher than the average yields of 131 kg DM/ha by treatment D. Treatment B produced an average of 359 kg DM/ha which was higher than treatment D by 74%.

The second harvest took place on July 28 and no significant differences between basal frequency treatments were observed ($P=0.06$). Overall a grand mean of 347 kg DM/ha of phalaris was produced. The third harvest on September 9 produced an average of 786 kg DM/ha of phalaris ($P=0.58$). There were no significant differences between basal frequency treatments, however, the grand mean was 130% higher than the previous harvest in late winter.

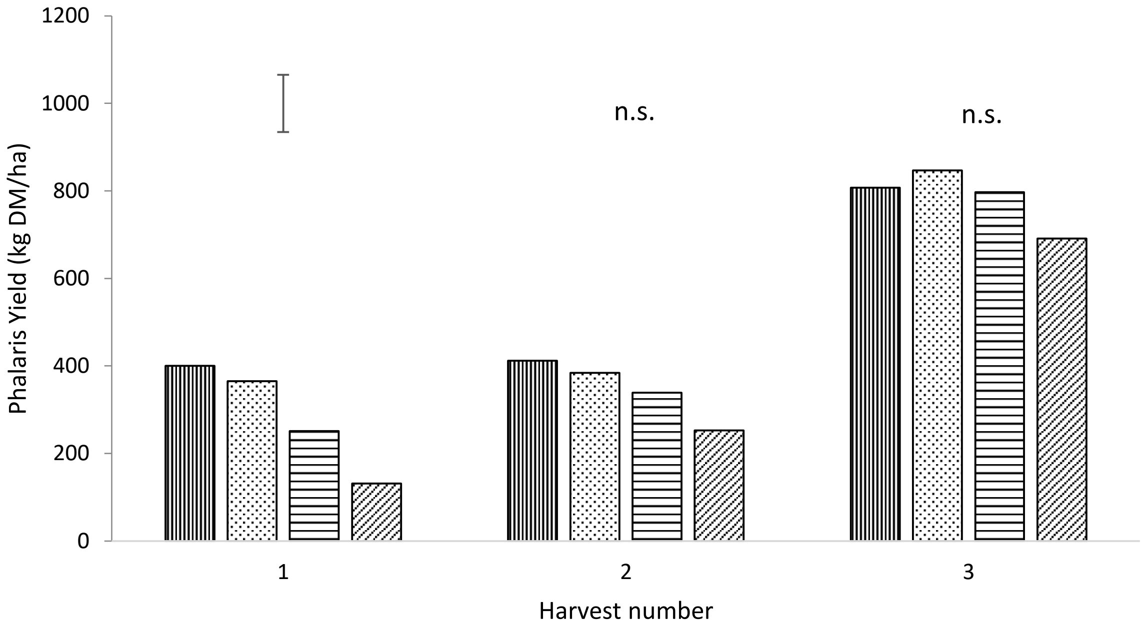

Figure 4.2. The effects of basal frequency on phalaris dry matter production (kg DM/ha) between April and September 2016 at the Bringenbrong field site. The bars indicate l.s.d. (P = 0.05) values at each harvest. Treatment A= 40-49% (vertical lines); B= 30-39% (dots); C= 20-29% (horizontal lines); D= 10-19% (diagonal lines). Harvest 1, 2 and 3 occurred on June 15, July 29 and September 9, respectively.

The effects of basal frequency on accumulative phalaris yield are shown in Figure 4.3. There were no significant differences between the two highest basal frequency treatments, A and B, throughout the experiment. Similarly, treatments B and C and also C and D had no significant differences between the mean accumulative dry matter yields throughout April and September. The mean total accumulated dry matter yield of treatment A was 1619 kg DM/ha, which was 51% higher ($P<0.05$) than the mean accumulated phalaris yield of 1075 kg DM/ha produced by plots in treatment D. Treatments B and C produced an accumulative total phalaris dry matter yield of 1597 and 1387 kg DM/ha, respectively.

Between July 29 and September 9, treatments A produced 50% of the accumulated phalaris total yield for that treatment. Whereas treatments B, C and D respectively produced 47%, 43% and 36% of their treatments total phalaris accumulated dry matter yield between July 29 and September 9.

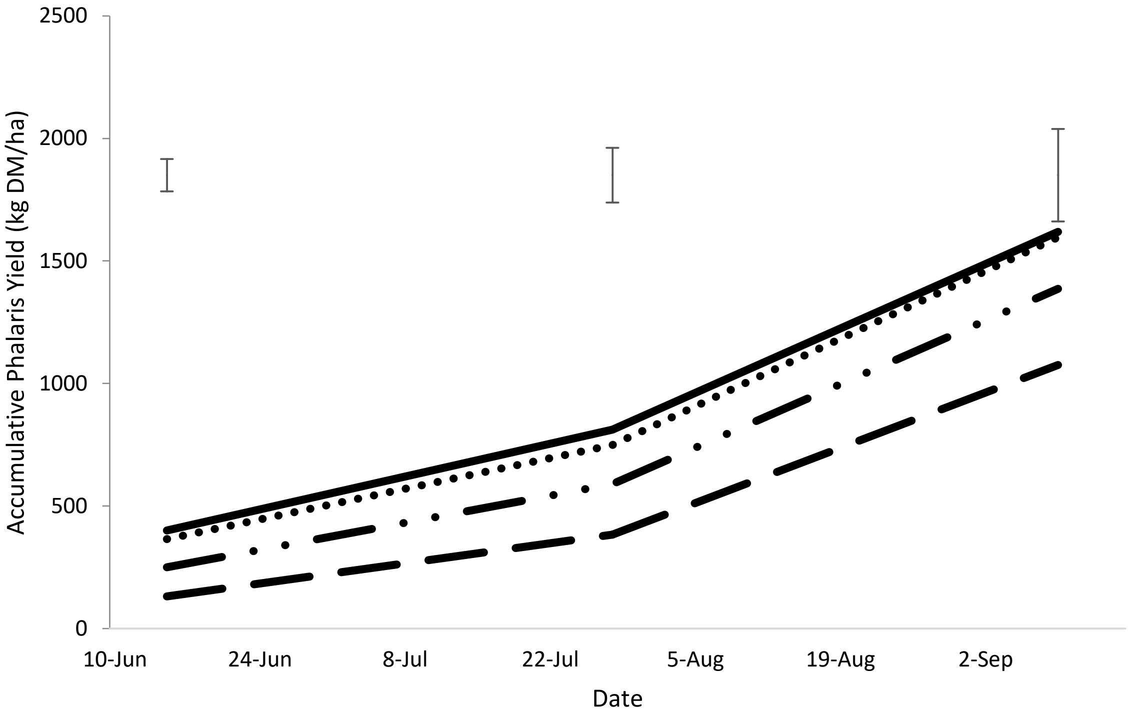

Figure 4.3. The effects of basal frequency on accumulative phalaris dry matter yield (kg/ha) between April and September 2016 at the Bringenbrong experimental site. Treatment A= 40-49% (solid line); B= 30-39% (dotted line); C= 20-29% (dash and dot combination line); D= 10-19% (dashed line). The bars indicate the LSD at each harvest date.

Basal frequency treatments had no significant effects on the non-phalaris pasture components dry matter yield (Table 4.2). Other grasses had the highest mean accumulative dry matter yield between April and September 2016. Clover had a small accumulative yield of 12.8 kg DM/ha.

Table 4.2. The effects of basal frequency treatment on the non-phalaris pasture component accumulated dry matter yields (kg DM/ha) at the Bringenbrong field site between April and September 2016. The LSDs (P=0.05) are shown for each pasture component. Treatments A, B, C and D represent basal frequency ranges 40-50%, 30-39%, 20-29% and 10-19%, respectively.

Pasture Component	**Treatment Yields (kg DM/ha**				**LSD (P=0.05)**
	A	**B**	**C**	**D**	
Clover	4.1	19.7	13.4	14	n.s.
Other Grasses	887	931	969	800	n.s.
BLW	547	476	425	313	n.s.

4.2.2. Tiller production

Tillers per 0.1m^2 were measured to assess the possible variations in individual plant tillering between April to September 2016. Basal frequency did not significantly influence individual plant tillering, indicating that there was minimal variation between individual plants throughout the treatments.

The effects of basal frequency on tiller production per m^2 are illustrated in Figure 4.4. All three assessments on June 14, July 18 and September 8 showed no significant difference between treatments A and B. The first assessment ranged from a mean of 1840 tillers/m^2 in treatment A, to 503 tillers/m^2 in treatment D. The means across all treatments were similar in assessment 2, ranging from treatment A producing a mean of 1840 tillers/m^2 to treatment D with 546 tillers/m^2. The third tiller assessment had lower means across all treatments. The range was between 1261 tillers/m^2 and 393 tillers/m^2, for treatment A and D respectively.

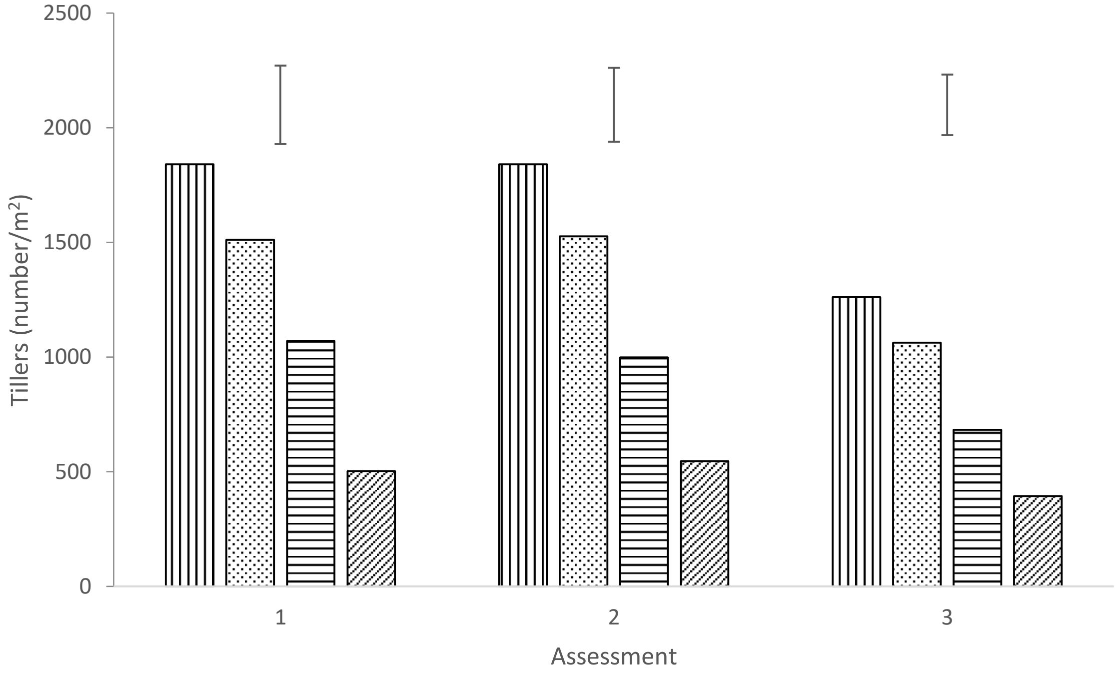

Figure 4.4. The effects of basal frequency on tillers/m^2 between April and September 2016 at the Bringenbrong field site. The bars represent the LSD (P=0.05) at each assessment date. Treatment A (vertical lines); B (dots); C (horizontal lines); D (diagonal lines). Assessment number 1, 2 and 3 occurred on June 14, July 28 and September 8, respectively.

4.2.3. Leaf Area Index (LAI)

Initially basal frequency also had a significant effect on LAI, however, the latter two harvests showed that basal frequency treatment had no significant effects on LAI (Figure 4.5). Over time, treatment D increased LAI. Whereas, treatment A displayed a decline in LAI between June 15 and July 28, followed by a slight increase to September 9. The grand means for all basal frequency treatments measured on July 28 and September 9 were 0.6285 and 0.753, respectively.

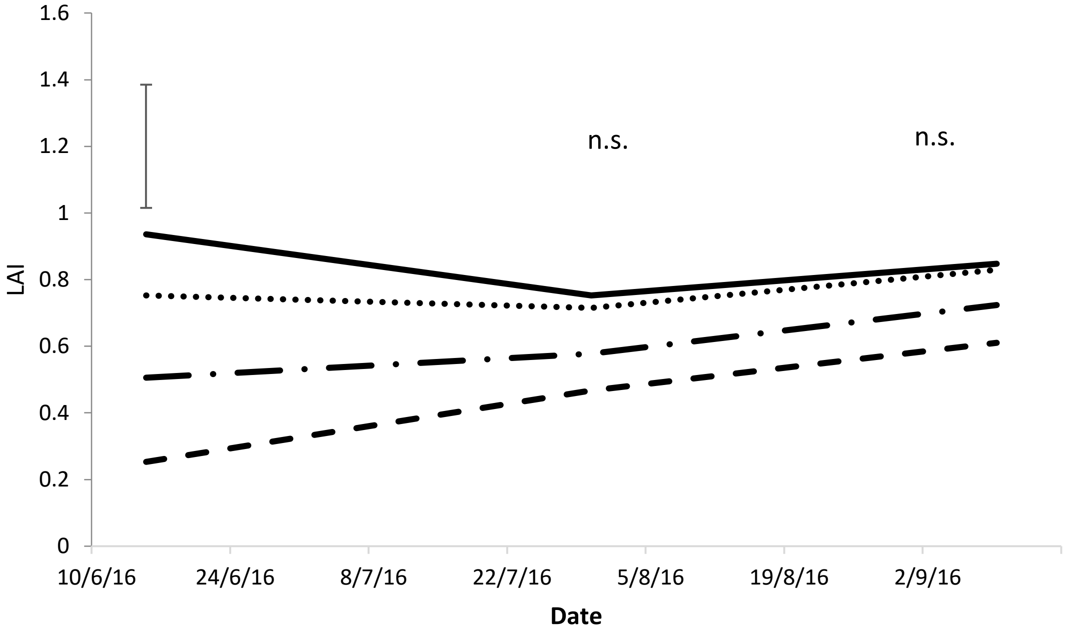

Figure 4.5. The effects of basal frequency on LAI. Harvest 1, 2 and 3 occurred on June 15, July 30 and September, respectively. Treatment A= 40-49% (solid line); B= 30-39% (dotted line); C= 20-29% (dash and dot combination line); D= 10-19% (dashed line). The bars indicate the LSD (P=0.05) at each harvest, with n.s. indicating no significant differences.

4.3. Effects of nitrogen fertiliser on production

4.3.1. Nitrogen fertiliser effects on dry matter production

The total dry matter yield of phalaris differed (P<0.05) under nitrogen fertilised and unfertilised conditions (Figure 4.6). The nitrogen fertiliser treatment was broken down into three applications of 46 kg N/ha of nitrogen fertiliser and was applied 6 weeks prior to each harvest. The first harvest occurred on June 15, with the mean dry matter production of N fertilised plots being 336 kg DM/ha, which was 42% higher (P<0.05) than the 237 kg DM/ha produced by unfertilised plots. The second harvest on June 29 had a yield of 473 kg DM/ha produced by N treated plots, which was 210% times more (P<0.001) than the mean of 222 kg DM/ha produced by untreated plots. The third harvest took place on September 9, with N treated plots producing a mean of 1226 kg DM/ha, which was 360% more (P<0.001) than the mean dry matter produced under nitrogen untreated conditions (345 kg DM/ha). Nitrogen fertiliser was found to have no significant effects on any of the basal frequency measurements or the RCBF (Table 4.1).

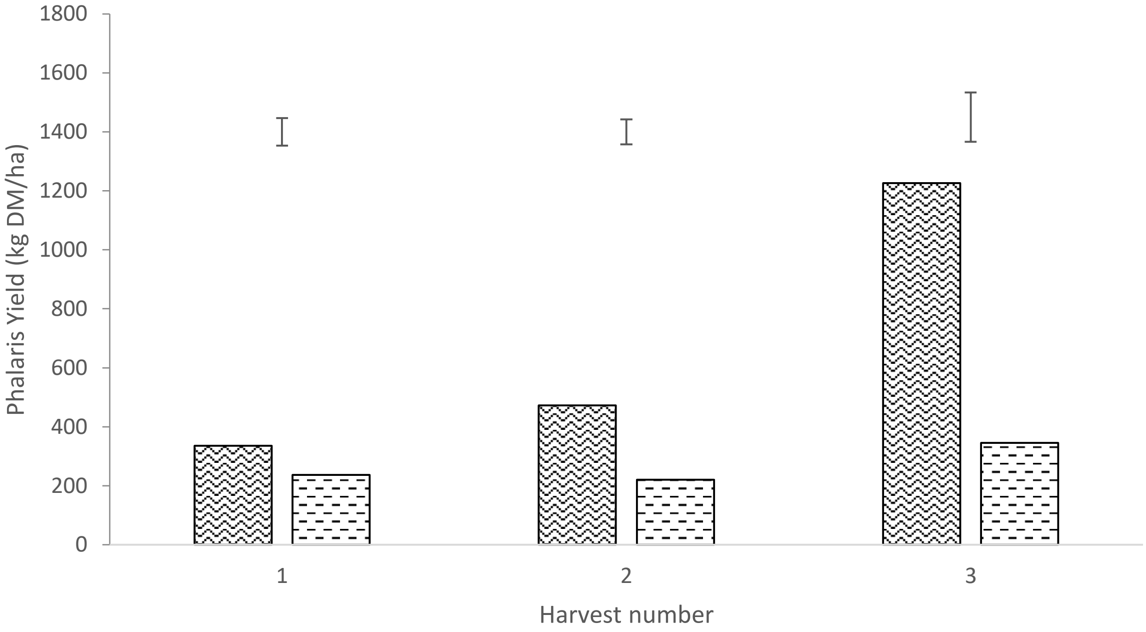

Figure 4.6: Pattern of phalaris dry matter production (kg DM/ha) between April and September 2016, with added nitrogen fertiliser (wave pattern; 46 kg N/ha applied 6 weeks prior to each harvest) and without nitrogen fertiliser (dashed lines) at the Bringenbrong field site, southern NSW. The bar indicates the l.s.d. (P = 0.05) at each harvest. Harvest 1, 2 and 3 occurred on June 15, July 29 and September 9, respectively.

The accumulative phalaris yield between April to September 2016 (Figure 4.7) was influenced by nitrogen fertiliser application. The mean total accumulated yield of nitrogen fertiliser (138 kg N/ha) treated plots was 2035 kg DM/ha, which was 2.5 times higher (P<0.01) than the 804 kg DM/ha produced in unfertilised plots. Between July 29 and September 9, 60% of the accumulated phalaris total was produced in nitrogen fertilised plots. Whereas in unfertilised plots, 43% of the total accumulated dry matter yield was produced between July 29 and September 9.

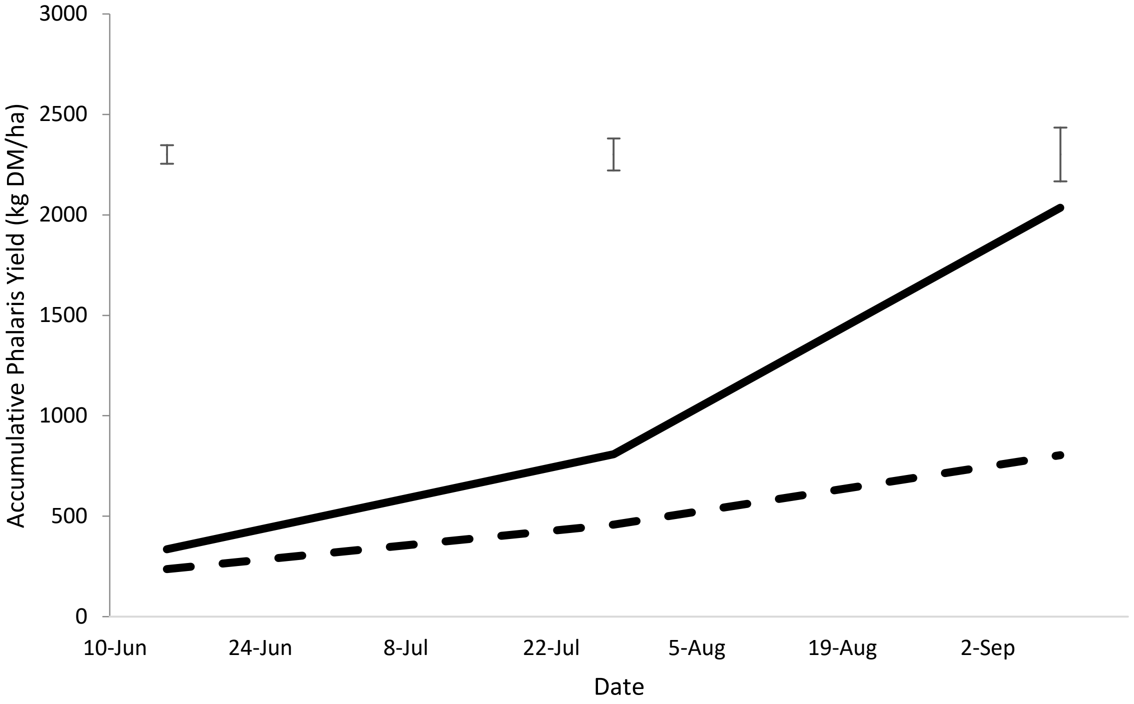

Figure 4.7. The effects of nitrogen fertiliser application on accumulative phalaris dry matter yield (kg/ha) between April and September 2016 at the Bringenbrong experimental site between. Nitrogen fertilised (solid line; 138 kg N/ha); Untreated with nitrogen fertiliser (broken line). The bars indicate the LSD at each harvest date.

There were three non-phalaris species components present in the field site: clover (subterranean clover*)*, other grasses (perennial ryegrass and winter grass) and also broadleaf weeds (BLW; capeweed, wireweed and sorrel). The accumulative dry matter production (kg DM/ha) is shown in Table 4.3. Nitrogen fertiliser application (138 kg N/ha) had no significant yield effects on clover and BLW over the monitoring period. The yield of other grasses under nitrogen fertilised conditions (1372 kg DM/ha), was 3.4 times higher (P<0.05) than the 402 kg DM/ha produced in unfertilised plots.

Table 4.3. The effects of nitrogen fertiliser application (138 kg applied N/ha) on the accumulative dry matter yield (kg DM/ha) of clover, other grasses and broadleaf weeds (BLW) at the Bringenbrong experimental site between April and September 2016. The LSDs are shown for each species at a 5% significance level.

Pasture Component	Nitrogen Applied (kg DM/ha)	Nitrogen Untreated (kg DM/ha)	LSD (P=0.05)
Clover	14.1	11.1	n.s.
Other Grasses	1372	402	321.4
BLW	921	173	n.s.

4.3.2. Effects of nitrogen fertiliser on tiller production

Tillers per $0.1m^2$ were measured to assess the possible variations in individual plant tillering between April to September 2016. Nitrogen fertiliser application had significant ($P<0.05$) treatment effects on individual phalaris plant tillering from April to September 2016 (Figure 4.8). The first assessment on June 14, was eight weeks after the initial application of nitrogen fertiliser (46 kg N/ha) on April 19. The mean number of tillers per $0.1m^2$ for nitrogen fertilised plots was 43.5, which is 20% greater ($P<0.05$) than untreated plots (36.4 tillers per $0.1m^2$). The second assessment on July 28 was six weeks following the second application of N fertiliser (accumulative application of 92 kg N/ha). The average number of tillers per $0.1m^2$ was 48 for nitrogen fertilised plots, 47% higher ($P<0.05$) than unfertilised plots (32.6 tillers per $0.1m^2$). The third assessment on September 8 was six weeks following the third application of N fertiliser (accumulative application of 138 kg N/ha). N fertilised plots were significantly higher ($P<0.05$) than untreated plots, producing a mean of 36.6 tillers/$0.1m^2$ compared to 19.2 tillers/$0.1m^2$. The mean tiller numbers for the third assessment was lower than the previous count due to an observation of less new tillers being produced.

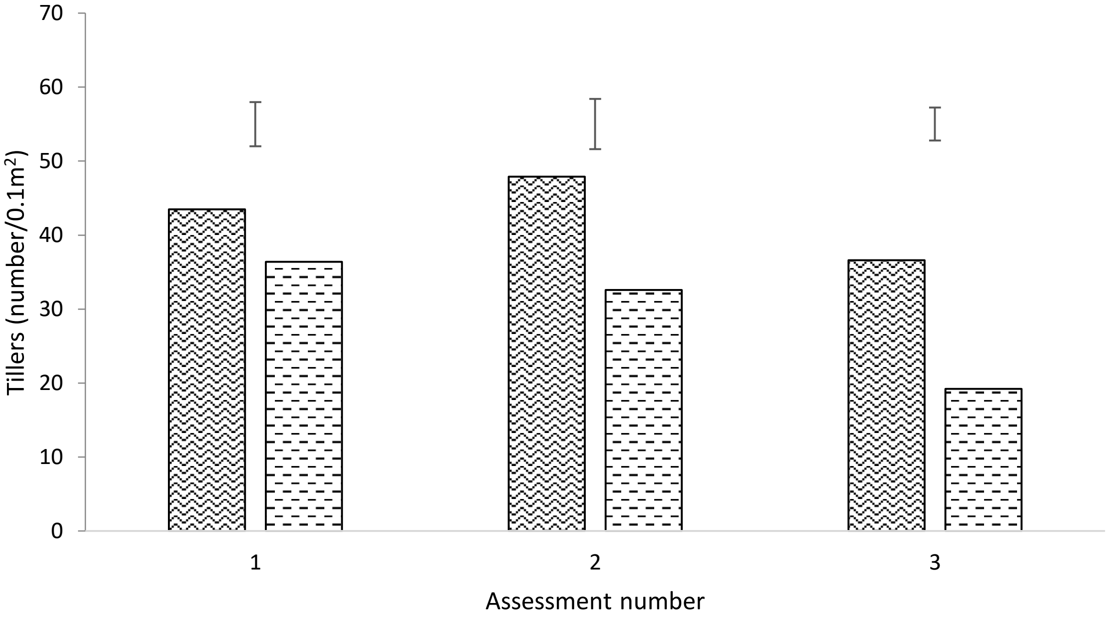

Figure 4.8. The effect of nitrogen fertiliser application on phalaris tillers/0.1m² between April and September at the Bringenbrong field site in 2016. The bars represent the l.s.d. (P=0.05) for each data collection. Nitrogen treated (solid line), nitrogen untreated (broken line). Assessment 1, 2 and 3 occurred on June 14, July 28 and September 8, respectively.

Nitrogen fertiliser application had significant ($P<0.01$) effects on tiller numbers per m^2 on the second and third assessments (Figure 4.9). After the initial application of N fertiliser (46 kg N/ha), there were no significant differences ($P=0.069$) between the means of fertilised and unfertilised plots. Six weeks following the second N application, N fertilised treatments produced 43% more tillers/m^2

(1445 tillers/m^2) than N untreated plots (1010 tillers/m^2). The third assessment on September 8 had the lowest mean tiller numbers of the three assessments and also exhibited the greatest difference between treatments. The N treated plots had a mean of 1095 tillers/m^2 which was 81% higher than untreated plots (605 tillers/m^2).

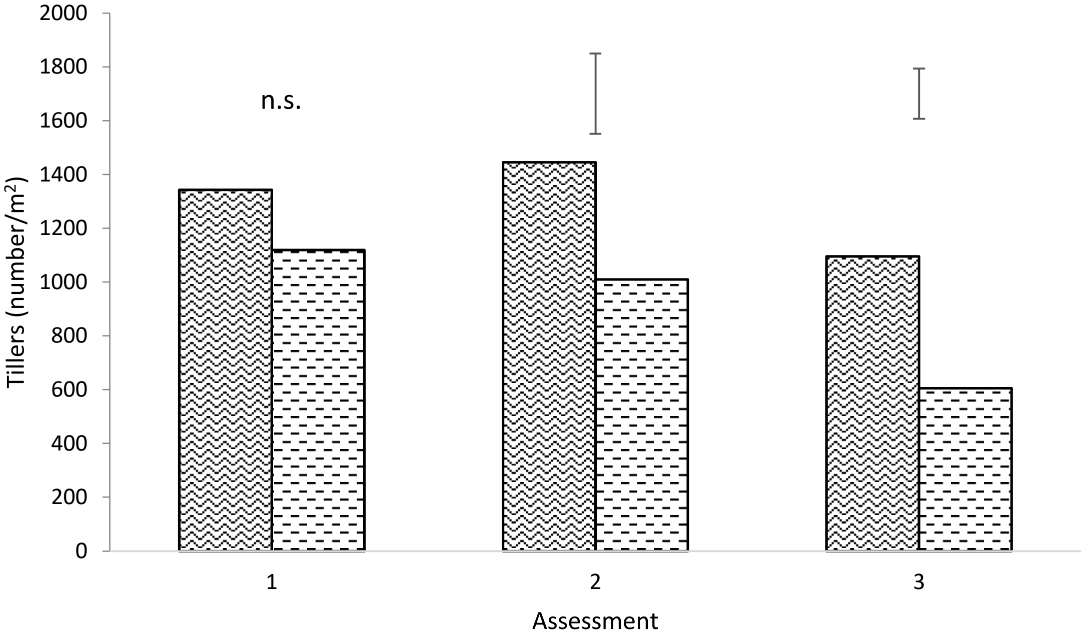

Figure 4.9. The effects of nitrogen fertiliser application on tillers/m2 between April and September 2016 at the Bringenbrong field site. N fertiliser application (solid line); unfertilised (broken line). The bars denote the LSD (P=0.05) at each assessment date. Assessment 1, 2 and 3 occurred on June 14, July 28 and September 8, respectively.

There is a significant (P<0.001) positive linear relationship (R^2= 0.50) between tiller numbers and accumulative phalaris dry matter yield (kg DM/ha) (Figure 4.10). This relationship identified that as tiller number increase, phalaris dry matter yield will also increase.

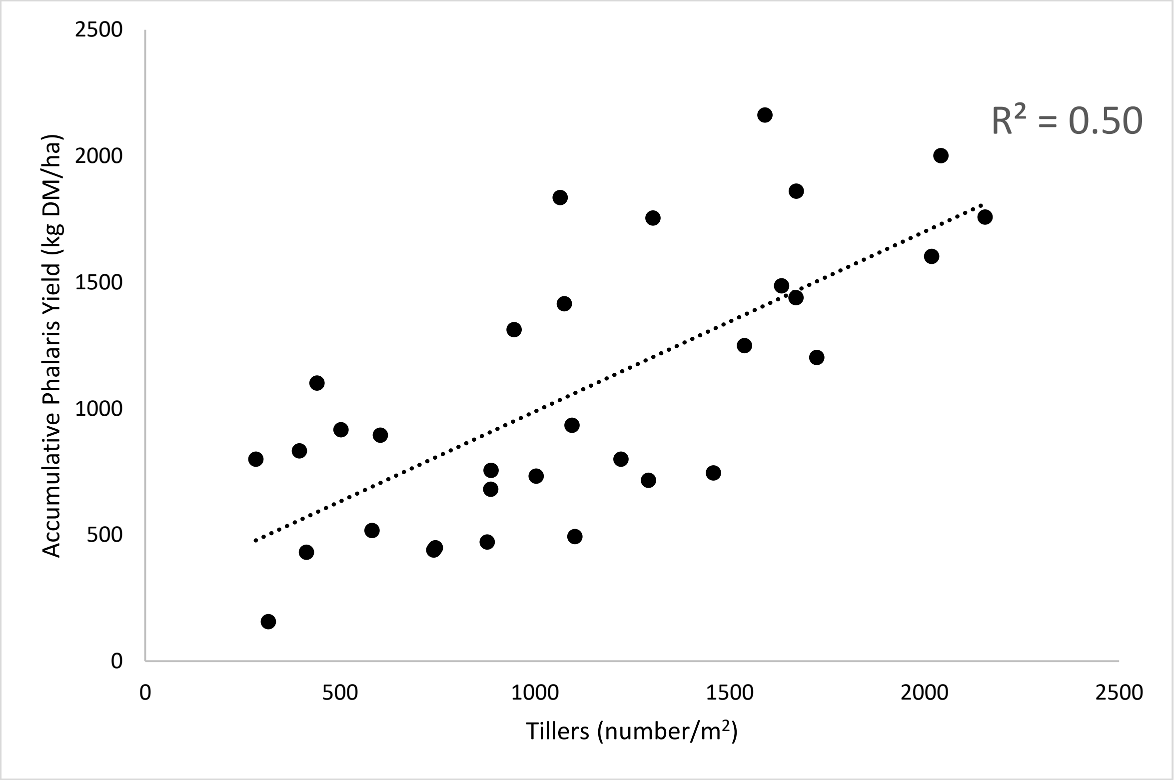

Figure 4.10. The relationship between accumulative phalaris dry matter yield (kg DM/ha) and average tiller numbers/m^2 *between April and September 2016 at the Bringenbrong field site.* $R^2 = 0.50$. $y = 0.71x + 276.6$

There is a significant ($P<0.001$) relationship with high variability ($R^2=0.11$) evident between the average tillers/m^2 and average estimated tiller weights (Figure 4.11). This negative linear relationship suggests that as tillers/m^2 increase, their estimated tiller weights will decrease.

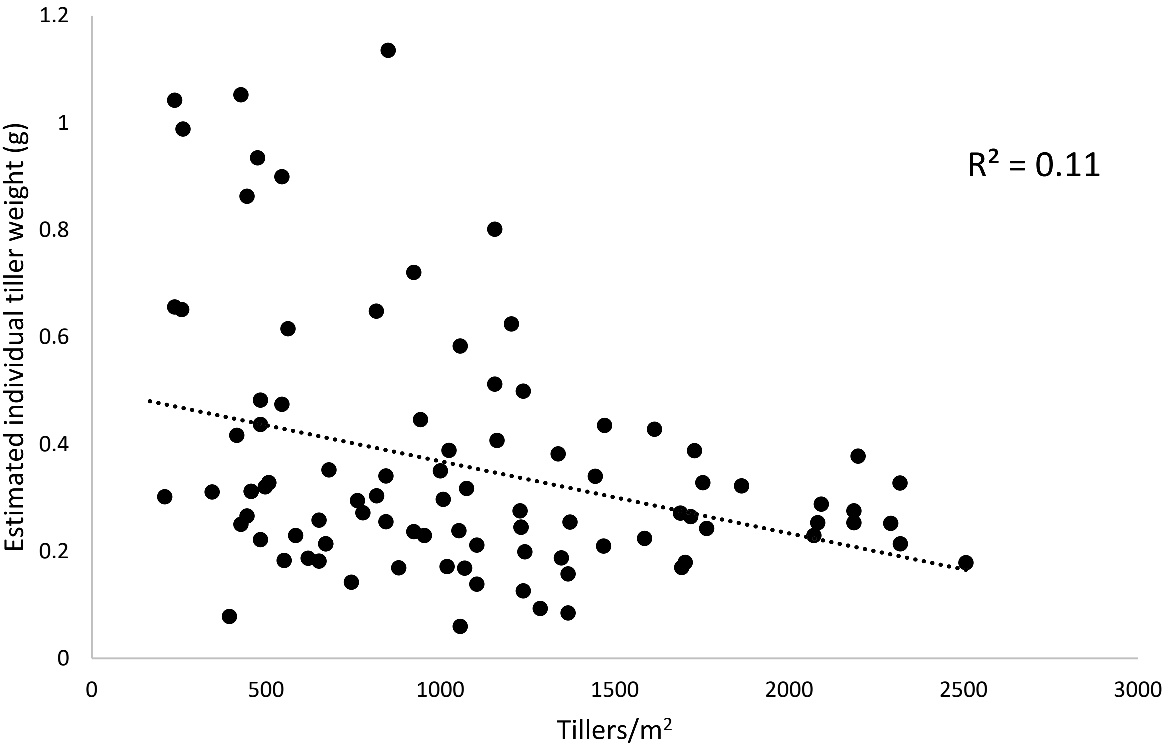

Figure 4.11. The relationship between average tiller weights (g) and tillers/m^2 at the Bringenbrong experimental site between April and September 2016. R^2=0.11; y = -0.0001x + 0.50

4.3.3. Leaf Area Index (LAI)

Leaf area index (LAI) is used to determine canopy characteristics of a species. Phalaris LAI was influenced throughout the experiment by nitrogen fertiliser application (**Error! Reference source not found.** 4.5). The differences between fertilised and unfertilised treatments became greater over time. Initially the fertilised treatments produced a mean LAI of 0.74, which was 1.55 times greater ($P<0.05$) than the unfertilised treatment mean (0.48). The N fertilised treatments on July 28 produced a mean LAI (0.851) that was 2.1 times more ($P<0.001$) than unfertilised plots (0.40). A further decline in the N fertiliser untreated plots was observed on September 9, with a LAI of 0.33. The N fertiliser treatment mean (1.20) was 3.6 times greater ($P<0.001$) than the untreated mean.

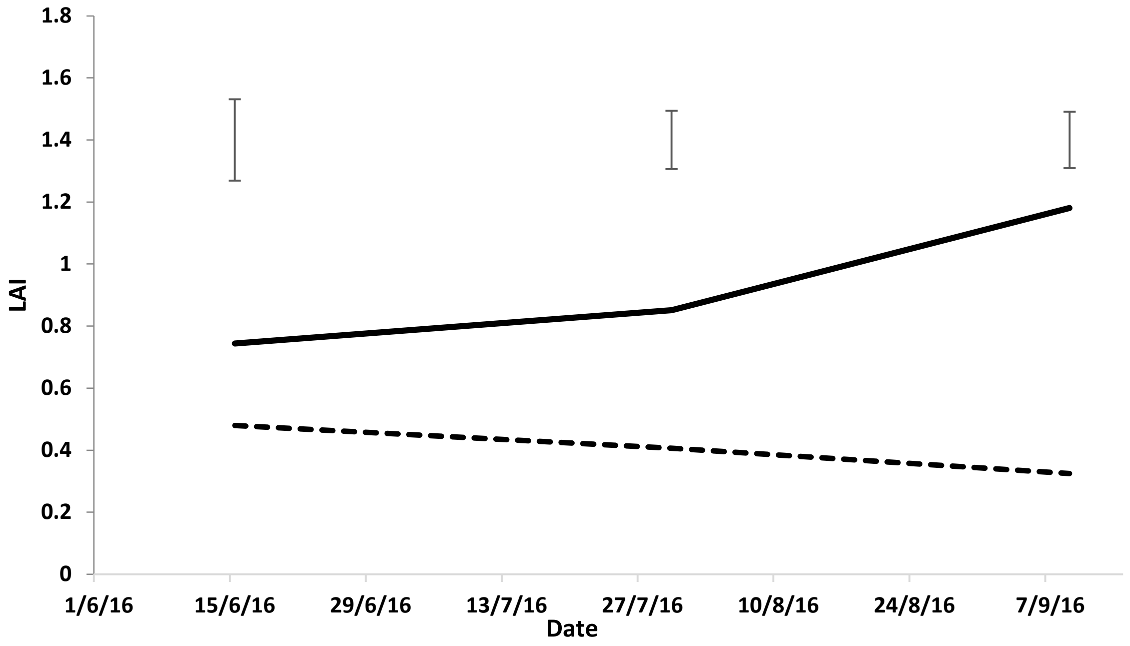

Figure 4.12: The effects of nitrogen fertiliser application on leaf area index (LAI) at the Bringenbrong field site between April and September 2016. Harvest 1, 2 and 3 occurred on June 15, July 30 and September, respectively. N fertiliser application (solid line); unfertilised (broken line). The bars represent the LSD (P= 0.05) at each harvest.

There is a significant relationship (P<0.001) between phalaris dry matter yield and LAI under both nitrogen fertilised and unfertilised conditions (Figure 4.13). The models show moderately positive linear correlations with similar R^2 values of 0.5. However, the slope of the nitrogen fertilised treatments is steeper (slope=760) than the slope of unfertilised treatments (slope=322). This indicated that there is more gain in dry matter yields with each increase in LAI under nitrogen fertiliser treatments.

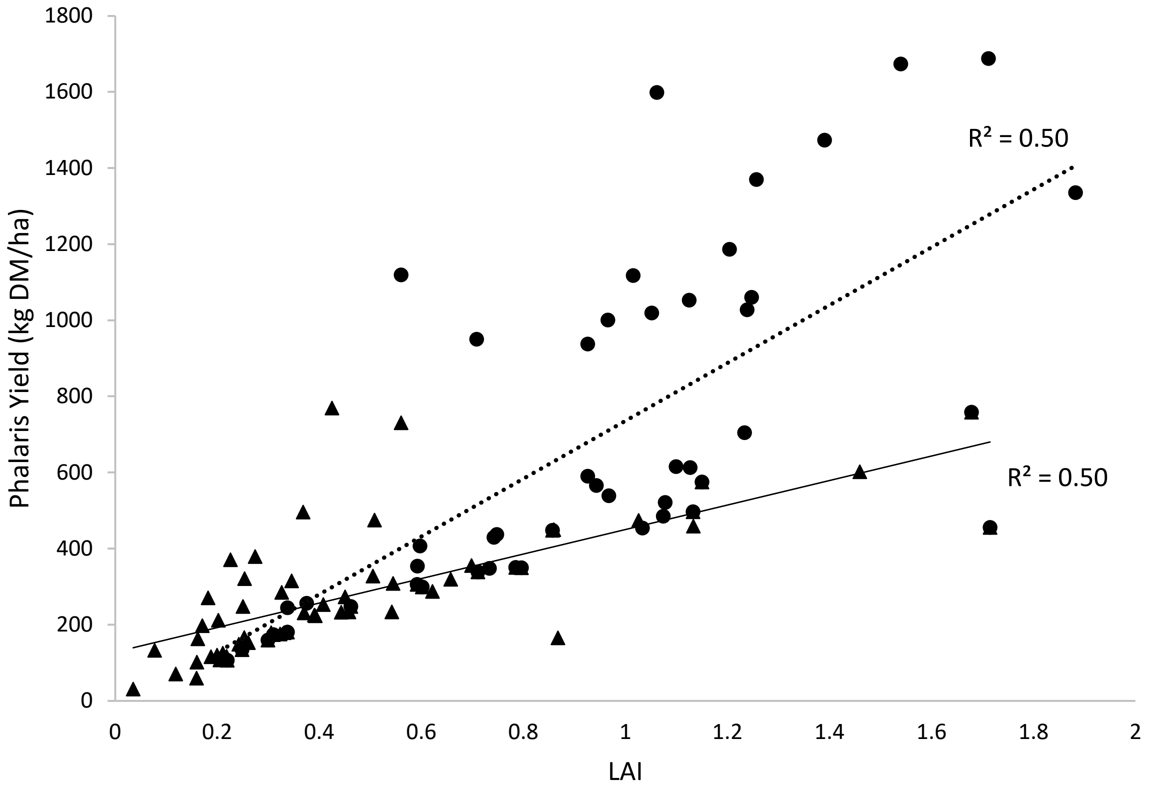

Figure 4.13. The relationship between phalaris dry matter yield and LAI under nitrogen fertilised (●; R^2=0.50; y = 760.18x – 24.99) and unfertilised (Δ; R^2=0.50; y = 322.35x + 127.43) conditions at the Bringenbrong field site between April to September 2016.

4.4. Accumulative species dry matter yields as influenced by treatments

The effects of phalaris basal frequency (Figure 4.14) had less of an effect over time than the nitrogen fertiliser treatments (Figure 4.15) on the accumulative yield of all species at the Bringenbrong site. The basal frequency treatments initially had a significant difference ($P<0.001$) between treatments, followed by no significance differences between treatments on the next two harvest in July ($P=0.19$) and September ($P=0.36$). Although there were no significant differences between the basal frequency treatment means of the last harvest, treatment A produced an accumulative production of 3445 kg DM/ha, which was 56% higher than the mean of treatment D. Nitrogen fertilised treatments consistently produced more ($P<0.05$) dry matter than untreated plots between April and September. The total accumulative yield of the treated plots was 3.1 times more than the untreated plots. Per kg of applied nitrogen, there an additional 21 kg/ha of dry matter produced.

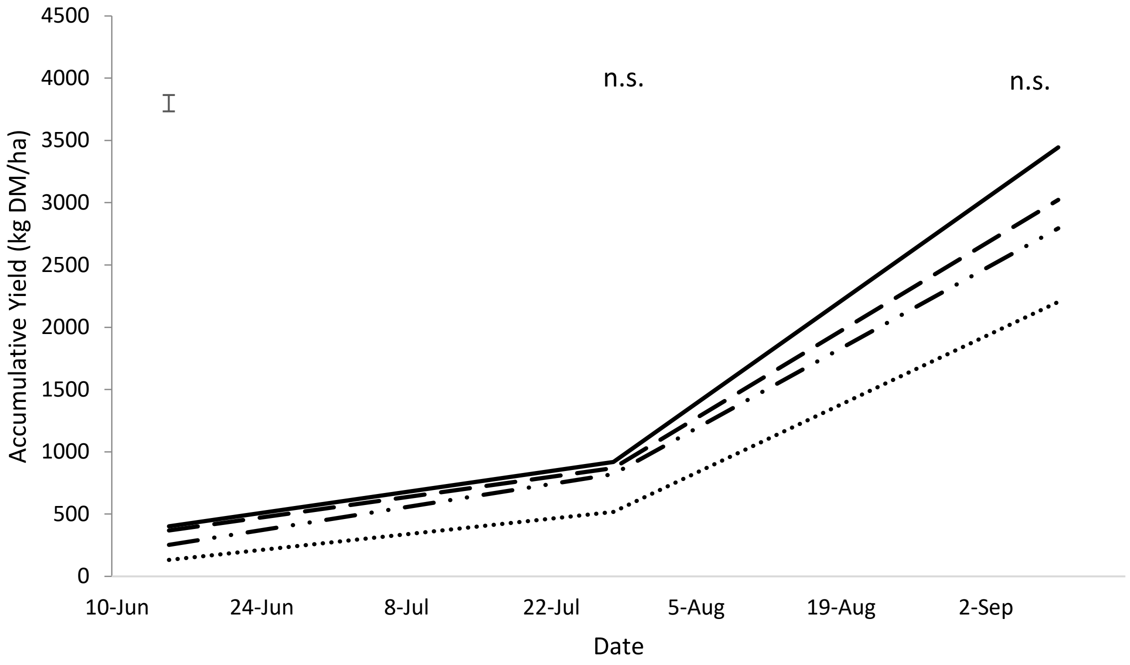

Figure 4.14. The effects of basal frequency on accumulative dry matter yield (kg DM/ha) of all species at the Bringenbrong experimental site between April and September 2016. Treatment A= 40-49% (solid line); B= 30-39% (dotted line); C= 20-29% (dash and dot combination line); D= 10-19% (dashed line). The bars indicate the LSD (P=0.05) at each harvest, with n.s. indicating no significant differences.

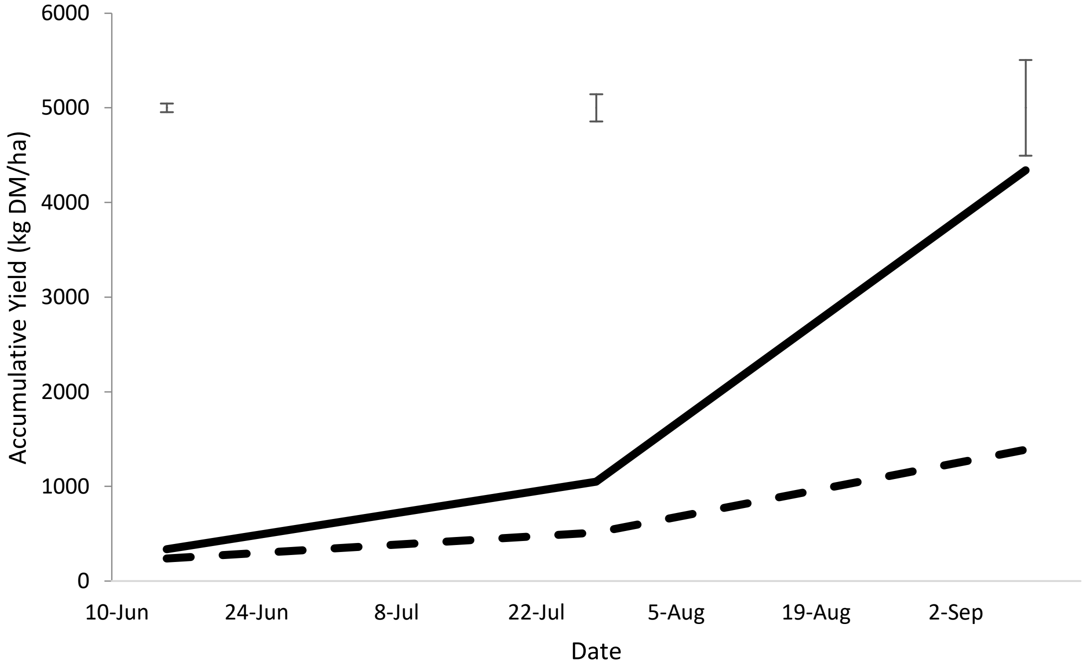

Figure 4.15. The effects of nitrogen fertiliser application on the accumulative dry matter yield (kg DM/ha) of all species between April to September 2016 at the Bringenbrong experimental site. N fertiliser application (solid line); unfertilised (broken line). The bars represent the LSD (P= 0.05) at each harvest.

5. Discussion

This experiment has shown that differences in phalaris basal frequency and nitrogen fertiliser application can each influence dry matter yield of Grazier phalaris under field conditions. Responses were observed during vegetative development throughout winter and early spring. There were no interactions observed between basal frequency and nitrogen fertility.

5.1. Phalaris basal frequency

Manipulating density by the removal of plants within an established pasture without causing environmental changes presents some difficulties. Removal of plants by herbicide use will increase soil organic matter and also remove any other species that comes into contact with the chemical (Tow & Lazenby, 2001). Physical removal of above ground components may leave the plants able to regrow from the underground components. Whereas, deep physical removal of all underground parts will cause soil disturbance which may influence microbial populations, changes in nutrient cycling and changes in soil structure (Tow & Lazenby, 2001). In order to get accurate phalaris removal with minimal environmental side-effects, shallow physical removal was used to remove the plant crown at the Bringenbrong site.

The basal frequency treatments were applied prior to the break of season rainfall while the phalaris was dormant in order to minimise disturbance levels. Upon vegetative growth of phalaris tillers, basal frequency was reassessed. All basal frequency treatments were identified to have significant differences in ground cover (Table 4.1). Initially, treatment A had a mean basal frequency of 45%. Treatments B, C and D had averages of 37%, 27% and 13% of ground cover per m^2, respectively.

One of the key aspects of perennial grass species is their ability to capture and utilise water, light and nutrient resources (Virgona & Bowcher, 2000). In order to do this successfully, plants must be able to colonise and occupy space. Colonisation can be a result of seedling recruitment, although there is minimal evidence to suggest that this mechanism results in established seedlings from the seed bank (Virgona, et al., 2000; Dear, et al., 2007), vegetative expansion (crown growth) or rhizatomous spread. Over the duration of this experiment, the was no relative change in the basal frequency treatments (P=0.32) (table 4.1). Earlier findings by Virgona and Bowcher (2000) reported a slight increase in basal area of Sirolan phalaris under irrigated conditions due to the crown growth of existing plants. Similarly, Oram and Culvenor (1994) identified that after phalaris damage, rhizomatous spread was able to recover basal frequency. Further, a grid was only counted as occupied when at least 50% of the 10 x 10 cm square was occupied by the base of the phalaris plants. It was observed that small amounts of crown expansion and rhizomatous spread were occurring around the occupied squares, but due to only occupying less than 50% of the adjacent squares, these expansions were not able to be counted using the defined assessment technique. It is likely that differences in the changing basal frequency would arise if the area was monitored over consecutive seasons.

5.2. Phalaris production

5.2.1. Phalaris dry matter production as influenced by basal frequency

All three harvests identified no significant difference between the phalaris dry matter yield of both treatments A (40-49%) and B (30-39%) (Figure 4.2). Phalaris dry matter production was consistently the highest for treatments A and B across all three assessments, respectively producing accumulative yields of 1619 kg DM/ha and 1597 kg DM/ha (Figure 4.3) between April and September 2016. Treatment A was 51% higher than the accumulative phalaris yield of treatment D (10-19%), which had the lowest total yield, producing 1075 kg DM/ha between April and September 2016. Since there is no significant difference between treatments A, B and C (20-29%) over time, a basal frequency cover above 20% is producing the optimum yield, with treatment D (<20% basal cover) displaying a significant yield decrease. The differences in biomass between the treatments were the greatest at the first harvest, with the differences between the means being lesser at the second and third harvests (Figure 4.2). The large treatment differences in the first harvest is the primary cause responsible for the accumulative yield differences throughout the experimental period.

Yield increased due to an increase in tiller numbers (Figure 4.4), which influences the leaf area available for photosynthesis, driving pasture growth. However, there was no significant response of individual plant tiller numbers to basal frequency treatments, this indicates there was little variation between individual plant tillering caused by basal frequency treatments. Instead the differences in tiller production per m^2 were caused by the varied basal area occupied by phalaris plants, with higher basal frequency contributing to more tillers per m^2 (Figure 4.4), influencing the photosynthetic potential of the sward which is given by LAI (Figure 4.5). Basal frequency was found to have an influence on LAI at the first harvest in June, with treatment A found to have a significantly higher LAI than treatment D. The latter two assessments on July 28 and September 8 found no significant differences between LAI and basal frequency.

There are three main components of canopy development as described by Davies (2001); the active increase in light capture as the canopy grows, light capture and growth rate reaching maximum, and maturation when self-thinning occurs and net dry matter gains cease. There is a moderate positive linear relationship (R^2=0.46; P<0.001) between tillers/m^2 and phalaris yields (Figure 4.10), demonstrating that an increase in tillers per m^2 is likely to increase phalaris dry matter production. However, the negative relationship between individual tiller weights and phalaris dry matter production (Figure 4.11) suggests that there is a compensatory effect responsible for the decline in individual tiller weights as tiller numbers increase. Similarly, a study by Cullen et al. (2005b) identified that an increase in either tiller density or tiller dry weight would increase the overall yield of the sward. This study also observed a negative linear correlation between found between tiller density and tiller weight. These findings are attributed to tiller size density compensation (SDC) which regulates tiller density in accordance to the maximum level for light competition and subsequently maximises photosynthetic potential (Matthew, et al., 1995). Whilst the trends are similar, Cullen et al. (2005b) observed a strong relationship (slope = -0.71) which was much steeper than the relationship observed at the Bringenbrong experimental site (slope = -0.0001; R^2= 0.11; $P<0.01$). The likely reason for difference is due to the pasture yields not being high enough to cause considerable competition for light resources. Throughout April to September 2016, the sward at the Bringenbrong experimental site was maintained at a height of 2.5cm, cut at six week intervals. With biomass yielding between 131 and 1226 kg DM/ha (Figure 4.2), with the highest production occurring at the third harvest in September (grand mean of 786 kg DM/ha). In comparison, a mixed pasture consisting of perennial ryegrass, winter grass and white clover was found by Bircham and Hodgson (1983) to display evidence of SDC at 700 kg DM/ha (harvested to the ground). Based on these findings, some phalaris tiller SDC could have been expected to occur, especially at the third harvest. However, there has been no similar studies done on phalaris-based swards and it is likely that the relationship between herbage mass and light interaction is different for perennial ryegrass and phalaris. These uncertainties demonstrate the need for further research into tiller management of phalaris based pastures to further improve livestock grazing systems.

Like tiller numbers, LAI was also shown to have a moderate correlation (R^2= 0.50) with dry matter yield (Figure 4.13). Indicating that as LAI increased, dry matter also increased. Although the rate of increase of dry matter yield in nitrogen fertilised treatments was higher than in untreated plots. Similarly, Kemp (1988) reported phalaris sward production to be a function of LAI. Over winter, the average range of LAI across all years was between 0 and 1.8, which is comparable to the findings from the Bringenbrong field trial. The LAI was found to be the lowest during winter due to the high proportion of young growing leaves.

5.2.2. Phalaris dry matter production as influenced by nitrogen fertiliser

Maintaining adequate soil nitrogen levels is required for high levels of pasture production in southern Australian soils. Phalaris production gains from improving soil fertility have been found to exceed production gains made from grazing management strategies (Chapman, et al., 2003). High inputs of N fertiliser on phalaris-based pastures in high-rainfall zones enables farm production to significantly increase through an increase of pasture growth, consequently aiding profitability from increased stocking rates (Chapman, et al., 2003).

Nitrogen is particularly important for leaf growth and consequently canopy development. Under nitrogen fertilised conditions during winter and early spring, grazier phalaris produced significantly higher dry matter (kg DM/ha) when compared to unfertilised conditions (Figure 4.7). The effects of the nitrogen fertiliser were greatest at the third harvest on September 8 with the fertilised treatments producing 3.6 times more dry matter (1226 kg DM/ha) than the unfertilised treatment (345 kg DM/ha) (Figure 4.6). These findings were supported by the findings of Hill & Watson (1989), who identified the addition of nitrogen fertiliser can increase dry matter yield by approximately three times the yield of unfertilised plants during spring. This late winter/early spring production accounted for 76% of the total dry matter produced in fertilised plots, with the remaining 24% attributed to winter production. In unfertilised plots, there was less early spring production with only 63% of the total yield occurring in this period. Similarly, Anderson et al. (1999) reported a winter production of approximately 26% of the total annual yield with the annual yields ranging 2400 – 5200 kg DM/ha. Overall, there was 138 kg N/ha applied to N fertilised treatments across 3 split applications. The accumulative yield of nitrogen fertilised plots (2035 kg DM/ha) was 2.5 times higher than unfertilised plots (804 kg DM/ha). Per kilogram of N fertiliser, there was an additional 9kg of phalaris dry matter produced on average. The differences in yield between nitrogen treatments is caused by LAI and tiller production. Across all assessments, LAI was significantly higher in nitrogen fertilised conditions (Figure 4.12). There were more tillers being produced by plants individually (per 0.1m^2) (Figure 4.8) under nitrogen fertilised conditions across all assessments, consequently, causing tiller number per m^2 to also be higher in the presence of nitrogen fertiliser (Figure 4.9).

The differences in LAI between nitrogen fertilised and unfertilised treatments became greater over time. Treated plots grew from being 1.5 to 3.6 times greater than untreated plots over the duration of the experiment. This increase indicated that the nitrogen fertilised plots had more leaf area available for photosynthesis, driving dry matter growth. A moderately strong relationship (R^2=0.50) was identified (Figure 4.13) between increasing LAI and dry matter yield. It can be identified that the rate of increase in phalaris yield as LAI increases is higher under nitrogen fertilised conditions.

Nitrogen fertiliser application caused significantly ($P<0.01$) higher production of tiller numbers per m^2 on the second and third assessments, with the first assessment approaching significance ($P=0.07$) (Figure 4.8). Unfertilised plots had a decline in tiller numbers over time, ranging from 1119 tillers/m^2 to 605 tillers/m^2. Whereas, the nitrogen fertilised plots maintained tiller numbers between 1343 to

1445 tillers/m^2, which was then followed by a decline to 1095 tillers/m^2 at the September assessment. The third assessment on September 8 had the lowest mean tiller numbers of the three assessments and also exhibited the greatest difference between treatments with fertilised plots producing 81% more tillers than unfertilised plots. The decrease in tiller numbers in September was due to less new tillers being produced as the transition to reproductive tiller growth begins. The phalaris tiller numbers reported in this study are at the lower end of the range reported by Cullen et al. (2005b), who reported densities of 1150 - 2500 tillers/m^2 in June for 3 consecutive years from a sward that was rotationally grazed every 6 weeks. In June at the Bringenbrong site, tiller production ranged 503 - 1840 tillers/m^2 with the lowest production occurring in treatment D basal frequency plots and the highest in treatment A. The differing tiller numbers is likely caused by environmental variation. The south-western Victorian site had many similarities to the Bringenbrong site in that the soil was a yellow sodosol and the timing of the autumn rain was also mid-April, however the pH($CaCl_2$) was 5.1, which was much higher than the 4.3 of the Bringenbrong site (Table 3.1).

Another possible reason for the dry matter decline in the nitrogen untreated plots is due to the lack of sub clover providing nitrogen inputs into the system. Typically, perennial grasses are sown with an annual legume component to symbiotically fix nitrogen into the system by rhizobia nodulations. Since there was very minimal clover growth at the site, there was presumably very little nitrogen being added to the system through this legume component. Due to the experimental site having been used for grass seed production for several years previously, there was minimal soil N (9.75 kg N/ha) present in the soil profile, further reducing the plant available N in the untreated plots. Bowcher (2004) found that a common pasture composition in southern New South Wales permanent pastures consisted of 25% subclover on average. With this in mind, the Bringenbrong trial site would not represent a typical pasture composition of this area.

5.2.3. Phalaris dry matter as influenced by soil acidity

Culvenor et al. (2011) described soil acidity and the associated aluminium (Al) toxicity to be responsible for reducing phalaris dry matter production through limiting root growth, causing a reduced intake of water and nutrients. Many studies have confirmed that phalaris is sensitive to the Al present in highly acidic soils (Ridley, et al., 1990; Ridley, et al., 2002; Li, et al., 2004; Ridley & Coventry, 1992; Coventry, et al., 1987). Earlier recommendations suggest that phalaris is unsuitable for growth in soils where exchangeable Al exceeds 10% and pH in $CaCl_2$ is less than 4.9 (Culvenor, et al., 1986). The results from this study indicate that the Grazier cultivar of phalaris is able to tolerate a pH ($CaCl_2$) of 4.3 and an exchangeable Al of 14% with adequate growth under nitrogen fertilised conditions (accumulative yield of 2035 kg DM/ha; Figure 4.3) whilst water is non-limiting. Later findings by Culvenor et al. (2011) have similarly identified that the previous advice was perhaps too conservative with all observed cultivars successfully tolerating 20% exchangeable Al and a $CaCl_2$ pH as low as 4.2. Cullen et al. (2005b) identified subsoil acidity to have the potential of reducing root extension at 1-2m depths, which would reduce phalaris survival in dry conditions. Further, Scott and Cullis (1992) observed pasture dry matter yield responses of up to 20% in response to lime. On this basis, it is likely to find greater limitations of soil acidity on phalaris production when water is limiting.

5.3. Clover production

In sown pastures, one of the key advantages of including a legume component such as clover is to increase soil nitrogen inputs by nitrogen fixation. Understanding the interactions between phalaris and clover can help to improve pasture systems through better management and improved sustainability. An adequate legume content in a pasture is able to contribute approximately 20-25 kg N per tonne of legume dry matter to the soil (Dear, et al., 1999). The low dry matter yield of the clover at the Bringenbrong site (Tables 4.2 and 4.3) indicated there would be little nitrogen being contributed to the soil through nitrogen fixation. Additionally, the experimental site has had no legume component present over previous years further contributing to the low N amounts available in the soil. Bowcher (2004) identified pastures throughout this region to have an average subclover component of 25%, indicating that the experimental site would not be typical of a pasture in the area. A similar soil site in Western Victoria was identified by Chapman et al. (2003) to have high subclover production, recording yields ranging 1060 – 3740 kg DM/ha over a 4-year period.

It is known that low rainfall, cold temperatures, pest damage and low phosphorous can impact on clover yield. However, it is unlikely that any of these factors have been the driving factor responsible for the low yield of the clover at the Bringenbrong site. Between the beginning of April and the last harvest on September 8, the site received 555mm of rain, which is 32% or 135 mm above the long term average indicating that water was not a limiting factor. The site received a uniform application of 25 kg P/ha, which is suffice for the site. Two pesticide applications were applied to prevent red-legged earth mite damage with no damage being observed. The minimum temperatures throughout the winter months were higher than the long term averages (Figure 3.3), with temperatures ranging between 2.8°C and 4.6°C.

Further, Evans at al. (1988) identified that there is a relationship between pH and rhizobia numbers, with acidic soils having low rhizobia populations and consequently minimising nitrogen fixation. It was observed that clover dry matter yields positively responded to nitrogen fertiliser additions by increasing dry matter production. The low pH at the Bringenbrong site is likely to be limiting rhizobia numbers, however, there was no increase in clover dry matter production under nitrogen fertilised conditions so it is unlikely that this is responsible for the low clover yields.

Another possible factor to the low yield of clover is in relation to the morphology of the species, having a large proportion of low growing points (Davies, 2001). Most of the clover biomass was below the 2.5cm cutting height during the winter harvests as the plant was becoming established. Whilst this may limit harvestable dry matter to a small extent, it is unlikely that this was the main factor behind the large differences in yields between the Bringenbrong site and other studies of similar climates. The findings of both Dear et al. (2000) and Bowcher (2004), reported that clover dry matter can be reduced by increased phalaris density, due to intense shading. This is a large contrast to the findings at the Bringenbrong experimental site (Table 4.2), where there were no interactions between clover dry matter production and phalaris basal frequency. Chapman et al. (2003) found set stocking to favour clover production when compared to a 6-week rotationally grazed cycle (1140 kg DM/ha v. 2490 kg DM/ha). It was suggested that these differences were likely to be caused by competition between phalaris and clover for light resources. The rotational grazing system allowed phalaris to accumulate more dry matter, intercepting more light and creating shading on clover plants. This is a plausible factor contributing to the low yields of the clover at the Bringenbrong site, however, it is unlikely this was a factor due to the low yields of phalaris producing very minimal shading on the clover plants throughout our experiment. Perhaps this would be more likely to show effects in spring when phalaris yields are expected to be higher and would consequently cause shading of other species.

One of the contributing factors of the low yield is expected to be the low germination of the clover throughout the site. There were no significant differences of clover establishment between plots with only 58 plants/m^2 becoming established from the applied seed rate of 300 seeds/m^2. Similar to plant removal, the addition of plants in an established pasture also has practical difficulty. The low establishment of clover throughout the Bringenbrong experimental site is attributed to two factors: the low soil pH of the site (Table 3.1) and also the difficulties of sowing seed into an established pasture. Whilst the pH at the site is low, clover is known to tolerate acid soils (Evans, et al., 1988). Therefore, it is unlikely that pH alone influenced the low establishment. Spreading seed across the soil into an established pasture often results in poor germination, with approximately 5% of seeds germinating without soil disturbance. To address this, clover seed was sown into the inter-row spacing of the phalaris, where the soil had been scarified to improve the seed to soil contact to aid germination. The site also received a uniform application of 20mm of water at the time of sowing, to aid germination at a time when rainfall was sparse. Follow up rainfall occurred 5 days after sowing and there were no water limiting periods proceeding this. A study by Dear et al. (1993) identified that one of the major factors in sub clover maintenance in a pasture is the numbers of seeds available for germination the following autumn. Subclover seed rains of between 247 to 345 kg/ha were recorded in 1984, with 2070 to 6266 plants /m^2 becoming established the following autumn. This evidence suggests that the seeding rate (20 kg/ha or 300 seeds/m^2) used at the Bringenbrong site was too conservative and consequently would have not mimicked the seed rain of an established pasture.

Whilst there are many different variables that are able to influence clover dry matter production, it is expected that the driving factor behind the low dry matter yields at the Bringenbrong field site are related to the low seed rates.

5.4. Grasses and broad-leaf weeds dry matter yield

Gaps in pasture systems provide the opportunity for either desirable or undesirable species to become established (Bowcher, 2004). By altering basal frequency, there is an opportunity for an altered botanical composition, with more undesirable species able to establish within a pasture. The ability for an annual species to establish within a perennial pasture depends on their ability to compete for resources. Piggin and Sheppard (1995) identified a relationship between dry matter accumulation of annual weed species and their subsequent seed production. Therefore, suggesting that reducing the annual dry matter production of annual weeds through increasing competitive pressure of the sown species should minimise weed seed production. This is a contrast to the findings at the Bringenbrong field site, with a weak positive correlation identified between phalaris dry matter production and both other grasses production (R^2= 0.21; $P<0.01$) and also BLW production (R^2=0.13; $P<0.05$). These findings suggest that as phalaris dry matter increases, the yields of both the BLW and other grasses components will also increase. A possible reason for these results could be the yields of phalaris failing to provide substantial competition with the weed species for resources. It is plausible that the expected higher spring yields of the phalaris will provide greater competition against the weeds species and consequently alter the relationship between annual weed yield and phalaris production.

The basal frequency treatments caused no significant differences between the accumulative dry matter production of the three non-phalaris components (Table 4.2). Clover contributed significantly less dry matter (12.8 kg DM/ha) than BLW (547 kg DM/ha) and the other grasses component (887 kg DM/ha). Nitrogen fertiliser effects had no significant effects on clover or BLW yields (Table 4.3). However, there was found to be significant effects on the other grasses component with nitrogen fertiliser conditions yielding 3.4 times more than untreated plots.

The biggest contributor to the BLW component was capeweed, with wireweed and sorrel contributing smaller portions. A study by Chapman et al. (2003) identified capeweed to be a significant portion of the phalaris-based pastures producing between 40 – 1220 kg DM/ha under rotationally grazed systems. These capeweed yields comprised of <15% of the total pasture yields, which is similar to the findings of the Bringenbrong field site where 19% of the total yield was produced by all BLW species combined.

A study by Culvenor et al. (1996) identified that presence of annual grass species in a phalaris-based pasture resulted in higher yields and also higher nutritional quality of the pasture over winter, leading to higher sheep live weights. However, due to these annual species having a shorter season than phalaris, they will decline in quality faster during spring due to reaching reproductive development earlier. The total accumulative dry matter production of all species rapidly increased over time, producing an accumulative total between 2202-3445 kg DM/ha (Figure 4.14). The first harvest in June identified a significant response between basal frequency treatments, whereas the latter two harvests in July and September showed no significant response. The initial response is attributed to the lack of companion species with phalaris being the dominant contributor to the produced yield. Once the other pasture components began producing more biomass, there was no observed response to dry matter yield as influenced by basal frequency treatments.

The total yields of all species were highly responsive to nitrogen fertiliser, with 3.1 times more dry matter being produced in the fertilised plots (4342 *v.* 1390 kg DM/ha; Figure 4.15). Currently urea costs $450/tonne. Therefore, at the total applied rate of 300 kg urea/ha, the total cost of application is $135/ha. The winter period in colder climates is often a period of reduced pasture supply due to the cold temperatures and shorter day lengths. Pasture hay currently costs between $220-$230/tonne in the Northern Victorian region. Therefore, considering there was an additional 3000kg DM/ha produced in N fertilised plots, applying N fertiliser has proven to be more economical when compared to buying in supplementary hay and would also likely be better in quality. Conversely, if the pasture was to be used for fodder conservation instead of grazing, the additional dry matter produced between April to September would equate to a $660-$690 increase in profits per hectare from additional fodder able to be sold. It is expected that this gap would be further increased over spring as pasture growth substantially increases, further increasing the potential profits gained under N fertiliser.

5.5. Pasture quality

The nutritive quality of livestock diets is determined by the supply of energy and nutrients ingested and measured as digestibility (%), metabolisable energy (ME) (MJ/kg DM), crude protein (CP) (g/kg

DM) and fibre (g/kg DM) content, with additional mineral and vitamin components. Anderson et al. (1999) suggested that maintaining high digestibility for prolonged periods, especially during maturation, will improve the nutritive value of pasture species. Phalaris nutritive values vary considerably throughout the year due to the varied structural composition and growth stages (Anderson, et al., 1999). Previous studies have identified phalaris to have the highest nutritive quality after the break of season, during vegetative growth stages (Anderson, et al., 1999; Greenwood, et al., 2006).

The implications of increased dry matter production on quality are related to the increase in ME on offer, with more pasture available equating to an increase of energy produced by the pasture. These increases in feed production can improve grazing productions by improving the carrying capacity of the pasture and reducing the need for supplementary feeding.

Variances in phalaris basal frequency in an established pasture resulted in a change in botanical composition (Culvenor & Oram, 1996). A study assessing phalaris basal frequency under grazing by Culvenor et al. (1996) identified that as phalaris dry matter (kg DM/ha) declined, both clover and other grass production increased. An increase in botanical diversity of the pasture will consequently alter the quality of the feed on offer and implicate livestock production. Legumes are considered to be nutritionally superior for ruminants when compared to grasses (Walsh & Birrell, 1987). This evidence suggests there is potentially a quality trade-off that is able to occur as phalaris basal frequency is reduced and clover basal frequency increased. However, the low dry matter yield of the clover at this field site would not be contributing enough to raise the quality of the phalaris pasture. Further study in a pasture with higher clover populations would be necessary to better assess any possible quality trade-offs. Annual grasses are highest in quality during vegetative growth over the winter season. As they start to mature and convert to reproductive development, quality declines. Phalaris maturation occurs later in the season than annual grasses due to the longer growing season of the perennial species. Therefore, prolonging the quality of the feed on offer for longer than comparable annual grass species.

6. Limitations

The experimental site is an established phalaris seed crop which was has had no legume component present for several years. Thus, limiting the accumulation of N in the soil profile from previous years of N fixation by the legume component. Due to this, the experimental site is not considered a typical pasture where a legume component is actively contributing nitrogen into the system. Further research would need to be conducted to quantify the effects of nitrogen fertiliser on an established pasture that has had a legume component present over previous years. With this in mind, it should also be noted that this limitation in nitrogen within the system did not influence basal frequency treatments. Due to the absence of an interaction between the nitrogen and basal frequency treatments, it was identified that the effects of basal frequency are consistent in both high and low nitrogen conditions in a phalaris dominant pasture.

Due to the scope of an honours year, this study is also limited by the time available to assess the relative change of phalaris basal frequency over an entire season. Further research assessing the response of phalaris and other companion species to basal cover over successive seasons would be beneficial. This would allow colonisation mechanisms to be further investigated which would clarify basal frequency effects for producers, identifying if there is opportunity for a phalaris-based pasture to be salvaged or if resowing at a basal cover below 20% would still be necessary.

7. Conclusions

Understanding the effects of phalaris basal frequency in an established sward is beneficial to producers for optimising pasture productivity and determining when production is low and pasture rejuvenation necessary. Basal frequency was shown to have significant effects on accumulative dry matter yields of phalaris across a six-week defoliation interval between April and September 2016. Density below 20% decreased phalaris yield whereas above this level was within the optimum range for dry matter production. In swards below 20% basal cover where production has declined, it would be appropriate to consider resowing the pasture to improve pasture productivity.

There were no interactions observed between nitrogen fertiliser and basal frequency treatments which indicated that the benchmark levels for basal frequency were held in both low and high fertility environments. The accumulative yield of phalaris dry matter was 2.5 times higher under nitrogen fertilised conditions, averaging an accumulative yield of 2035 kg DM/ha. This is an average of 9kg/ha of extra phalaris DM produced per kg of N/ha applied.

There was no response by clover and broad-leaf weeds to basal frequency treatments or nitrogen fertiliser application. However, the annual grass component had a significant response to fertiliser application. The combined accumulative dry matter yield of all species was 3.1 times higher under nitrogen fertilised conditions, producing an additional 21 kg DM/ha for every kg of applied N/ha.

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