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LEGUME ABUNDANCE IN NEW ZEALAND SUMMER-MOIST AND SUMMER-DRY HILL COUNTRY PASTURES

A thesis presented in partial fulfilment of the requirements

of the degree of

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*To Paulina, for her love, patience and constant support
To Nicolas, Benjamin, Vicente and 'Chumi', my dear boys
To my dear father who inspired me
To my mother for her unconditional love*

... 'Immer wenn Du meinst, es geht nicht mehr, kommt von irgendwo ein Lichtlein her...'

ABSTRACT

The introduction of legumes has been a central factor in hill country pasture improvement in New Zealand since they are able to fix atmospheric nitrogen to contribute to pasture production and also improve pasture quality. However, at present legume content of hill swards has dropped to generally very low levels which will likely affect medium-long term sustainability of these pastoral ecosystems. This thesis is focussed on determining the relative importance of management and environmental factors that affect legume abundance in hill country swards. A series of field experiments were undertaken between May 2000 and April 2002 in contrasting summer-moist (Ballantrae; 40°19'S, 175°50'E) and summer-dry (Waipawa; 40°00'S, 176°23'E) hill country areas, including north aspects and south aspects at Waipawa, to evaluate the relative impacts of cutting height (targets of 3 or 7 cm), grass suppression by application of selective herbicide, soil-P status (high or low), autumn nitrogen application (0 or 50 kg N/ha), defoliation management (cutting, and rotational grazing with sheep), on legume abundance. A glasshouse experiment involved the effects of companion grasses and defoliation on individual white clover and subterranean clover plants grown in pots.

The suppression of grass competition caused the most marked changes in short-term sward composition, with an increase in legume abundance at all sites. Increasing soil-P status increased legume abundance, especially where white clover was present as a major botanical component. Altering pasture cutting height or applying nitrogen in the autumn had comparatively minor effects on legume abundance. Defoliation management (i.e. rotational grazing with sheep compared with cutting) played a secondary role in affecting legume abundance of swards, at least in the short term.

Residual effects of grass suppression resulted in an increase in legume abundance, which persisted for at least one year after treatment and affected legume species composition in the drier Waipawa north aspect. Pastures in the summer-moist areas showed a high degree of resilience and reverted quickly to the original grass dominance. Inter-annual and site contrasts in soil moisture patterns highlighted the relevance of soil moisture as a key factor in determining legume abundance and production, mainly in the summer-dry areas. In the glasshouse trial, severe defoliation had very strong effects, reducing plant size, leaf area, vegetative stem development and branching of individual legume plants. Moreover, root competition from grasses was seen to significantly limit clover shoot growth, this being more important than the shading effect.

From these experiments, it is suggested that the relative importance of factors affecting legume abundance in hill pastures is: soil moisture (if limiting, e.g. summer-dry hill country) > grass suppression > soil-P status > defoliation management > nitrogen application. However, some of these factors have been noted to interact, and relationships can acquire higher levels of complexity.

This study highlighted the relative importance of factors that influence legume abundance of hill country swards and showed that pasture composition can be dramatically modified and legume content increased, but also that these changes can be short-lived. Summer-dry hill country pastures strongly rely on highly variable non-manageable seasonal and inter-annual soil moisture profiles, and legume abundance is difficult to predict and less stable in time than in summer-moist conditions. However, a high potential of legume abundance is achievable with adequate soil moisture in summer, even at low soil-P status. In these dryland areas, the combination of limiting soil moisture, close-to-ground defoliation, and selective grazing, is likely to severely limit white clover growth and spread, and be aggravated by low soil-P status, as well as subterranean clover growth and seed set, therefore compromising legume abundance in the following season.

High tiller population density, combined with a high frequency and intensity of legume defoliation, will put legumes under stress from severe grass competition, ultimately affecting legume abundance. This is likely to be the case for many intensively set stocked hill country systems managed with sheep.

Keywords: Hill country pastures, legume abundance, white clover, subterranean clover, soil moisture, summer-dry, summer-moist, grass suppression, competition, cutting, rotational grazing, soil phosphorus status, nitrogen fertiliser.

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CHAPTER 1

GENERAL INTRODUCTION



***Summer-dry hill country at Waipawa
(Hawke's Bay, North Island, New Zealand)
(November 2001)***

1.1 INTRODUCTION

The development of New Zealand's hill country pastures has been based on fertiliser topdressing (especially phosphorus and sulphur), over-sowing with improved grass and legume species, subdivision and stock management to ensure full pasture utilisation. This has been the result of decades of research and has been extensively reported in the literature (Levy, 1970, Suckling, 1975, Lambert *et al.*, 1986a, 1986b, Lambert *et al.*, 1986c, White, 1990).

A central factor in hill country pasture improvement has been the introduction of high producing legumes (White, 1990), white clover being the most widespread (Caradus *et al.*, 1996b), especially in areas with summer-moist conditions. Increased legume content in the sward is of paramount importance to ensure that adequate nitrogen is fixed and made available for grass growth (Chapman and Macfarlane, 1985, Lambert *et al.*, 1986a, White, 1990, Caradus *et al.*, 1996b, Woodfield and Caradus, 1996). Improved legumes and particularly white clover also improve sward feed quality, complement the seasonal production of the grass component of the sward, and improve forage intake and utilisation rates of stock (Caradus *et al.*, 1996b).

In the summer-moist hill country of the North Island, with moderate to high rainfall, white clover is the most important legume species in pastures (Suckling, 1975, Lambert *et al.*, 1986a, 1986b, White, 1990). On the other hand, the legume component on the dry hill country areas is dominated by annuals, which have a more limited growing period, and make a lower contribution to production and N fixation (Chapman and Macfarlane, 1985, Gillingham *et al.*, 1998).

Hill country pastures present a high degree of diversity, due to spatial variation in the factors that influence plant growth, such as temperature, rainfall, soil moisture, soil fertility, grazing behaviour and pasture management. Slope and aspect of hills modify

the preceding factors and produce a series of micro-sites with contrasting pasture production (White, 1990).

Superphosphate topdressings in the initial developments of hill country pastures resulted in high legumes content (Suckling, 1975, Lambert *et al.*, 1982, White, 1990, Gillingham *et al.*, 1998). Legume participation in the sward production has declined since, and ideal levels of at least 20-25% stated by Suckling (1975) are rarely achieved under hill country conditions. Levels of 10% after years of pasture improvement on summer-moist hill country have been reported (Lambert *et al.*, 1982), while lower levels of 8% in spring/summer and 4-5% in autumn and winter are reported by Barker and Dymock (1993a). On dry hill country, legume content of the swards is even lower and less predictable due to inter-annual rainfall differences. On resident pastures white clover contribution varied from 2 to 5% between years (Barker and Dymock, 1993a, Barker *et al.*, 1993a, Orr and Wedderburn, 1996). Gillingham (1998) observed subterranean clover levels of only 2-4%, even at high P applications.

Legume persistence (maintenance of clover content per unit area over time) (Woodfield and Caradus, 1996) is a generalized problem in hill country pastures, even at adequate phosphorus soil levels. The likely causes for the low legume contents in swards include increased grass competition due to improvement in fixed nitrogen content in the soil (Lambert *et al.*, 1982, Lambert *et al.*, 1986a, Woodfield and Caradus, 1996), lack of soil moisture (Chapman and Macfarlane, 1985, Barker *et al.*, 1993b), high temperatures (Chapman and Macfarlane, 1985, Barker *et al.*, 1993b), and frequency and intensity of defoliation (Suckling, 1975, Lambert *et al.*, 1982, Chapman and Macfarlane, 1985, Lambert *et al.*, 1986a, Barker *et al.*, 1993b, Woodfield and Caradus, 1996, Gillingham *et al.*, 1998). Considerable effort has been put into attempts to re-introduce legumes through over-sowing of hill country pastures, generally with limited success (Awan and Kemp, 1994), while it has also been shown that natural seedling regeneration of white clover plays a minor role in moist environments (Chapman, 1987).

Price structures of the markets, higher costs and removal of fertiliser subsidies have also caused a reduction in inputs to hill farms, such as maintenance fertiliser (White, 1990). This could also be a threatening factor to hill pasture sustainability, as legume levels could drop further. In some situations, the strategic use of nitrogen to boost early pasture growth can also have a deleterious effects on legume content (Ball *et al.*, 1976, Lambert and Clark, 1986, Barker *et al.*, 1993a, Gillingham *et al.*, 1998).

Likely causes for low legume abundance (and especially white clover and subterranean clover) in hill country pastures have been reported, but their relative importance has not been sufficiently tested under various conditions, especially on summer-dry hill country. Inadequate soil moisture seems to be an overriding factor, but it is of interest to study the effect of different factors and also their likely interactions on legume abundance, in contrasting environments of the North Island hill country, and determine how management practices could be modified to increase the legume content of these swards.

1.2 OBJECTIVES

Recognising the overall importance of legumes in hill country pastoral systems, both for optimal animal production and for the sustainability of these relevant New Zealand environments, and taking into account the problem of normally low average legume abundance in hill pastures, the aim of this research project is: *'to determine the relative influence of management and environmental factors on legume abundance in New Zealand summer-moist and summer-dry hill country pastures'*.

The objectives of this study are the following:

- a) to determine effects of pasture cutting height, grass suppression, soil P status, and nitrogen application on legume species abundance in contrasting environments.

- b) to evaluate the effect of rotational grazing and cutting management on legume abundance and production of contrasting swards.
- c) to analyse the effect of grass suppression and companion grasses on the growth of individual *Trifolium repens* L. and *Trifolium subterraneum* L. plants.
- d) to evaluate the relative importance of these factors on legume abundance in hill pastures growing in contrasting environments.

1.3 THESIS OUTLINE

The thesis is organised in six chapters, starting with a review of relevant literature (chapter 2), followed by experimental results from field studies carried out in summer-moist (Ballantrae near Woodville) and summer-dry (Waipawa, Hawke's Bay) hill country (chapters 3 and 4), results from a glasshouse experiment to test effects on individual legume plants (chapter 5), and a final section (chapter 6) where a general overview is given and conclusions drawn with possible implications. The mentioned chapters can be described as follows:

1.3.1. Chapter 2

The chapter consists of a review of literature, starting with a general overview of the relevance of legumes in New Zealand hill country systems, and focusing afterwards on factors affecting legume performance, abundance and persistence, especially in hill country environments.

1.3.2. Chapter 3

This chapter presents a set of three field experiments under monthly cutting management, that were established on the north and south aspects of a summer-dry hill pasture, and on a summer-moist hill country pasture, respectively. The effects of grass

suppression, cutting height, soil-P status, and N application on legume species abundance are tested. Standing herbage mass and botanical composition are quantified.

1.3.3. Chapter 4

Chapter four focuses on two field experiments that were carried out on two of the previous year's trials, in which the effect of rotational grazing on legume abundance was introduced as a factor, maintaining swards with different grass suppression levels, and also contrasting soil-P levels. Standing herbage mass, as well as herbage accumulation and its corresponding botanical composition were measured.

1.3.4. Chapter 5

This chapter describes a glasshouse experiment designed to evaluate the effect of companion hill grasses on the growth of individual white clover and subterranean clover plants. It measures the effects of different levels of grass interference, defoliation, and root exclusion on legume growth and production. Legume plant variables measured include shoot DM, shoot composition, leaf area, branching, and root mass.

1.3.5. Chapter 6

This final chapter presents a synthesis and integrating discussion of the main results exposed in the previous three chapters, with some implications, and followed by general conclusions of the study.

CHAPTER 2

LITERATURE REVIEW

The available information on white clover and for subterranean clover, is extensive and covers multiple aspects related to these important legume species. This review starts with an overview of the relevance of legumes in New Zealand hill country, considering the development of hill pastures, the contrasts of hill country sites, and the main characteristics of white clover and subterranean clover as important legumes in hill swards. After these preliminary considerations, the literature review is focused mainly on the impact of factors that can affect legume (particularly white and subterranean clover) persistence and abundance, and acts as a framework for the research undertaken in this thesis.

2.1 RELEVANCE OF LEGUMES IN NEW ZEALAND HILL COUNTRY

2.1.1. Pasture development in hill country

Since the arrival of European settlers, pastoral farming in New Zealand has passed through different stages of development. The utilisation of existing grassland (pastoralism) was the first phase and occurred mainly in the South Island up to 1870. The development of the frozen meat industry was the cause for extensive clearing of bush for pasture development between 1870 and 1920. Intensification of farming followed between 1920 to 1970 through the use of science and technology. In the last decades, the use of science and technology have been intensified, and issues like product quality, marketing and diversification became central (White, 1999). More recently, sustainability of pastoral farming has become a major issue (Mackay *et al.*, 1993).

A substantial contribution to the New Zealand economy comes from hill country pastures, since its 3.5 million ha support 35% and 20% of the total sheep and cattle population respectively (Valentine and Kemp, 1999). To achieve this, large-scale improvement of hill country pastures was based on the development of aerial topdressing and oversowing techniques (Charlton and Grant, 1977, White, 1990).

Together with the application of fertiliser (especially P and S based), the introduction of legumes was the key to improve hill country pastures. This generated a cycle of soil fertility building that started with initial legume dominance characterised by high nitrogen fixation, followed by a gradual change to grass dominance as the C:N ratio decreased, and ending with a grass dominant sward (Brock *et al.*, 1989, White, 1990).

Although the introduction of species or improved cultivars in hill country may improve botanical composition of pastures, it is only complementary to other management procedures that influence resident pastures. Fertiliser application and stock management are likely to have a dominant influence on animal performance and farm productivity (Chapman and Macfarlane, 1985, Lambert *et al.*, 1985, Kemp *et al.*, 1996).

Long term pasture yields and pasture feed quality are likely to be affected if clover yields are significantly reduced in hill country (Luscombe *et al.*, 1981), and better persistence and reliability, especially of white clover, is critical in sustaining a competitive New Zealand farming industry (Woodfield and Caradus, 1996).

More recently, low prices, higher costs, and removal of subsidies have caused hill farmers to reduce inputs such as maintenance fertiliser (total fertiliser applied by air had a five-fold decline between 1980 and 1987 (White, 1990). Hill farming systems are not sustainable at current levels without sufficient fertiliser input and grazing pressure, as pastures may revert to lower producing grass species and eventually to woody shrubs (Parker and McCall, 1986, Valentine and Kemp, 1999). Experiments that have withheld P on previously topdressed hill country have reported a medium-term reduction in pasture production and stocking capacity (Gillingham *et al.*, 1990). Signs of

deterioration that affect overall sustainability of pastoral farming in hill country have been reported, like soil slips and erosion losses (Trustrum *et al.*, 1984, Mackay *et al.*, 1993), decrease in soil organic matter (Lambert *et al.*, 2000), on-site land degradation, and steadily decreasing average returns for production (Mackay *et al.*, 1993). Lambert and Barker (1996) studied biophysical indicators of sustainability of hill pasture systems, and suggested that botanical composition and earthworm populations may be useful variables involved, and these were also highly correlated with herbage production.

2.1.2. Hill country contrasts

In New Zealand, the influence of the position of the mountain ranges in both islands on a predominantly westerly airstream creates differences in rainfall distribution. Western areas are characterised by wetter than average conditions, while drier than average conditions prevail in the eastern areas, where evaporation rates exceed incoming rainfall for much of the year and seasonal droughts are common (White, 1999). Hill country in the North Island is therefore traditionally divided into summer-moist and summer-dry areas. The main legume in summer-moist hill country is white clover, while mostly annual species occur in summer-dry hill country pastures (Suckling, 1975, Chapman and Macfarlane, 1985, Lambert *et al.*, 1986a, 1986b, White, 1990).

Soil moisture constraints are a major limitation to pasture growth in hill country and are not necessarily confined to summer-dry sites. Moisture deficits can also occur on a more localised scale within wet regions, as is the case of steep north faces (Chapman *et al.*, 1986). In general, pasture herbage accumulation is greater on south aspects than on north aspects of summer-dry hill country, and over summer and autumn, herbage on south aspects has a higher digestibility than on north faces (Radcliffe, 1982). Gillingham (1973) reported higher pasture growth rates during winter and early spring on steep north aspects, that may produce more total annual dry matter than on south aspects. North faces had higher wind speed and higher evapotranspiration values than south aspects. Contrasts between north and south faces included, net radiation differences

being largest during winter, soil moisture lowest in north aspects, but north aspects being warmer than south aspects, especially between January and August (Lambert and Roberts, 1976).

Within aspects, the slope category influences soil moisture status and soil fertility, which in turn will affect pasture production and botanical composition. Areas on slopes are consistently drier in the surface horizon because of less effective rewetting compared with flat areas. Longer rainfall events are required for adequate soil moisture to develop, which has an impact on seasonal reseeding (Sheath and Boom, 1985a, Dodd *et al.*, 1995a). On steep slopes, soil fertility is lower, and easy and medium slope sites had 88 and 36% greater herbage production than steep slopes (Lambert *et al.*, 2000). Differences in soil fertility between slope categories are partially due to differential dung deposition in relation to slope, being greater on easy than steep land (Gillingham, 1981). Camp sites and stock tracks usually have higher organic carbon, nitrogen, phosphorus, and potassium levels, and reflect nutrient transfer by grazing animals and also *in situ* nitrogen fixation (Sheath and Boom, 1985a, Ledgard *et al.*, 1987, Rowarth and Tillman, 1992). Stock campsites had the highest DM production (14.3 t DM/ha), followed by gentle slopes with white clover (WC), gentle slopes with subterranean clover (SC), and the least DM production was on steep slopes with SC (5.3 t DM/ha). Lower yield of ryegrass on slopes largely caused the differences observed (Ledgard *et al.*, 1987).

Reduction in pasture production with increasing slope was connected to decreasing moisture and nutrient availability, and more photosynthate being partitioned to roots, to compensate for limited resources available (Saggar *et al.*, 1999). Typically, land up to 15° slope will contain WC as its main legume component, and in steep land over 30° annual legumes will be the dominant legumes, while on intermediate slopes, both annual and perennial legumes will co-exist (Ledgard *et al.*, 1987). Higher proportions of legumes, especially annuals like *Trifolium dubium* L. (suckling clover), are often reported on steep slopes, which may reflect the lower N status of these sites (Luscombe

and Fletcher, 1982, Saggar *et al.*, 1999). The complexity of plant communities was also seen to increase between the flat areas and easy hill country slopes, and changes in species composition through management were observed (Sheath and Boom, 1985b).

Although annual legumes are most abundant on steeper slopes or warmer north aspects, populations are often more related to micro-topographical variation of micro-sites, rather than uniformly spread throughout the sward (Sheath and Macfarlane, 1990b). These micro-sites differed especially in soil strata characteristics, many times determined by differential nutrient fluxes as affected by grazing animals, and summer rewetting patterns of particular micro-sites, and differences may be of higher magnitude than those between aspects (Radcliffe, 1982, Sheath and Boom, 1985a). Micro-site differences also affect species distribution in the pasture, ryegrass being dominant on nutrient rich campsites and tracks, browntop abundance increasing with steepness of slope, WC peaking on rolling and easy slopes, and annual legumes abundance increasing in steeper terrain (Sheath and Boom, 1985a).

2.1.3. Legume species in hill country

Amongst the benefits of the introduction of improved plant species to hill pastures are: improved annual or seasonal production, higher nutritive value, and better tolerance of low fertility, grazing, drought, treading, or pest and diseases (Lambert *et al.*, 1985).

White clover (*Trifolium repens* L.) is the most important species for introduction under moderate to high rainfall. Even in lower rainfall areas, where subterranean clover (*Trifolium subterraneum* L.) may be the more important species, white clover has still a space in shady slopes, wet hollows, and other sites where soil moisture is not a major constraint (White, 1990). In summer-dry hill country areas, where white clover growth is limited by a seasonal deficit of soil moisture, subterranean clover has a potentially important role in the sustainability and productivity of hill country/dryland pastures (Dodd *et al.*, 1995c), due to its adaptation through larger seed size, rapid establishment and good cool-season growth (Chapman *et al.*, 1986).

2.1.3.1. *White clover (WC)*

White clover is probably the most important pasture legume in temperate zones of the world, with a wide climatic range and high nutritional quality, it contributes significantly to the economy of grass/WC pastures by fixation of atmospheric nitrogen (Frame and Newbould, 1986). WC is a stoloniferous clonal legume and its populations develop through both seedlings (genets) and node production (ramets) (Barrett and Silander, 1992). It is regarded as a perennial, but ecotypes found in marginal environments may display annual habit (Lane *et al.*, 2000). Some authors have classified WC as a winter annual that may behave as a perennial through asexual propagation (Hollowell, 1966). In temperate climates, annual production of WC monocultures ranges from about 4000 to 14000 kg DM/ha (Harris, 1987).

The basic structural unit of the WC plant is the stolon, which consists of a series of internodes separated by nodes which form as a result of growth at the apical bud. Each node bears a trifoliate leaf with an erect petiole, two root primordia, and, during the purely vegetative stage of growth, an axillary bud which is capable of growing into a lateral stolon (Thomas, 1987, Forde *et al.*, 1989). The formation of adventitious roots at the nodes in contact with moist ground provide a degree of nutritional independence to lateral stolons and permit their viability when the parent stolon dies off (Thomas, 1987).

The most important adaptive feature of the WC root system is its capacity to form nodules hosting symbiotic microbes of the genus *Rhizobium* which provide a supply of N to the plant independent of that available in the soil (Harris, 1987). For adequate fixed nitrogen supply resident rhizobia must be available or seeds need to undergo inoculation and eventually pelleting (Macfarlane and Bonish, 1986).

When established from seed, two distinct morphological growth stages occur, a seminal tap-rooted phase with radiating stolon systems lasting 1-2 years, followed by a clonal growth form. Transition of a plant from tap-rooted to clonal form occurs when the parent stolon dies, releasing a variable number of stolon systems as independent clonal

plants (Brock, 1972). The nodal roots often grow up to 15 cm long before lateral roots begin to grow from them and form a vigorously branching root system. In some cases, adventitious roots can have secondary development to become taproots (Thomas, 1987).

WC follows strong seasonal variations in plant size, with a significant decrease in spring with recovery over the following summer. In spring, stolon death exceeds stolon formation, and plants break up into smaller, less branched and more fragile units (Brock *et al.*, 1988, Hay *et al.*, 1988, Brock *et al.*, 1989), and at this stage starch reserves in stolons reach also a minimum level and the plant is at a particularly vulnerable stage (Hay *et al.*, 1989b). Depending on season, different proportions of stolons may be also either buried, at the surface, or aerial (Hay *et al.*, 1983); surface stolons peak in summer (48%), while maximum buried stolons occur in early spring (86%) (Hay and Chapman, 1984), and it is during the spring period where most buried stolons die, as large plants break up into smaller, less branched plants (Hay *et al.*, 1989a).

Stolons are the main storage organs that support WC growth, and the position of a node in a stolon largely determines the predominant carbohydrate content (hexose, sucrose or starch) (Hay *et al.*, 1989b). Highly-branched WC plants are regarded as more stable than weakly-branched plants, since C fluxes occur between branches and parent apex and *vice versa*, and defoliation or shading effects may therefore be buffered (Chapman *et al.*, 1989, Chapman, 1992).

A mature WC plant consists of a hierarchy of stolons (Thomas, 1987), and each successive order of branch stolon is smaller than the preceding. Brock *et al.* (1988) found that in branched plants, 55% of stolons were rooted, and rooted stolons accounted for 85% of stolon length, and carried 62% of the leaves, 48% of growing points, and 90% of axillary buds per plant, respectively.

The major problem with contemporary WC cultivars, particularly in dry environments, is that production fluctuates widely from year to year, which is largely due to poor

stolon survival during summer moisture stress (Lane *et al.*, 2000). Harris (1987) showed a large variation from 11.8 to 38.5% in WC content of swards in New Zealand.

WC has two complementary mechanisms of reproduction; vegetative perennation through the stolon system and regeneration by seedling recruitment from seed; the relative importance of these mechanisms depends on the influence of the environment on stolon survival (Hoglund and White, 1985, Lane *et al.*, 2000), and the flowering and seed production mechanism will be of particular importance where conditions are marginal for stolon survival (Hay and Chapman, 1984, Lane *et al.*, 2000).

During the reproductive phase, inflorescences are borne singly in the axils of some leaves, replacing the vegetative buds which otherwise form in those positions (Thomas, 1987). Each inflorescence consists of 20-150 florets (Lane *et al.*, 2000). In environments where moisture stress is regular and severe, WC will need good seedling establishment to maintain its population in most years, which may be limiting due to its small seed and slow seedling growth (Chapman *et al.*, 1986). In drought-prone areas seedling densities in excess of 150/m² in autumn may contribute to sward stability (Macfarlane *et al.*, 1990b). In wetter areas, seedling recruitment will be of much lower magnitude, but at least several new genets are added to these populations on a yearly basis, especially on disturbed sites (Barrett and Silander, 1992). In some circumstances allelopathic effects from the same species or companion grass species may also influence low germination and seedling survival (Lane *et al.*, 2000).

In New Zealand, Macfarlane *et al.* (1990a) concluded that WC content was more defined by site factors than genetic potential of cultivars. However, specifically selected cultivars for New Zealand hill country situations have been developed (Grasslands Tahora and Prop), that are small and densely-leaved with a high stolon density and tolerance to continuous defoliation (Tahora), with early and prolific flowering (Prop) and tolerance to lower fertility levels (Macfarlane and Sheath, 1984, Chapman and Macfarlane, 1985, Macfarlane *et al.*, 1990b, Caradus *et al.*, 1996a, Caradus *et al.*, 2000). It is more adapted to set stocking with sheep than other cultivars (Brock, 1988). Larger-

leaved cultivars, like Grasslands Huia, have been seen to have lower adaptability to hill country conditions, especially when grazed mainly by sheep (Brock, 1972, Charlton, 1984), owing to factors like slower stolon elongation rate (Caradus *et al.*, 2000) and vulnerability of stolons to damage by grazing (Macfarlane *et al.*, 1990b).

Finally, WC has some ‘anti-nutritional’ factors that can have negative effects on animal performance. These include bloat, cyanogenesis, and in some cases oestrogenicity are mentioned for WC (Lane *et al.*, 2000).

2.1.3.2. *Subterranean clover (SC)*

Subterranean clover or subclover (*Trifolium subterraneum* L.) is a winter annual forage legume with prostrate growth habit and branching non-rooting stems, which grow close to the soil surface. It is tap-rooted with many lateral root branches. From the three subspecies (*subterraneum*, *brachycalcynum* and *yanninicum*), the former is the most widely grown (Frame, 1998). Adapted to hot dry summers and moist mild winters, SC has a life cycle adapted to escape summer drought, germinating in autumn, followed by a main growth period during autumn to late spring. It produces seed prolifically and remains dormant during summer with the seed burrs embedded or buried (geocarpy) in the upper layers of the soil (Rossiter, 1978, Frame, 1998, Frame *et al.*, 1998).

In southern Australia, SC is the dominant pasture legume species present (Rossiter, 1978). It was introduced to New Zealand at the end of the XIX century and subsequently was widely sown on the dry plains of Hawke’s Bay, the Wairarapa, Marlborough, and Canterbury (Suckling *et al.*, 1983). It is used particularly where rainfall is less than 750 mm and summer moisture deficits are likely, fertility is moderate to high, and frosts are infrequent (Hoglund and White, 1985, White, 1990). SC is usually linked to sites where WC does not persist (Sheath *et al.*, 1990). Although SC responds to P application, it is able to maintain high levels of growth at low soil P levels, as reported by Dodd and Orr (1995b). As SC is predominantly self-fertilised, the cultivars tend to retain their characteristics even when grown in mixtures (Suckling *et al.*, 1983).

There are three main stages in the life cycle of subterranean clover: survival of seed and re-establishment, vegetative growth, and seed production of the established seedlings (Smith and Crespo, 1979). Regeneration of subterranean clover is the result of a complex interaction between times of flowering, rainfall and temperature regimes (Smetham and Wu Ying, 1991).

Annual seed production is an important feature for persistence of subterranean clover, and high seed yields are linked with the ability of lines to recommence flowering after drought periods (Smetham *et al.*, 1994, Lodge, 1995). Sowing date influences the length of the intervals to flowering, with the longest intervals occurring with early sowing dates, while highest numbers of burrs and seed are obtained with intermediate sowing dates (Lodge, 1995). However, the length of the flowering period is not necessarily linked with successful reseeding (Dodd and Orr, 1995b).

The soil seed bank maintains large reserves of seed available for seasons of low seed production (Frame, 1998). Sheath and Macfarlane (1990a) reported that seed inputs of 2000/m² were required to generate maximum subterranean clover densities within the pasture community of a drought prone hill environment. However, between seed set and the following winter, seed counts decline sharply, and total seedling emergence accounts for only a small proportion of estimated seed production (Lodge, 1995).

The proportion of hard seed is usually quite variable, but can reach 40% or more of total seed produced (Frame, 1998). Limitations to germination are due to impermeability of the testa or hardseededness, and other types of dormancy, mainly embryo dormancy (Rossiter, 1978). The characteristic of a high level of hard seed is desirable under some circumstances to provide insurance against false strikes in the same season, but a high degree of such hardseededness should be lost before autumn if adequate germination and successful establishment is expected to occur (Smetham and Wu Ying, 1991). Hard seed may not survive to contribute to successive generations as well as has been supposed, and only a relatively small amount of seed does carry over to the second season and very little indeed survives for two or more years (Smetham and Wu Ying, 1991). Taylor and

Ewing (1988) found that 20-25% of the SC seed set in year 1 germinated in year 3, while a very low proportion (3%) survived to germinate in year 4.

The false germination strike events in summer, where subsequent drought kills emerging seedlings are an important source of seed loss (Sheath and Macfarlane, 1990b, Dodd *et al.*, 1995a), and SC regeneration is limited especially when reseeding levels are low (Sheath and Macfarlane, 1990b).

Larger seed and seedling size than WC, and faster seedling growth make SC more competitive at establishment (Awan and Kemp, 1994, Frame, 1998), and winter densities of *c.*200 plants/m² are sufficient to achieve high pasture yields within any one year (Sheath and Macfarlane, 1990b). Winter plant population density is also related to spring cover, while late-season cover was related to the subsequent year's regeneration (Dodd *et al.*, 1995b).

Attributes of SC include the existing genetic diversity (strains), number of seeds per burr, and the capacity to form viable seeds aboveground (Rossiter, 1978). Key factors in SC production and persistence in New Zealand summer-dry hill country are characteristics of late maturity, strong autumn regeneration with at least 200 plants/m², a long growing season, and prostrate growth habit to allow close grazing (Chapman *et al.*, 1986, Smetham and Wu Ying, 1991, Dodd *et al.*, 1995a).

Suckling and Forde (1983) collected naturalised SC from 51 old pastures and after comparing them with a range of commercial lines concluded that 74% were cv. Mount Barker type, and 21% matched the cv. Tallarook type. After, in some cases 60 years, plants collected differed little from corresponding commercial lines, although local variation was significant. Macfarlane and Sheath (1984) stated that naturalised SC tends to have longer flowering periods than the standards, and has thus developed a more flexible reseeding pattern. SC cultivars most extensively used in New Zealand belong to the medium to late maturity group, and Mount Barker, Tallarook and Karridale (cultivar

that replaced Mount Barker) have an average flowering time of 137, 163, and 137 days from sowing respectively (Ru and Fortune, 2000).

For hill country areas with little risk of late spring-early summer droughts, a late flowering, small-leaved, dense SC plant type appears best suited, to take advantage of a longer growing season, especially on steep, north facing dry hillsides (Chapman and Williams, 1990b, Chapman, 1992). Even in summer-dry environments, late flowering lines of SC should always be included in mixtures, to ensure adequate regeneration in wetter than normal seasons (Smetham *et al.*, 1994).

Cultivars Tallarook (late) and Mount Barker (mid) have been traditionally the main SC lines utilised in the hill country of the North Island of New Zealand (Macfarlane *et al.*, 1990a), and have been also the best to persist over time, with tolerance of intensive sheep grazing, with their small-leaved, prostrate habit, and dense sward characteristics (Chapman and Williams, 1990b, White, 1990), and being able to flower and regenerate after intense grazing (Chapman, 1992, Frame, 1998). A late-flowering cultivar of similar morphology to Tallarook, but containing little or no oestrogen, would be best suited to hill country environments (Chapman and Williams, 1990b).

In summer-dry North Island hill country, SC can persist and have a spring production of over 1000 kg DM/ha in a mixed sward, at a time when herbage intake by grazing animals is limited (Dodd *et al.*, 1995a). Average production levels of 700 kg DM/ha are reported by Macfarlane and Sheath (1990c), with an accumulation of seed reserves of 1500 seeds/m². Late flowering cultivars can produce more, when no strong moisture limitations occur, because they have a longer period available for branching and consequently more sites for leaf and flower production. The flowering period coincides with maximum leaf area and maximum herbage accumulation rates (Chapman, 1992).

Ru and Fortune (2000) evaluated 26 subterranean cultivars and found that leaf had the highest DM digestibility (DMD) and nitrogen concentration, with a slight decline in

DMD over time for leaves, and a significant decrease for stems and petioles. A leafy sward in late season will therefore improve DMD of a SC pasture.

2.1.3.3. *Other legumes*

In hill country areas suffering summer moisture stress, summer active perennial legumes will be less successful than winter active annuals, particularly on warmer coastal sites or on sunny aspects. This means WC giving way to SC on higher fertility sites, while on low fertility sites a range of naturalised annuals predominate (Hoglund and White, 1985).

Dodd and Orr (1995a) screened legume species which may have potential as alternatives to WC in environments of low P fertility and/or summer drought. *Trifolium pratense*, *Adesmia bicolour*, *Trifolium semipilosum* and *Trifolium fragiferum* showed growth rates similar or superior to WC, particularly under low soil-P conditions. *Trifolium dubium* (suckling clover) performed better than WC at low P during the growing season. After germination in autumn, suckling clover formed a very dense sward in early spring, with short, erect branches. With warmer spring weather branches elongated rapidly and plants became lax and progressively more open in habit as flowering and seed formation proceeded. Plants died during January of each year (Brock, 1973).

Orr and Wedderburn (1996), when evaluating the introduction of alternative legume species into summer-dry hill country with low (3%) legume content, observed that introduced legumes replaced resident species rather than increasing total legume levels.

2.1.4. **Legume establishment in hill country**

Oversowing with legumes, along with subdivision and topdressing, as well as adequate stocking at rates that ensure full utilisation of the increased pasture growth, are considered key factors for increased production from hill country pastures, (Suckling, 1975). To match pasture production and nutritive value, the aim is to produce herbage high in legume and green leaf content and low in dead matter. However, low legume

content is still a common feature of many improved hill pastures; the ideal being at least 20-25 percent legume on an annual average basis (White, 1990).

Wedderburn *et al* (1996) saw no advantage in oversowing WC on existing swards, indicating the difficulty in achieving changes in genetic composition of the swards. The minor role of seedling regeneration in WC persistence in summer-moist hill country was established by Chapman (1987), who measured very low recruitment rates of 1 seedling/5.5 m², and stated that WC behaves as a 'true' perennial in those environments, where high stolon densities are achieved. WC was also slow to recover after seedling regeneration, owing to low winter temperatures and competition from established perennial grasses (Archer and Robinson, 1989). Moreover, owing to a high turnover rate of the buried seed pool and a relatively short viable life (not more than one year), seed reserves are of recent origin and an ineffective source of new plants within resident swards (Chapman and Anderson, 1987).

It is important to improve the establishment rate from oversowing into summer-dry environments to increase legume contribution to pasture productivity (Awan *et al.*, 1993). Losses at the germination and establishment phase are high, resulting in seedling establishment of less than 5% for WC, and higher at 28% for SC (Awan *et al.*, 1993, Awan and Kemp, 1994). However, legume seedling density was not related to legume biomass proportion, and seedling survival may not imply higher productivity (Awan and Kemp, 1994).

Using different methods to improve oversowing, and evaluating their effects on seedling survival, resulted in a response of herbicide > burning > hard grazing with treading > hard grazing without treading (Awan and Kemp, 1994). The use of herbicide in close association with oversowing and stock management has been seen to improve legume content in pasture establishment (Arnst and Park, 1984, Wedderburn *et al.*, 1996). Higher sowing rates were also seen to increase legume contribution to total herbage mass, mediated through higher seedling density and thus higher competitiveness relative to the resident sward (Awan *et al.*, 1994).

2.2 FACTORS LIMITING LEGUME ABUNDANCE IN HILL COUNTRY

2.2.1. Climatic factors

2.2.1.1. Temperature

Temperature varies with latitude and altitude, but also with season and aspect. In hill country, aspect has a direct effect on soil temperature, and pasture response will depend on the relative importance of temperature or moisture as limiting factors at each site (White, 1990). The optimum temperature for growth of WC is 24°C, with a broad range of 16-30°C for adequate performance. Minimum temperature for shoot growth is 5.8°C, although significant growth and nitrogen fixation require at least 9°C (Frame and Newbould, 1986, Brock *et al.*, 1989).

Germination in WC is temperature dependent, and occurs within the range 5-20°C, being more rapid at the higher end of the range. Stolon elongation increases with increasing temperature, while branching is stimulated when temperature declines (Chapman and Macfarlane, 1985, Hampton *et al.*, 1987, Brock *et al.*, 1989). Higher thermal requirements of WC compared to grasses can mean several weeks difference in periods of active growth (Chapman and Macfarlane, 1985), but also means a more stable herbage production over the growth season, as grasses and WC provide maximum yields at different times of the year (Harris and Thomas, 1973).

Positive responses of SC to temperatures of up to 20-25°C have been observed in young swards at seedling stage, while in older swards with closed canopy, temperatures above 20°C can be detrimental to sward growth (Rossiter, 1978), by stimulating senescence. Germination of most subterranean clover cultivars at low temperatures is usually high (Hampton *et al.*, 1987), but temperatures below 10°C were considered limiting for seedling emergence (Evans *et al.*, 1976). SC leaf appearance rate seems to respond less to temperature, showing a more constant rate compared to WC, which doubled its leaf appearance rate between late winter and early summer (Chapman, 1992).

In autumn and winter, soil surface temperatures may be up to 5°C lower than 10cm-soil temperatures for at least part of the germination period, limiting oversowing results (Hampton *et al.*, 1987). On the other hand, maximum soil surface temperatures of 45-50°C can be reached on clear days on slopes with low pasture cover in summer, and lead to stolon death (Sheath and Boom, 1985a, Brock *et al.*, 1989). Aspect can strongly influence soil temperature and create contrasting pasture growth patterns between sunny and shady aspects (Gillingham, 1973, Suckling, 1975).

Temperature and its effect on legume growth may interact with other factors, e.g. competition from grass (Harris, 1987), grazing pressure (Cocks, 1973), soil moisture (Scott *et al.*, 1985), and nitrogen fixation (Harris and Thomas, 1973). Low temperature amplitude has also been stated as a cause for legume hardseededness under New Zealand conditions (Smetham and Wu Ying, 1991).

2.2.1.2. Soil moisture

Despite relatively high annual rainfall, many regions of the North Island are regularly, or at least occasionally, affected by summer and/or autumn moisture deficits (Chapman and Macfarlane, 1985, Sheath and Macfarlane, 1990b). Soil moisture is seen as the most important and overriding environmental factor limiting pasture and legume growth (Frame and Newbould, 1986, Kemp *et al.*, 2002), while annual species will be more successful by avoiding moisture stress, existing as dormant seeds during drought periods (Chapman and Macfarlane, 1985). For the development of compatible grass-clover hill swards, adequate soil moisture is required, especially in spring and summer, to allow legume growth and persistence (Gillingham *et al.*, 1998), and under extreme dry conditions legumes like WC or SC may not be able to survive (Woodman *et al.*, 1992), when pasture growth may come to a complete halt due to summer drought (Hoglund and White, 1985). However, when summer rainfall is more predictable, WC should be considered in pasture development due to its production potential and quality (Kemp *et al.*, 2002).

Inter-annual variation in legume content is generally higher in drought-prone environments, and is linked with rainfall distribution patterns (Harris, 1987). Korte and Quilter (1990) in the east coast of the North Island, found that legume content varied from 16% in years of adequate summer rainfall to only 4-5% when summer rainfall was low and/or less reliable, and indicated that SC may be a better legume for the latter situation. Work by Suckling (1975) in Te Awa, near Kiwitea, found inter-annual fluctuations of up to 30% in pasture production.

While the duration and intensity of summer moisture stress is unpredictable and variable and has direct effects on pasture performance, spring rainfall has been shown to influence not only the current spring production but also total annual pasture production to an even greater extent (Hoglund and White, 1985) as legumes may not recover even with subsequent rainfall. Hutchinson *et al* (1995) found that mid-late spring rainfall in the current year was positively correlated with white clover cover in early spring of the following year, and also that the length of summer drought of the current year determined the amount of WC cover in the subsequent spring.

Low water storage capacity of hill soils makes them highly dependent on rewetting frequency rather than total rainfall, and probably less than 50% of total rainfall is effective in replenishing soil moisture for plant use (Bircham and Gillingham, 1986). The patterns of solar radiation, rainfall, and wind exposure in different aspects of hill country slopes will affect evapotranspiration levels and will cause soil moisture differences between hill faces. For example, a sunny north face exposed to wind will be much drier than a sheltered south aspect, and differences in pasture production and botanical composition will occur (White, 1990). Other factors like soil texture, water absorption rate, steepness of slope, and rapidity of runoff, will interact, reducing effective rainfall and making moisture stress more limiting to pasture growth than temperature (Suckling, 1975, White, 1990). Lower winter production and delayed spring growth occurred on shaded aspects, while overall annual pasture yield on sunny aspects was 25% higher than on shady aspects (Suckling, 1975). However, in very dry

environments the opposite can be the case, as soils in sunny aspects may be below wilting point for over six months of the year (Hoglund and White, 1985).

In dry environments the presence of vegetation, mainly grasses, can have positive effects by for example, protecting stolons, and legume growing points and seedlings, from excessive temperature occurring in open spaces (Brock, 1988, White, 1990); or negative effects, e.g. drying off surface soil more rapidly and affecting seedling germination and establishment (Dear *et al.*, 1998). Grasses are capable of maintaining a higher leaf potential than legumes, related to leaf rolling mechanisms in grasses, e.g. tall fescue (Hill and Hoveland, 1993).

Susceptibility of WC to mismanagement or drought is highest in spring, when plants are small and branching structures are simple (Hay *et al.*, 1988, Brock *et al.*, 1989), and grazing managements that encourage high stolon density and also maintain shelter to the clover by high grass density will perform better under drought stress (Brock and Kim, 1994).

In summer-dry environments, the WC population can collapse but has been seen to recover to pre-drought levels (Macfarlane *et al.*, 1990a), although this can take a long time (Chapman and Macfarlane, 1985). Survival and recovery of stolon material which survive drought appear to play a large role in re-establishing WC populations (Chapman and Williams, 1990a), as WC shows an intermediate level of resistance (ability to maintain function) and also resilience (ability to recover) from drought events (Davis *et al.*, 1994). Under more severe circumstances, WC plants die and regeneration has to occur from seed and seedling establishment (Barker *et al.*, 1988, Archer and Robinson, 1989, Kemp *et al.*, 2002), or vegetative and reproductive mechanisms may co-exist (Kemp *et al.*, 2002). Brock and Kim (1994) found that the number of WC plants surviving drought was related to pre-drought plant density, and cultivars with higher stolon density (e.g. Grasslands Tahora) had a higher plant survival. Survival of shaded stolons (55%) was higher than for buried (25%) or fully exposed (17%) stolons.

As the soil dries from the surface downwards, moisture stress will depress root initiation, and older, well developed roots in deeper layers will supply water to WC stolons. If drought continues, however, these old roots will also become moisture stressed, resulting in death of the stolon and compromising clover persistence (Stevenson and Laidlaw, 1985). WC has relatively low root density, with a short-lived original taproot, and a shallow fibrous root system in the surface soil profile (Lane *et al.*, 2000). While taprootness has been suggested to be a drought-tolerance factor in WC, no real advantage over the hill country cultivar Grasslands Tahora was observed (Brock and Kim, 1994). Selection of lines from drought-prone environments may be a more effective strategy than direct selection for root morphology (van den Bosch *et al.*, 1993), although dryland collections were more taprooted than plants collected from moist sites (Woodfield and Caradus, 1987). High stolon density and/or free seeding ability still seem to be the most desirable characteristics in summer-dry hill country for WC (Macfarlane *et al.*, 1990c).

The failure of SC to persist at an adequate level in many perennial grass swards, can be explained in part by poor seedling establishment in autumn, where moisture stress and other grass-induced factors play a role (Dear *et al.*, 1998). However, SC has normally advantages over WC in seedling survival, due to faster germination and more robust radicle to enter surface soil layers (Awan *et al.*, 1996).

Mid-late flowering SC cultivars seem to adapt better to New Zealand North Island summer-dry hill country conditions, allowing a longer growth period, but having adequate seed set before the drought-risk period, and generating sufficient seedling regeneration the following autumn (Sheath and Richardson, 1983, Sheath and Macfarlane, 1990b, Dodd *et al.*, 1995b).

2.2.2. Soil fertility

Aerial topdressing, mostly with normal superphosphate, has been one of the key factors in improving production and quality of hill country pastures in New Zealand (Levy,

1970, White, 1990, 1999). The plasticity of hill country swards to the application of fertiliser has been shown by Luscombe *et al* (1981). Modifying fertiliser inputs produced dramatic changes in species composition, starting from an *Agrostis capillaris* L. (browntop) dominant pasture with 8% clover content. With high application of N and P, *Lolium perenne* L. (perennial ryegrass) dominance was achieved (78%). Browntop was more competitive if either P or N were low, and *Anthoxanthum odoratum* L. (sweet vernal) and *Cynosurus cristatus* L. (crested dogstail) content was reduced as N and P rates increased, due to exclusion by ryegrass. P fertiliser boosted clover content up to 39%, but N application reduced clover content.

2.2.2.1. Soil Phosphorus status

Lambert *et al* (2000), in a long-term analysis of P topdressing in hill country, indicated that P initially accumulated mainly in inorganic forms, with organic P accumulating at a slower rate. Soil N remained constant in low P plots while it increased at a rate of 19 kg/ha/year in high P soils. Immediate increases in clover production following P application is a consequence of the low N status of the soil, when grasses will be at a competitive disadvantage (Harris, 1987, Gillingham *et al.*, 1998).

Widespread P deficiency has been reported in the east coast of New Zealand, (O'Connor and Gray, 1984), while hill pastures dominated by low fertility-tolerant grasses in summer moist areas responded vigorously to lime and superphosphate (Lambert and Grant, 1980) and repeated superphosphate application over a period of six years increased pasture production from 8.5 to 12 t DM/ha (Lambert *et al.*, 1982). In Australia, levels of response to applications of P on ryegrass/SC pastures were highest in spring, especially when good SC regeneration occurred in winter and the legume was capable of expressing growth potential (Cayley *et al.*, 1998). Applications of 50 kg P/ha/year produced maximum herbage yield on easy slopes (14.9 t DM/ha), while 30 kg P/ha/year were necessary on steep slopes to produce 7.7 t DM/ha, showing a much higher absolute P efficiency on easy slopes (Gillingham *et al.*, 1984). Lower P efficiency

in terms of DM produced per unit P applied was also seen by Edmeades *et al* (1984) in reverted pasture dominated by low fertility grasses like browntop.

Response to P in plant growth is governed by the concentration of P in the soil solution. When fertiliser P input is reduced, there is a decline in soil solution P, but there is also a decrease in the marginal increases in P concentration when P is reapplied (Mouat, 1984). The responses in early stages to applied superphosphate is shown by the legume, which is able to overcome the N deficiency by fixation of atmospheric nitrogen, although legume content declines with time (Lambert *et al.*, 1982, Harris, 1987). On P (and eventually S) deficient soils, superphosphate application rate may speed up botanical progression to clover-dominance initially and the onset of grass-dominance is accelerated (Wolfe and Lazenby, 1973a, 1973b).

Several studies have looked at effects of withholding P fertiliser in hill country pastures, as a response to increasing costs and declining product prices. Withdrawal of P fertiliser generally results in lower total annual herbage production (29-35% less), lower legume production (up to 72% less), reversion to low fertility grass dominance, a decline in Olsen P, an increase in soil organic P, and a decline in soil N status (Gillingham *et al.*, 1990, Mackay *et al.*, 1990, Ledgard and Brier, 1993, Roach *et al.*, 1996). This process is gradual and, if initial Olsen P levels are adequately high (over 15), and stocking rates not extremely high, P fertiliser could be withheld for up to two years without significant losses in pasture production (Shannon and O'Connor, 1986). However, at sub-optimal P supply, competition for P between browntop and clover is increased, especially in young swards (Jackman and Mouat, 1972b).

As inorganic soil-P becomes depleted, plant P uptake decreases, with less dung P return and a slower rate of dung decomposition, the P cycle slows down, lowering herbage DM produced and slowing regrowth. Fertiliser P re-application can recover the soil from this state, but a significant time-span for the recovery of a high producing sward composition is involved (Rowarth and Gillingham, 1990). Pasture responses to P re-application are characterised by an initial increase in legume growth and content,

reflecting the reduced plant available soil N status due to previous low inputs from N fixation, and thereby increasing the competitive advantage of legumes over grasses (Ledgard and Brier, 1993, Roach *et al.*, 1996). Nitrogen fixation is estimated to increase from 30 to 130 kg N/ha/year when P application is resumed, starting the grass-stimulating cycle once more (Ledgard and Brier, 1993). Increasing P supply to clover plants has also been seen to increase total non-structural carbohydrates (TNC) concentration, reversing the decline in %TNC resulting from frequent defoliation (Singh and Sale, 1997).

The available soil P pool measured by Olsen P is well correlated with plant P uptake, although water extractions most accurately predict subsequent plant P uptake (Rowarth and Tillman, 1992). Olsen P on easy and steep slopes rose significantly at high rates of P fertiliser (100 kg P/ha) indicating that P gains exceed P losses. At low P rates (10 kg P/ha) Olsen P decreases on easy slopes, indicating that P losses exceed P gains (Rowarth *et al.*, 1992). However, Olsen P is generally used to reflect application rates of P over time (Lambert *et al.*, 2000).

P is not a mobile nutrient in the soil profile, and below 30 mm soil depth, Olsen P values after 4 years for easy and steep slopes were similar to initial values, except at the 100 kg P/ha rate of fertiliser (Rowarth *et al.*, 1992). While erosion will seriously deplete soil P accumulated in the topsoil (Rowarth *et al.*, 1992), earthworm activity may help to improve P re-distribution within the profile, as subsurface wormcasts and the lining of burrows were seen to contain higher available P concentration than the surrounding soil at depths of up to 250 mm (Mouat and Keogh, 1986).

Production from grazed low-fertility hill country pastures is very responsive to superphosphate application, when high utilisation pressure is also applied (Lambert *et al.*, 1982). As a result from grazing systems, the dung distribution within paddocks has also important effects on differential P accumulation, 60% being deposited on campsites, and only 5% on steep slopes. This has consequences for the P balance of different topographical situations within paddocks (Rowarth and Gillingham, 1990).

In many pastoral soils, the absorbing surface of white clover roots is extended by their association with arbuscular vesicular mycorrhizal fungi ('mycorrhizas'). The growth of the host is increased as a result of the ability of the hyphae to extend the host's root system, thus increasing the volume of soil from which P can be absorbed and transporting it to the host plant (Frame and Newbould, 1986, Dunlop and Hart, 1987).

2.2.2.2. *Nitrogen application*

The relevance of legumes in pastoral production systems is primarily related to its unique feature, the formation of a symbiosis relationship between the plant and soil bacteria of the genus *Rhizobium*, which results in fixation of atmospheric nitrogen, and confers legumes a specific adaptation to soils with low N status, and a competitive advantage to other species (Frame and Newbould, 1986, Harris, 1987). Legume-fixed N is transferred to the grass through herbage death and decay, or through animal excreta (Chapman and Macfarlane, 1985).

Nitrogen deficiency is the main nutrient limitation to pasture growth in most hill country situations (Chapman and Macfarlane, 1985, Gillingham *et al.*, 1998), especially in spring due to seasonal biological N immobilisation (Luscombe and Fletcher, 1982), and is usually linked with clover content in swards (Harris, 1987).

The nodulation with rhizobia and the N fixation process are strongly affected by soil temperature, soil moisture, and soil pH (acidity) (Frame and Newbould, 1986, Morton *et al.*, 1993). Nitrogen fixation depends on photosynthesis and respiration for the supply of carbon and energy, and uses carbohydrate reserves during the dark period (Hart, 1987). In North Island dry hill pasture communities, WC and SC are seen to be complementary in their fixed N supply, as SC growth is significant in spring, and WC in summer-autumn (Ledgard *et al.*, 1987). Atmospheric N fixed by clover tissues was as high as 82%, and average total N in WC and SC tissues ranged between 4.4 to 5.1%, which will become available to grasses through decay and animal cycling (Chapman and Macfarlane, 1985, Ledgard *et al.*, 1987, Sheath and Macfarlane, 1990b). Nitrogen

fixation has also an effect on soil acidification, which is produced by the H^+ ions generated within the legume root when carboxyl groups of aminoacids are dissociated (Bolan *et al.*, 1991).

Since N fixed by the clover has to be made available to grasses partly through decomposition of clover tissues there is a time delay, and thus the yield of clover in the previous year, and also the decrease in clover yield between successive years, is often more highly correlated with grass N yield than the current year's clover yield (Stewart and Chestnutt, 1974, Harris, 1987). N is transferred both 'below ground' (decomposition of legume roots and nodules), and 'above ground' (return in animal excreta and shoot tissue decay) (Ledgard and Steele, 1992). Under cutting or intensive grazing, N transfer mechanisms occur mainly through root and unharvested shoot material (Grant *et al.*, 1981). Variation in N return via animal excreta exists in hill country situations, and uniformly sloping paddocks will have a much more even dung distribution than paddocks including different topographical units (Luscombe and Fletcher, 1982).

Nitrogen fixation generates a dynamic relationship between legumes and grasses, whereby grasses take up fixed N from the soil and reduce inhibition of legumes by soil N, but also competition by grasses reduces legume production, and thereby nitrogen fixation (Ledgard and Steele, 1992). Some grasses, like ryegrass, are more compatible with legumes in mixtures, since high potential growth rates of these grasses in late winter and early spring tend to deplete soil N, favouring growth of legumes, like WC, that grow mostly from late spring onwards (Harris, 1987). Adequate legume content in hill swards is important to sustain systems without the use of artificial N, and target levels of 30-50% in clover content are mentioned to maintain stable pasture production (Evans *et al.*, 1992). In a superphosphate topdressing programme on summer-moist hill country, an initial increase of legume content from 5% to 23% was observed, which declined to 10% at the end of the period. This was related to an increase in soil N and increased competition from grasses (Lambert *et al.*, 1982). The importance of N influencing the clover regeneration cycle may be more critical in areas where moisture

stress is infrequent, and perennial grasses persist and are dominant; while in dry sites factors like climatic stress, grazing disturbance, and competition from annual species, may be more important (Hutchinson *et al.*, 1995). In a study by Gillingham *et al.* (1998) clover depression was attributed to competition for moisture, P supply and shading of stolons by rank pasture.

In New Zealand, nitrogen fixation by legumes plays a major role in agricultural systems, and a high range is reported, between 17-680 kg N/ha/year, and if only grazed pastures are considered, the range narrows to 17-380 kg N/ha/year (Crush, 1987) or 55- 296 kg N/ha/year (Ledgard and Steele, 1992). In extensively grazed hill pastures low values of 34 kg N/ha/year are reported and they relate closely to legume DM production, while about 50% of the amount fixed is attributed to non-symbiotic free-living microorganisms (Grant and Brock, 1974).

The processes of uptake of mineral N and nitrogen fixation can occur simultaneously, although clover will first utilise soil mineral N if available, and satisfy the remaining demand via fixation (Brock *et al.*, 1989). At early stages of seedling development, when nodules are not formed, clover will need a small starter supply of mineral N (Frame and Newbould, 1986). In pure stands with adequate mineral N status, clover is capable of taking up similar N amounts from the soil to grasses; however, in developed mixed grass/clover swards, grasses will be at an advantage, as they are more efficient in N uptake than clover. The inability to compete with grasses for mineral N, and the depression of N fixation will affect clover populations and a decline will be observed in the sward (Stewart and Chestnutt, 1974, Harris, 1987, Munoz and Weaver, 1999).

The use of fertiliser nitrogen on pastures is widespread in Europe, and the average total production for grass/clover swards in the UK is 8.3 t DM/ha without N application, while it increases to 9.8 t DM/ha with the application of 200 kg N/ha/year. The increase in production is paralleled with a reduction in clover content of the sward (Frame and Newbould, 1986). Larger differences are observed in individual situations, but generally N application increases total herbage production (Luscombe and Fletcher, 1982, Frame

and Newbould, 1986), with the largest proportional responses in autumn and winter (Ledgard *et al.*, 1995). Responses to nitrogen fertiliser of up to 41 kg DM/kg N applied are reported by Jiayou *et al* (1993) in hill country near Palmerston North, while a range of 10-25 kg DM/kg N is given by Luscombe (1980), when relatively low rates of N are applied. Preliminary results by Gillingham *et al* (1998) in summer-dry hill country, suggest that autumn applications of N are recommended only on dry north-facing slopes, as legume levels and P responses from a sward mainly composed by grasses are commonly low.

The application of N usually produces a decline in legume production in the sward (Luscombe and Fletcher, 1982, Harris, 1987, Eltilib and Ledgard, 1988, Caradus *et al.*, 1993, Morton *et al.*, 1993, Ledgard *et al.*, 1995, Gillingham *et al.*, 1998, Sibbald *et al.*, 2002). Low applications of 25 or up to 50kg N/ha in autumn have little or no detrimental effect on clover yield (Luscombe and Fletcher, 1982, Eltilib and Ledgard, 1988, Caradus *et al.*, 1993), while winter or early/spring applications even at low levels have detrimental effects on clover content (Luscombe *et al.*, 1981). Fertiliser nitrogen may not only reduce clover nitrogen yield, but also the effectiveness of the clover in supplying nitrogen to the grass (Stewart and Chestnutt, 1974), through reduced N fixation rates (Luscombe and Fletcher, 1982), and lower the stolon growing point density (less young branches) by increasing grass leaf area index (Laidlaw and Withers, 1998). However, faster grazing rotations or higher stocking rates may offset the adverse effects of N on legumes by utilising the additional grass produced and reducing competition for light (Woodfield and Caradus, 1996). Sibbald *et al* (2002) stated that the use of nitrogen fertiliser can be reduced or even removed without compromising animal performance, provided that clover content and sward height are maintained, i.e. by the adjustment of stocking rate.

2.2.2.3. *Other nutrients*

Shortage of N, P, K, S, Ca, Mg, Mo, Cu, Mn, Fe, Bo and Zn can develop and cause different symptoms in white clover and other legumes, while excess of Al, Mn and Bo may also cause toxicity signs (Dunlop and Hart, 1987). Some of these, especially Ca, P, Fe and Mo affect root nodule bacteria, and deficiency may depress growth, survival and population of rhizobia, and cause constraints on nitrogen fixation (O'Hara, 2001).

On some New Zealand soils sulphur deficiency is widespread, but the S content of superphosphate has usually been adequate to correct this deficiency (Brock *et al.*, 1989). Application of S increases clover growth and N fixation when no N fertiliser is used, while when N is also applied, higher rates of S application reduce clover suppression by grasses (Harris, 1987). Major losses of S (as SO_4) by surface run-off or leaching can occur in hill country slopes, encouraged by annual applications above 24 kg S/ha (Saggar *et al.*, 1990).

Other elements important to legume growth or N fixation include molybdenum, copper, cobalt and boron (Brock *et al.*, 1989, Jiayou *et al.*, 1993). Molybdenum is an important trace element also for practical purposes, as it can reduce liming requirements (Harris, 1987), as results from lime application seem to be related to higher Mo availability by increasing pH values (Lambert and Grant, 1980). The effect of a number of nutrient elements on legume growth is influenced by soil pH, and lime is often applied to increase soil pH. One of the most common effects of lime is also to reduce toxic effects of aluminium and manganese (Dunlop and Hart, 1987). Superphosphate application effects include increased soil Olsen P, legume herbage N and P, but decreased legume Cu (Lambert and Grant, 1980).

2.2.3. **Competition**

A plant may influence its neighbours by changing their environment. These changes may be by addition or subtraction. It is reasonable to expect that plants growing together may shade one another and there may result a mutual or one-sided depression of growth

due to light constraints. Similarly the roots of plants may be using limited resources or restricted water supplies, and growth may be depressed in similar ways (Harper, 1981). Therefore, a competitive relationship arises which can be divided into inter-specific, or intra-specific competition, depending on the relationship being between different species or between individuals of the same species, respectively. This review will refer mainly to the grass-clover relationship, while the competition between clovers (especially between WC and SC due to the relevance to this thesis) and some intra-specific competition will also be considered.

2.2.3.1. *Grass-clover competition*

Plants growing in mixtures compete above ground for space and light and below ground for space, water, and nutrients (Frame and Newbould, 1986). Environmental conditions will be interacting and affecting legume growth. Under hill country situations, in dry areas low soil moisture and dessication are likely to be a problem, while in wetter areas competition from resident pasture plants will be of greater importance (Lambert *et al.*, 1985).

Legumes have adopted different strategies to compete with neighbours, some of which include rapid attainment of light interception by horizontal leaf arrangement and petiole length adjustments, ability to colonise widely by stoloniferous growth, different growth periodicity from that of other resident species, and by the ability to use atmospheric N rather than mineral N from the soil (Frame and Newbould, 1986, Harris, 1987, Marriott *et al.*, 1997).

However, root morphology of WC contributes to its poor competitive ability, being shorter, thicker and less branched than the fine, extensively branched root system of grasses (Dunlop and Hart, 1987, Brock *et al.*, 1989). Grasses usually have a more extensive root system, enabling them to compete adequately with legumes, being more efficient in nutrient uptake (Harris, 1987), while low fertility tolerant grasses like browntop are able to increase root growth more rapidly in response to a developing

nutrient deficiency than associated species (Dunlop and Hart, 1987). Ryegrass roots were more efficient at taking up phosphate than SC roots, probably due to root hair characteristics and the ability to reduce P concentration at the root surface, and the higher P transfer to the shoot (Barrow, 1975).

The type of companion grass has a strong influence on the spread of WC plants, tall fescue depressing least severely, ryegrass was of intermediate severity, and browntop depressed spread most severely (Campbell *et al.*, 1994), and annual grasses may restrict legume growth more than perennial grasses (Kemp *et al.*, 1996). Competition from grasses was seen by Hill and Hoveland (1993) as a major effect on legume performance, compared to cutting or moisture stress treatments. In mixed swards, where the populations of grass and clover have been adjusting in response to N status of the soil, as affected by N fixation, an equilibrium is attained at 30% clover content, which is dynamic, with seasonal changes of ryegrass and clover content but without marked effects of dominance and suppression (Harris and Thomas, 1973).

The presence of SC in a mixture with perennial grasses reduces grass yield more than when WC is the competitor, and SC is able to remain competitive in subsequent years, as opposed to WC (Lodge, 2000). SC tended to suppress *Phalaris* when grown in mixture, while WC showed more complementarity with the same grass species, as they were competing for slightly different niches (Hill and Gleeson, 1988). Defoliation frequency affects SC competitiveness, as SC is more aggressive under infrequent cutting, while WC is more aggressive under frequent cutting, as well as when it is a major component of the mixture (Hill and Gleeson, 1988).

Competition between establishing seedlings depends on the relative vigour of the seedling and their respective densities, which is also related to seedling growth rate. For example, substantial WC seedling mortality occurred when it was in mixture with grass or SC (Hill and Gleeson, 1988).

One resource that is in limited quantities in mixed swards is light, and it becomes a source of inter-specific competition when two or more species grow sharing the same environment. Pasture legumes are less tolerant to shading than the grasses, and light constraints which increase under lax or infrequent defoliation, can be markedly suppressive (Jackman and Mouat, 1972b, Harris, 1973, 1987, Korte and Quilter, 1990). The sole presence of a neighbour is not sufficient for a plant to alter its morphology, as partial shading and not just reflected light is necessary to trigger changes (Marcuvitz and Turkington, 2000). The nature of the neighbour is also important, and dicotyledoneous herbs might be more clover-suppressive, as they exhibit more fundamental similarities to clover in growth form and habit (Turkington *et al.*, 1979).

Excessive grass development (as can occur in late spring-summer) can effectively shade WC, reducing node activity and the ability to regrow leaf, which may cause sharp declines in subsequent clover content (Jackman and Mouat, 1973, Brock, 1988).

Shoot dry weight and branch numbers per plant were linearly reduced when levels of shade were increased from 73% of full photosynthetically active radiation (PAR) to 14% PAR in both WC and SC (Devkota *et al.*, 1997). Marriott *et al* (1997) observed that WC stolon extension rate was greater on the edge of a patch than inside the patch, while light quality at ground level (red/far-red ratio) was lower under taller swards, and higher under a grass canopy than under a mixed grass-clover patch. The effect of poor light quality was fewer branched nodes and less well developed branches (Thompson, 1993) and consequently less growth (Marcuvitz and Turkington, 2000). The artificial increase of red light at the base of a mixed sward largely removed the effects of canopy shading on WC nodes, and plants resembled those growing in full light, which highlights the relevance of the radiation environment at the base of the canopy (Thompson, 1993). Further, Teuber and Laidlaw (1996) found that the increase in red light and PAR reaching stolons and petioles released WC buds to form branches.

A response mechanism of clover to the increase of sward height, leaf area index and consequent shading, is the lengthening of successive petioles, which allows clover to

keep new photosynthetically active leaves near the top of the sward in a full light environment (Dennis and Woledge, 1982, Marcuvitz and Turkington, 2000).

Legume seedling mortality from competition with resident pasture can be high, especially in moist-climates, and may compromise oversowing results, as seedlings tend to etiolate and so become more accessible to defoliation (Sheath and Boom, 1985b). Hard grazing before sowing and control of competition by uniform grazing after sowing may stimulate seedling growth and survival (Sheath and Boom, 1985b, White, 1990, Barker and Dymock, 1993b).

In dry/hot environments, the effect of shade from neighbours can be beneficial to clover, as they modify the soil surface temperature and moisture, and thus moderate shading by a companion grass may improve white clover persistence (Harris, 1987), while companion grasses may also eventually protect stolons from the grazing animal (Evans and Williams, 1987).

Part of the niche of clover is occupied by grasses and weeds, and species competition seems to have been able to occupy space available for clover colonisation, especially in moist and fertile environments (Harris, 1987, Macfarlane *et al.*, 1990a). Nie *et al* (1996) found an inverse relationship between grass tiller density and WC growing point density, while Brereton (1985) indicated that clover suppression occurred only when grass tiller density was above a threshold of 5000 tiller/m². Grasses developing less tiller density are therefore expected to encourage WC spread, through reduced spatial competition and enhanced light penetration to the base of the sward (Swift *et al.*, 1993).

In a review of root/shoot competition studies, Wilson (1988) concludes that root competition usually affects the balance between components more, and is usually more intense, than shoot competition, and suggests that the relative importance of root competition increases with time. The overriding effect of root competition on the growth of neighbouring plants, over other factors such as light or defoliation, has been reported (Cook and Ratcliff, 1984, Hayes and Williams, 1995, Lodge, 2000). Chapman

(1987) observed highest WC seedling survival on steep hill country slopes and nil on flat slopes, which he related to stresses from neighbouring vegetation. SC grew best when root competition was totally or partially excluded, and was classified as sensitive to root competition (Bolger, 1998).

Cook (1985) found that, although competition for nutrients appeared to be the main factor affecting seedling growth, this was largely overcome by application of fertiliser. However, it is argued that competition does not uniformly lower the resources supplied, and that despite high levels of nutrients and water, local depletion of resources occurs in the vicinity of individual roots. To successfully compete a plant must be able to deplete the amount available to its neighbour (Bolger, 1998), and higher requirements of e.g. fertiliser may be necessary to overcome seedling competition in a live sward than on pastures oversown on herbicide-treated swards (Cook, 1985).

Grasses can negatively affect clover growth through mechanisms such as reducing the phosphate availability by both direct competition and decreasing soil moisture, which will be especially dramatic in dry environments with low soil P and/or high P fixation. (Jackman and Mouat, 1972a, 1973, Dear *et al.*, 1998). A reduction in nitrate availability triggered by grasses is also mentioned as a limiting factor in SC seedling establishment (Dear *et al.*, 1998). However, in established pastures, the reduced clover growth induced by grass competition will be partially offset by a reduction in available soil N by grass uptake, which, depending on the N status of the soil, may encourage clover and N fixation (Brock *et al.*, 1989).

Root competition control through the use of either excluding tubes or non-selective herbicide significantly increased seedling growth of oversown species, although total sward herbage mass produced may be lower than on untreated swards, and weed content may increase (Cook, 1985, Awan and Kemp, 1994). Selective herbicides can rapidly change botanical composition of a pasture and, with adequate management, the changes induced may be long-lasting (Harris, 1987). However, through applications to suppress

grass in a summer-moist hill country pasture increased legume content initially, differences disappeared in subsequent years (Rolston *et al.*, 1985, Barker *et al.*, 1988).

The application of grass-suppressants can reduce total herbage accumulation, reduce summer dead matter content, and increase in-vitro digestibility in early summer, and increase the proportion of clover in the sward (Williams and Palmer, 1970, Rolston *et al.*, 1985, Sheldrick *et al.*, 1993), especially by increasing WC stolon population density, branching complexity and winter clover production in milder environments (Sheldrick *et al.*, 1993, Patterson, 1995). Williams and Palmer also observed a delayed recovery of grasses after herbicide use, which improved overall production in the subsequent winter and spring. The botanical changes favouring clover content in the sward are also seen to improve animal performance, especially lamb finishing and ewe flushing before mating (Williams and Palmer, 1970, Rolston *et al.*, 1985). Herbicide (paraquat) use was required on hill country pastures to maximise legume seedling establishment, which proved more efficient in reducing grass competition than intensive grazing (Macfarlane and Bonish, 1986), although the flush of WC growth following herbicide application may diminish the contribution of new seedlings to pasture production (Barker and Dymock, 1993b). No major effects of herbicides on microbial decomposition of shoot and root litter, or on rhizobia activity, have been reported (Grossbard, 1970, Wardle *et al.*, 1994), while more development of work that integrates grass suppressants with animal production systems is required (Frame and Newbould, 1986).

In dry environments competition from resident vegetation is usually less than on moist environments, but seedlings must be encouraged to quickly establish deep roots to withstand eventual drought (White, 1990), and also to win in the race for success of seedling regeneration in autumn, which will be finally determined by competition from other pasture species, as they recover from summer drought (Sheath and Macfarlane, 1990a).

2.2.3.2. *Inter- and intra-legume competition*

Intra-specific competition between WC genotypes is greater than between clover and the grass companion, and thus competition between individuals tends to be greater than between species (Annicchiarico and Piano, 1997), as they are occupying similar niches in the sward (Hill and Gleeson, 1988). It was observed that SC apparently experienced more intra-specific competition than competition from grasses, as individual plant growth was higher in a mixture with other species, compared with its monoculture (Hill and Gleeson, 1988), and also the number of SC seedlings at emergence were inversely correlated with surviving seedlings two months after emergence (Hill and Gleeson, 1990).

In established pastures, soil variability and spatial separation of micro-sites will probably allow WC and SC to co-exist without major competition. However, when summer moisture is high, WC may proliferate and result severe competition for SC (Hill and Gleeson, 1990).

At a given level of leaf area index, light interception characteristics of a WC canopy will negatively affect growth of prostrate species growing underneath, probably to a larger extent than where the overtopping canopy is composed by grasses (Harris, 1987). In mixed hill country swards, WC was seen as the aggressor species, partially determining SC levels (Sheath and Boom, 1985b), and even excluding SC populations where WC was the dominant legume (Macfarlane *et al.*, 1990a). SC growing in swards with WC produce fewer burrs, reduced number of seeds per burr, and a lower individual seed weight, and the DM yield of SC declines linearly with the increase of WC DM (Smith and Crespo, 1979). The decline of competitive ability of SC during flowering is linked to the fact that at that stage WC still has active vegetative growth, which allows WC to gain competitive advantage for resources such as light and water, which in turn depresses SC seed set (Smith and Crespo, 1979, Hill and Gleeson, 1990).

In dry environments, where WC has to act as an annual, SC is likely to dominate mixtures, but if WC stolons can survive over summer, the competitive advantage would be for WC (Hill and Gleeson, 1988). When re-population from seed occurs for WC and SC, initial seedling density is low and plants of both species have unlimited access to resources and light for growth. However, prior to canopy closure, SC occupies the vacant interplant space more rapidly and excludes WC (Hill and Gleeson, 1990). WC has the ability to produce one large, tall leaf, capable of competing for light in the canopy. The removal of this leaf is most disadvantageous to WC when SC is present, as it tends to readily replace the gap left by WC (Hill and Gleeson, 1988). SC forms a relatively short, dense canopy with a series of layers of fully expanded, while WC is able to elongate petioles to positions above the SC canopy, creating a morphological complementarity, which in some circumstances may explain overyielding (Hill and Gleeson, 1990). WC and SC have been also seen to complement themselves, as their main growing periods do not coincide in time, and therefore significant WC growth in such mixtures will depend on adequate conditions for the survival of seedlings and the removal of the aggressive SC competition as it completes its life cycle (Hill and Gleeson, 1988).

Light limitations may explain competition between SC and WC in understocked pastures in spring, but other factors may be important in intensively grazed swards. The tolerance of survival mechanisms such as seed production (SC and WC) and stolon burial and rooting (WC) to grazing, and plant morphological plasticity may become more relevant (Hill and Gleeson, 1990).

2.2.4. Pasture utilization

2.2.4.1. Legume defoliation effects

The relative content of clover in mixtures is determined by frequency, intensity and timing of defoliation of pastures. A modifying effect can be introduced by the diet selection ability of grazing animals (Harris, 1987).

Frequent defoliation can be viewed as especially prejudicial to erect grass species, whereas the stoloniferous habit of white clover means that a smaller proportion of its total biomass is removed in any one defoliation. Therefore, where clover is at a competitive disadvantage, frequent cutting may increase clover content (Harris, 1987).

It is generally considered that frequent defoliation of a grass/WC pasture will increase its clover content by reducing grass competition, especially during spring, however infrequent defoliation could be expected to increase clover content where it is already competing successfully or growing actively (late spring-summer), and therefore able to take advantage of the longer spells between defoliations (Harris, 1987, Brock *et al.*, 1989). However, too lenient grazing is linked with lower survival rates of white clover, due to higher DM residues in winter and spring and consequently more intense competition from surrounding vegetation (Chapman and Williams, 1990a). Defoliation frequency will create substantial differences in plant size with increasing intervals permitting larger plant organs (Brock *et al.*, 1989). High defoliation frequency greatly reduces SC competitive advantage in mixtures during the vegetative growth (Rossiter, 1978).

Increased intensity of defoliation of mixed grass/WC swards, especially early in the season, has often increased the proportion and numbers of growing points of clover in the sward, although usually at the expense of lower total DM production (Harris, 1987, Hay and Baxter, 1989), and the reduction of plant size (Briseño de la Hoz and Wilman, 1981). However the timing will be important, as overgrazing in summer has been seen to be detrimental to WC, causing a loss of stolon and productive growing points (Brock *et al.*, 1989), which also affected potential reproductive growth by reducing the proportion of floral buds (Grant *et al.*, 1991, Hay and Newton, 1996). Higher severity of grazing, as can be the case of some intensive rotational systems, may combine low plant density and severe physiological stress, which may compromise pasture regrowth (Brock *et al.*, 1989).

Many SC cultivars require lenient grazing pressure (>5 cm residual height) for a period of 3-4 weeks during peak re-seeding in spring to allow regeneration (Chapman *et al.*, 1986), and higher leaf densities maintained throughout spring by SC Mount Barker and Tallarook suggested that they are more tolerant to harder grazing conditions than other cultivars, which have elevated runners prone to removal by grazing stock (Sheath and Richardson, 1983). In high soil P status situations it was also observed, that an increased amount of flowers were above cutting height, which could be detrimental to seed set under grazing conditions (Dodd and Orr, 1995b).

The renewal of the leaf canopy after defoliation is supported by reserves translocated in stolons and roots (Harris, 1987). After defoliation, horizontal arrangement of clover leaves allows them to redevelop light interception more quickly than grasses and, as grazing usually removes mostly leaf tissue, some petioles and most stolon tissue remains intact below grazing height. Therefore, the post grazing residual and its structure will govern WC regrowth (Brock, 1988, Brock *et al.*, 1989). Remaining stolons and petioles will be in a highly illuminated environment and will generate photosynthate. Stolon burial or petiole removal can therefore put branch survival at risk (Grant *et al.*, 1991). Starch reserves in stolons are the main method of reserve storage in WC, but under frequent defoliation these reserves are depleted, and larger fractions of water soluble carbohydrates and nitrogen reserves are used (Grant *et al.*, 1991, Lawson *et al.*, 1998). A close direct relationship between starch concentration in stolons and DM yield of leaves was observed by Singh and Sale (1997), indicating that starch reserves are a function of the leaf canopy size.

Repeated defoliation of WC leaves causes a change in phenotype, plant parts becoming smaller and more carbon is partitioned to stolons rather than leaf and petiole tissue (Hay and Baxter, 1989). A decrease in leaf size and emergence rate and an increase in expansion and unfolding rate is also observed (Carlson, 1966). However, when the regrowth period of WC was uninterrupted by new defoliations, a ceiling leaf area index was achieved after 20 days in a pure stand. The size of new appearing leaves was

progressively larger and petioles longer and heavier than previous leaves, and senescence of tissue increased, with consequent loss of tissue (Brougham, 1958). Seedlings that were not affected by defoliation produced ten times more stolon than early defoliated or intensively defoliated seedlings, demonstrating the intense effect of tissue removal on plant size and production (Hayes and Williams, 1995).

The strong effect of defoliation on root growth was demonstrated by Evans (1973), who tested different defoliation heights and found depression of root elongation, with the most intense 25mm treatment causing complete or nearly complete cessation of root elongation. A higher percentage of grass roots died as a result of defoliation than in clovers, even though more leaf lamina was removed in clover, as the single horizontal canopy is more fully removed (Evans, 1973).

2.2.4.2. *Grazing systems*

To maximise pasture productivity and utilisation, swards high in green leaf and legume content grazed by stock of high genetic merit at high stocking rates are necessary, which have to be complemented by adequate management of these factors (Clark *et al.*, 1982). Within a range of acceptable levels of pasture utilisation, a relative equilibrium in leaf growth is maintained, and therefore other factors like fertiliser topdressing or stocking rate will largely alter pasture and animal production (Chapman and Clark, 1984). Hill country pasture management will also need to take into account the seasonal imbalance of feed supply and demand, and factors of animal selectivity and preferences, which in turn will influence pasture utilisation patterns by grazing animals (Sheath, 1981)

Grazing management can eventually lead to two opposite situations which will limit hill country pasture production. A too lax grazing to residues of 2.5-3 t DM/ha will allow accumulation of dead matter, shading of clover and reduced sward density; while extremely hard grazing to residues of 0.8-1 t DM/ha will also lead to reduced pasture density, exposure of bare ground and weed invasion. Management systems will

generally work between these limits (Chapman and Macfarlane, 1985), where there is scope for relatively minor but nevertheless important adjustments.

Grazing pressure is a key management requirement for good pasture production in hill country (Chapman and Macfarlane, 1985), and significant improvement in botanical composition (more high quality grasses and clover) can be achieved by full utilisation of pasture (Suckling, 1975), implying the regulation of stocking rates and subdivision (Fitzharris and Wright, 1984, Chapman and Macfarlane, 1985). In hill country, a combination of rotational grazing and set stocking is usually recommended, and the timing and intensity will depend on factors like summer rainfall (summer-moist, summer-dry), animal physiological stage (ewe flushing, tupping, lambing, etc), slope category, and oversowing requirements (Brougham, 1960, Sheath and Boom, 1985c, White, 1990) For example, in a drought prone environment, excessive grazing pressure in late spring-summer can reduce reseeding and restrict subsequent pasture regeneration (Sheath and Boom, 1985c)

Cutting management produces an open sward, with grass plants retaining their individuality with erect growth habit, while clover occupies the space between them. In contrast, grazing management generate a highly tillered sward with smaller clover stolons proliferating at the base of the canopy (Evans and Williams, 1987). Under cutting, grass and clover appear to base their relationship on competition, high grass yields occurring with lower clover yields and vice versa. Williams *et al* (2001b) state that, under grazing, high grass yields can be obtained without necessarily reducing clover yields, by the use of more compatible varieties, usually small-leaved clovers which develop high stolon density.

Pasture management can help to manipulate the botanical composition of grass/clover swards. Yarrow and Penning (1994) compared cutting (without N; high clover content), grazing with cattle (intermediate clover content), and grazing with sheep + 300 kgN/ha (low clover content), treatments that yielded 237, 81, and 3 kg DM/ha of live clover respectively at the end of the year. Most of the differences between the high and

medium clover content treatments were lost over winter, but those of the sheep grazed swards persisted, showing the extreme plasticity of sward changes. Similar plasticity for WC in swards grazed by sheep, cattle or under cutting, is reported by Briseño de la Hoz and Wilman (1981).

WC content was increased more under cutting than under grazing (Williams *et al.*, 2001a), and likely causes were the richer N environment generated by the return of dung and urine by grazing animals, and selective grazing effects affecting clover competitive ability (Harris, 1987), as well as higher stolon density (Sheldrick *et al.*, 1993), and removal of stolons by grazing stock (Evans *et al.*, 1992). Under cutting conditions, a significant amount of clover remains below cutting height, and can be as high as 50% of the yield above cutting height, while grazing with sheep left significantly less, between 28-37% (Evans and Williams, 1987). On dry hill country slopes, in pastures laxly grazed during the pre-dry period, WC stolons became elevated above the soil surface, and thus very vulnerable to grazing, especially if followed by hard grazing in summer (Sheath and Boom, 1985b). Lower grazing pressure by low stocking rates produced patchy grazing, and clovers tended to become suppressed under tall pasture, which remained uneaten in spring and summer (Suckling, 1975).

One of the aims of grazing management is the control of reproductive growth in grasses and the encouragement of WC, and systems of rotational grazing (RG) involving frequent defoliation in the spring, followed by less frequent grazing in summer, are seen to improve WC growth (Brougham *et al.*, 1978). Longer regrowth intervals (35 d) compared to short intervals (14 d) encourage the clover component in rotationally sheep-grazed pastures (Sheldrick *et al.*, 1993). Clark *et al* (1982) pointed out that RG of hill pastures may allow greater conservation over the spring period and provide extra feed at very high grazing pressures, but is unlikely to give greater animal production.

For SC growing in a drought-prone environment, RG during spring with post-grazing residues of 2-3 cm produced higher levels of regeneration and allowed cultivar differences to be tested (Sheath and Macfarlane, 1990b). Gillingham *et al* (1998)

observed a decline in SC content in summer-dry hill country swards, which they attributed to the RG management imposed, mob grazing restricting SC seed-set and burial in late spring-early summer. It was observed that mob-stocking management caused between 36-67% of flowers to be removed by grazing, and therefore not contributing to re-seeding, and compromising sward regeneration (Chapman, 1992). Grazing of swards to heights of 1-3 cm is common practice in hill farming during spring (Sheath and Macfarlane, 1990b).

In the UK, in continuously grazing systems, maintenance of sward heights around 5 cm support high clover content (Swift *et al.*, 1993), while Hay and Baxter (1989) under New Zealand temperate conditions conclude that combined set stocking (SS) in spring, to achieve high stolon density, combined with RG in summer, will more efficiently convert pasture DM into animal products.

Grasses with open growth habit, like tetraploid ryegrass, were better able to sustain higher legume contents under SS, especially if combined with a densely stoloniferous small-leaved white clover (Swift *et al.*, 1993). Brock (1988) evaluated white clover cultivars and, under SS, the hill country cultivar Grasslands Tahora had higher growing point numbers, but similar leaf size and leaf numbers than other cultivars, which resulted in greater leaf biomass.

It is generally accepted that RG encourages clover performance more than SS, partly because it reduces selective defoliation and allows the plant to elongate its petioles and place them in the top of the canopy (Frame and Newbould, 1986), and achieve larger plant sizes than under SS (Brock *et al.*, 1988). The inverse relationship between tiller density and tiller growth, the greater defoliation frequency under SS, the higher defoliation intensity under RG, the higher leaf extension rate for RG, smaller and fewer leaves per growing point under SS, the thinner stolons under SS, the higher growing point density under SS, and the higher tiller numbers under SS, tend to compensate each other, and herbage grown and consumed under SS and RG systems is similar (Clark *et al.*, 1982, Chapman and Clark, 1984, Brock, 1988, Hay *et al.*, 1988). Similar residual

biomass, but half the grass tiller and WC growing point density under RG v SS systems, had implications for stolon mortality under stress conditions, especially with extreme temperatures of bare ground (Brock, 1988). RG swards had lower WC leaf appearance intervals than SS pastures in summer (Chapman and Clark, 1984), but stolons were less branched for a longer time than in SS in spring, which made plants more vulnerable to stress conditions (Hay *et al.*, 1988). In general, under RG management, and with no stress situations like drought, WC could better use favourable growth conditions, while under SS there was less WC growth, but more stability over stress periods (Hay *et al.*, 1988).

Briseño de la Hoz and Wilman (1981) observed that sheep grazed clover preferentially and the plant reduced the amount of stolons, had shorter internodes, petioles and leaflets, and stolons were thinner and closer to the ground, than when grazed by cattle or under cutting conditions. It is proposed that, where swards tend to become clover dominant, increased grazing pressure by sheep will usually reduce clover content, whereas to increase clover content it is necessary to increase the intervals between grazing events, replace sheep with cattle, or take a conservation cut (Evans *et al.*, 1992). In summer-moist hill country, RG by cattle increased ryegrass and WC (13%) content, compared with RG (7.4%) or SS (8.1%) by sheep (Clark *et al.*, 1982), while similar results are reported by Hay (1985), with very different sward structures developing over a period of three years under RG by cattle v SS by sheep (14.4 v 10.5 t DM/ha; 15% v 8% WC; 7700 v 15000 tiller/m²; 2700 v 3800 gp/m²; twice stolon DM, and half the branch numbers in RG v SS), heavier and thicker stolons developing in RG pastures by cattle (Hay and Chapman, 1984).

Cattle seemed to graze more evenly on clover, and when WC stolons were grazed, cattle removed older leaves and rarely destroyed the growing point, newly expanding leaves or any nodes (Clements, 1989). In the UK, Laidlaw and Toal (1995) saw similar herbage production and WC contents little affected in the long term under SS with cattle, when swards were intensively grazed with spring targets of 5-9 cm height and summer targets

between 7-9 cm. The use of cattle as an effective control of weeds in hill pastures, is also reported (Suckling, 1975).

In Scotland, in mixed ryegrass/WC swards grazed by sheep with 120 kg N/ha/year or without N, effects of sheep grazing (especially under wet conditions) was much more important than the deleterious effect of N on WC, as higher stocking rates affected survival and production of new branches, especially by stolon burial (Barthram *et al.*, 1992). Similar responses were recorded by Grant and Marriott (1989), and these were aggravated by the urine effects on clover, which augmented stolon death and reduced branching rate and increased grass tiller population density. These effects explained patchy distribution of WC in the sward and variation between sites. WC being a species that is found usually in patches within a pasture, WC yield in a mixed sward was described as the product of patch density (n patches per ha), patch size (m² per patch) and clover mass per patch (kg/m²/patch), all three components being positively correlated with yield (Nie *et al.*, 1996). The net effect of trampling and excretal N can lead to clover reduction in the sward, as clover is more susceptible to treading than grass, while excreta return encourages grass growth which may suppress clover (Frame and Newbould, 1986).

Clover content of pastures is reduced under sheep grazing, whether by preferential grazing or by encouragement of a dense tiller density in the sward. Selective grazing is observed in most animals, and the diet chosen is usually of higher nutritive value than that rejected (Harris, 1987), while competitive ability of clover may be put at a disadvantage owing to stolon removal or preferential grazing (Jackman and Mouat, 1972b). Even after short grazing periods on RG swards, all accessible clover leaves, petioles and stolons were grazed, while grasses were left largely untouched (Evans and Williams, 1987). During a grazing period in which both monocultures of WC and ryegrass were available, sheep attempted to maintain their dietary preference, by increasing their grazing time as intake rates for WC decreased due to lower sward

heights. Extra grazing time was spent mostly on clover (Penning *et al.*, 1997, Cosgrove *et al.*, 2002, Rook *et al.*, 2002).

Even different animal classes within a species may generate contrasting effects on botanical composition, as intensity of grazing may vary due to factors like physiological stage of animals (maintenance, pregnancy, lactation, etc.) and the consequent nutritional requirements (Quigley and Foot, 1998).

The availability of WC, given by its height within the sward, was seen to increase WC in the diet of sheep, when WC height increased. When clover was short, sheep tended to graze longer, but were not able to compensate for lower intake and lower clover content in the diet eaten (Harvey *et al.*, 2000). A study on oesophageal-fistulated sheep showed that the proportion of WC in the diet was generally higher than that in the sward, especially when the clover content of the grazed horizon was below 40% (Milne *et al.*, 1982). Milne *et al.* (1982) also suggested, that WC in the diet can be increased when the WC content in top layers of the sward is highest.

Preference for SC continues to be expressed in swards with low herbage on offer, and thus sheep are not grazing at an optimum intake rate, as other abundant species are avoided, which will in turn create a competitive disadvantage for SC and eventually compromise its persistence (Broom and Arnold, 1986). For senescent SC material, clovers with a long growing season tended to have higher preferences by grazing stock, than short-season cultivars (Colebrook *et al.*, 1990).

Subterranean clover must reseed for continued survival, and may disappear if under RG management with infrequent intervals in spring, due to flower removal, while under more frequent RG or SS, SC flowered freely and produced seed (Lambert *et al.*, 1985). The compatibility of growth habit and intensive sheep grazing is seen as a key factor in SC persistence success. Flowers, burrs, and runners of erect, open cultivars are vulnerable to intensive grazing, and consequently regeneration is poor. Prostrate cultivars have more profuse reseeding and regenerate more successfully (Sheath and

Macfarlane, 1990a). In summer-dry hill country, SC abundance is increased by laxer grazing during the pre-dry period, and harder grazing during the summer. Hard intermittent grazing in spring (as is usually the case in hill country), encourage reproductive organs into the grazing layer, and are removed by hard grazing. Therefore, a higher post-grazing residual in spring seems to be necessary for successful reseeding (Sheath and Boom, 1985b, Sheath and Macfarlane, 1990b, Conlan *et al.*, 1994). This is in contrast with management requirements of WC for the same periods, especially if vegetative reproduction will be the main method of persistence, as rank pasture in summer will protect vegetative WC growth, but will affect SC seedling establishment in autumn (Sheath and Boom, 1985b). In WC, more flowering activity was seen under RG than under SS, with 89-97% of flower-heads removed by stock within the first 12 days of their appearance, unripe and therefore unable to shed seed (Chapman and Anderson, 1987). In general, annual species should not be grazed severely in spring when producing seed, as flowers and seed can be removed by stock (Chapman and Macfarlane, 1985, Dear *et al.*, 2002). In a drought-prone environment, competition from annual species, including annual legumes, largely explained WC decline over a period of 30 years, which was accelerated by SS management. Both grazing and competition effects lowered WC seed-bank reserves, and WC will increasingly show lower post-drought resilience (Hutchinson *et al.*, 1995).

Animal preferences in hill country are also affected by topography, as stock preferably graze on easy than steep slopes, especially when herbage on offer is still high (Sheath, 1981). Overgrazing of stock camps makes pastures highly sensitive to drought and losses of white clover are observed (Suckling, 1975), while the timing effect of grazing pressures during reproductive or establishment phases of hill pastures are higher on steep land than easy land, as annual species dominate in the former (Sheath and Boom, 1985b).

2.2.4.3. *Fallowing*

Fallowing can be defined as the spelling of a pasture, during which it is not subjected to cutting or grazing management. Long spelling periods (early spring to autumn) have major effects on sward density, effectively reducing tiller populations and altering the sward structure of hill country pastures (Mackay *et al.*, 1991, Nie *et al.*, 1997). A 72% decrease in tiller numbers and 87% decline in WC growing points was observed by Nie (1997), and was attributed to above-ground biomass accumulation, which altered sward structure, and led to inter-plant competition and mortality by self-thinning.

However, the opening of the sward creates new opportunities for WC, as niches become available to be colonized through spreading, as well as better opportunities for oversowing of improved seed into pasture (Mackay *et al.*, 1991, Nie *et al.*, 1996, Nie *et al.*, 1997). Although WC was reduced in the short term, WC growing point density doubled after four years compared to non-fallowed swards, and was four times that of swards after the first year of fallow. WC content was increased from 3% to 8.5%, and stolon length and size was also significantly increased (Nie *et al.*, 1996), and clover dispersion was stimulated by internode elongation (Nie *et al.*, 1998). On previously rested compared with weekly cut swards, WC leaf appearance rates were increased by 40% and branching rates by 164%, showing the potential advantages to clover of an appropriate rest period from grazing (Grant and Barthram, 1991). Sibbald *et al* (2002) also observed the benefits of resting pastures from grazing, in sustained WC content by alternating ensiled and grazed areas over a 3-year period.

The timing and duration of a fallow can produce different results. Starting a fallow in late spring produces a high proportion of reproductive tillers and favours natural reseeding, which is not desirable if pasture will be oversown in the following spring (Nie *et al.*, 1998). In summer-moist hill country, a full spring-autumn pastoral fallow increased germinated legume seed population the following season by 51%, compared with grazed swards, and it was shown, that the timing and duration of the fallowing

period can be manipulated to produce more or less seed quantity, and that the legume seed population was higher in shady than on sunny aspects (Nie *et al.*, 1999). An autumn fallow of hill pastures with application of N, considerably reduced plant population density for oversowing new species. (Nie *et al.*, 1998). In dry prone hill country, spelling or lax grazing during dry conditions (January-April), resulted in low production, and therefore increased pasture utilisation to levels that do not affect pasture density is suggested to maximise growth (Sheath and Boom, 1985c).

Compared to RG pastures, fallowed swards had less root biomass at the 0-50 mm soil depth, while hydraulic conductivity and soil moisture were increased by 67% and 10-15% respectively, while soil bulk density was reduced by 11%. No significant differences were observed in soil nutrients between grazing and fallowing managements (Nie, 1997). N fixation was seen to increase in the year after fallow, increasing the potential N pool of the soil (Mackay *et al.*, 1991).

2.2.5. Genotype

Improvement of WC persistence through plant breeding may be achieved by increasing the rate of stolon formation and the decrease of the rate of stolon death, concentrating on genotypes with higher spread potential, better at competing with grasses, and adequate performance in low P environments (Woodfield and Caradus, 1996).

WC cultivars are commonly grouped according to leaf size into small, medium and large-leaved varieties (Frame and Newbould, 1986). Larger leaved clovers will withstand severe competition from grass better, especially if N fertiliser is applied (Harris, 1987), and will usually outyield small leaf varieties, although within leaf categories no correlation is seen between leaf size and yield, and growing point density might be a better predictor of yield in this case (Williams *et al.*, 2001a). WC cultivars with higher growing point densities at a given leaf size, should improve persistence and maintain a greater yield potential (Woodfield and Caradus, 1996), such as cv. Sustain or cv. Challenge. Large-leaved varieties perform better under a cutting regime, whereas

under SS small and medium-leaved cultivars are the most productive (Evans and Williams, 1987), and these are considered to withstand frequent close defoliation (Harris, 1987).

Under intensive grazing, a prostrate, dense, medium to small leaved growth habit is desirable for persistence and production (Chapman and Macfarlane, 1985). Although small leaved varieties of WC have a slower establishment in the sward, compared to larger leaved varieties, they will have a greater persistency under grazing (Evans *et al.*, 1992). Also, the characteristics of WC roots has been related to leaf size, with a strong development of taproots being correlated with the large-leaved habit, and predominantly fibrous root development with the prostrate, small-leaved habit (Harris, 1987).

In a summer-dry hill country site, the white clover hill country selections established better than Grasslands Huia in spring and autumn, with a subsequent higher overall clover content (8.7% v 2.8%) and a six times higher growing point density (1240 v 198 grow. points/m²) compared to Grasslands Huia (Charlton and Giddens, 1983). Cultivars of WC can also differ in starch concentration (Lawson *et al.*, 1998), N fixation efficiency (Etilib and Ledgard, 1988), the ability to grow in soils low in P (Caradus and Snaydon, 1986), adaptation to dry conditions (van den Bosch *et al.*, 1993), improved capacity to spread in the sward (Campbell *et al.*, 1994), or to compete with grasses (Harris, 1987, Ledgard *et al.*, 1995), factors that may influence cultivar persistence.

WC persistence has been a limitation in SS hill country swards, which led to the development of Grasslands Tahora, a small-leaved cultivar developed from moist hill country high producing ecotypes, characterized by higher stolon densities than Grasslands Huia, which ensured better performance under hill country SS grazing conditions (Brock *et al.*, 1989, White, 1990, Caradus and Woodfield, 1997).

The ideal SC cultivar should be compatible with the environment in which it is growing and the management to which steep hill country is usually subjected. Therefore it should set seed in late spring, be prostrate in crown and runner habit, and be low in oestrogenic

content (Sheath and Macfarlane, 1990b). On the other hand, an open erect growth habit is likely to improve accessibility by the grazing animal, and thus compromise regeneration (Sheath and Macfarlane, 1990b, Dodd *et al.*, 1995c). Dodd *et al.* (1995b), reported various SC lines with a good ability to regenerate seedling populations over 300 plants/m², and accumulate buried seed reserves of over 1000 seed/m², and indicated that there is material available to develop a New Zealand cultivar. Late flowering SC types were able to maintain adequate cover to December, while early flowering lines had already disappeared (Dodd *et al.*, 1995a). In pure SC stands, levels exceeding 2700 kg DM/ha and more than 7000 seeds/m² were produced by local lines (Dodd *et al.*, 1995c). The Australian cultivar Tallarook is usually used as a standard to compare SC cultivars, and it has generally performed better than others, while cultivar Karridale has performed well in terms of regeneration and early season growth (Dodd *et al.*, 1995b), while cultivar Denmark has shown better early season growth than Tallarook (Dodd *et al.*, 1995c). Early-flowering cultivars set more hard seed than late-flowering cultivars, although in years with adequate summer rainfall, all cultivars showed a high degree of hardseededness (Smetham and Wu Ying, 1991). It is concluded that early- to mid-season flowering cultivars of SC, appeared inadequate for high-rainfall, but summer-dry, North Island hill country (Sheath and Richardson, 1983).

Some SC cultivars have a high content of isoflavones (formononetin, genistein and biochanin A), which have oestrogenic effects and may cause reproductive disorders in sheep. The late flowering cultivar Tallarook, although having the desirable characteristics of prostrate growth habit, it has high levels of formononetin. An analysis of Tallarook showed formononetin levels of 0.96% of DM, significantly higher than the maximum of 0.2% generally recommended to avoid infertility problems in grazing stock (Dodd *et al.*, 1995c).

2.2.6. Pests and diseases

There is a large number of diseases and pests colonising white clover, but only a few have proven to have economic effects. Many are likely to act at a sub-clinical level, and

are difficult to detect and quantify (Brock *et al.*, 1989). Diseases in WC can be classified into fungal diseases (e.g. clover rot, leaf rust and root-rot complex), and viruses and mycoplasmas (Brougham *et al.*, 1978). Pests and diseases tend to selectively reduce WC in mixtures, and their effects resemble the action of selective defoliation (Harris, 1987).

The grass grub and the subterranean grass caterpillar are two important insect pests affecting WC in New Zealand (Harris, 1987), but also nematodes (e.g. stem eelworm, root cyst nematode) cause damage in some areas (Brougham *et al.*, 1978). Resistance to some pests, such as clover cyst nematode, root-knot nematode and clover flea have been reported, and offer a possible way of control (Woodfield and Caradus, 1996). The decline in WC content through the use of fertiliser nitrogen and the suppression of WC using herbicide has been seen to significantly reduce grass grub density in the pasture (MacCallum *et al.*, 1990). More recently, Barratt *et al.* (1996) have reported the clover weevil as a potential threat to clover in pastures of the North Island.

Subterranean clover is less prone to diseases than most other forage legumes, but it can be affected by root diseases like root rot, and other fungal diseases such as clover scorch and powdery mildew. The use of cultivars with resistance to diseases is the best strategy to combat disease. Aphids can also transmit a number of viruses (Frame, 1998). Susceptibility to clover flea damage and also viral problems have been reported for SC (Dodd *et al.*, 1995c) in New Zealand, while fungal diseases causing clover scorch and root-rot are major diseases in Australia (Rossiter, 1978).

2.3 CONCLUSIONS

Legumes have played a central role in New Zealand farming history, and their ability to fix atmospheric nitrogen, and in turn make it available to grasses, has been the cornerstone of animal production systems. An enormous amount of research has been undertaken, especially in relation to white clover, by far the most used and widespread legume both in hill country and lowlands of New Zealand. Aspects such as anatomy, physiology, nutritive value, nitrogen fixation, management, plant breeding, and animal

behaviour, have been covered, both internationally and also applied work locally. Subterranean clover has also been studied, especially in Australia, where it is a very relevant pasture component for temperate dryland areas. In New Zealand, SC has been less studied, and its relevance is highlighted in summer-dry hill country areas.

Adequate legume content in hill country swards is a key factor in achieving high pasture production and animal performance levels, with sound economic returns from the hill farming activity. However, legume content reported for hill pastures is generally very low, well below the 25-30% minimum annual legume average (DM base) stated by some authors, and many times as low as 5% or less. Low legume content in hill swards is a source of concern, as the medium-term sustainability of hill-based systems is jeopardised, with direct impacts on the New Zealand economy, as this area sustains a significant proportion of sheep and beef exports.

Why is there so little legume abundance in hill country swards? Multiple factors affecting legume performance, persistence, and abundance are cited, and their relative importance is likely to change according to climatic, soil, and topographical variables, as well as characteristics related to resident pastures and their utilisation. Inadequate soil moisture appears to be an overriding factor in determining legume abundance, especially in summer-dry environments, and is usually a non-manageable factor under hill country conditions.

The preceding review of literature has pinpointed and highlighted the areas of knowledge in relation to factors affecting legume dynamics in pastures. However, and provided that adequate cultivars are chosen for a particular location, other factors such as the competition from companion grasses, levels of pasture management and utilisation by grazing animals, soil phosphorus status, and the application of nitrogen fertiliser, amongst others, have been reported to affect legume abundance in swards. The effects of these factors have been studied, many times independently, and more information is necessary in relation to likely interactions between factors, as well as to

determine their relative importance in influencing legume abundance on contrasting summer-dry and summer-moist hill country situations.

CHAPTER 3

INFLUENCE OF MANAGEMENT AND ENVIRONMENTAL EFFECTS ON LEGUME ABUNDANCE UNDER CUTTING CONDITIONS AT CONTRASTING HILL COUNTRY PASTURE SITES

3.1 INTRODUCTION

The literature review has highlighted the relevance of legumes to New Zealand pastoral systems and stated their generally low abundance in hill country pastures. A content of legumes higher than current averages in hill country is desirable, to address limitations of production, nutritive value, seasonality, and to ensure medium-term sustainability of New Zealand hill country pastoral systems.

Numerous factors that affect the abundance and production of legumes in pastures have been listed (Section 2.2) and many effects have been studied and quantified under particular situations. The factors that affect legume abundance are very likely to interact, and therefore to constitute responses of relatively high complexity. Furthermore, different environmental conditions imposed by the highly variable hill country in New Zealand, especially those referred to seasonal soil moisture patterns, will probably also influence the outcome.

Likely causes for low legume participation in hill country pastures have been reported, but their relative importance and likely interactions have not been sufficiently tested, especially on dry hill country. A set of three experiments was designed with the general objective of exploring the short-term effects on resident pastures, and the relative importance of different factors that have been seen to encourage/discourage legume persistence in hill pastures, under three contrasting environmental conditions (summer-

moist hill country, and summer-dry hill country (north and south aspect)). Factors considered in the present study include pasture utilization height under cutting, grass suppression, soil-P status, and autumn nitrogen application.

3.2 MATERIALS AND METHODS

3.2.1. Sites

In autumn 2000, three replicated experiments were established on contrasting hill country sites, two in Waipawa (Hawke's Bay) and one in Ballantrae (near Woodville).

3.2.1.1. *Waipawa sites*

The area is located about 4 km west of Waipawa, in the summer-dry hill country area of the east coast of the North Island (40°00 S, 176°23 E). The two experiments were installed within a larger pre-existing AgResearch farmlet grazing and fertilizer trial (Gillingham *et al.*, 1998). Both a north-facing dry aspect and a more humid south facing aspect were selected, within low P fertility farmlets. The experiments were installed on intermediate slope areas (19.0° for the north aspect and 26.3° for the south aspect). The soils correspond to the Waipawa silt loam type derived from white argillite (Yellow-grey loam) (Pohlen *et al.*, 1947).

3.2.1.2. *Ballantrae site*

The third experiment was carried out at the Agresearch Hill Country Research Station 'Ballantrae' (40°19' S, 175°50' E). This site is representative of the summer-moist hill country of the southern part of the North Island. The experiment was installed within a farmlet grazing experiment on an east-facing aspect with an average slope of 15.2°. Soils are classed as yellow-brown earths and intergrades to yellow-grey earths formed from tertiary sandstone, siltstone and mudstones (Hewitt, 1998).

3.2.2. Previous management

3.2.2.1. Waipawa

The farmlets on which the experiments were installed correspond on both aspects to hill pastures which received since 1995 low levels of P fertiliser as superphosphate to maintain the original Olsen soil P status of 9. The area was oversown with white and subterranean clover seed in autumn 1995 and 1996 (Gillingham *et al.*, 1998). Pastures are at present dominated by browntop (*Agrostis capillaris* L.), with a contribution of other grasses, like sweet vernal (*Anthoxanthum odoratum* L.), crested dogtail (*Cynosurus cristatus* L.), chewing's fescue (*Festuca rubra* L.), cocksfoot (*Dactylis glomerata* L.), brome (*Bromus spp*), and perennial ryegrass (*Lolium perenne* L.). Low amounts of legumes are also present, represented by white clover (*Trifolium repens* L.), subterranean clover (*Trifolium subterraneum* L.) and other annuals, especially suckling clover (*Trifolium dubium* Sibth.) and clustered clover (*Trifolium glomeratum* L.). Broadleaved weeds include, yarrow (*Achillea millefolium* L.), catsear (*Hypochoeris radicata* L.), narrow-leaved plantain (*Plantago lanceolata* L.), Californian thistle (*Cirsium arvense* (L.) Scop.), mouse-ear chickweed (*Cerastium fontanum* Baumg. ssp. *triviale* (Link) J alas), and dandelion (*Taraxacum officinale* Weber). Farmlets are self-contained and stocked with breeding ewes and managed under a rotational grazing regime to allow full pasture utilisation. Cattle are also stocked to allow utilisation of the spring growth peak.

3.2.2.2. Ballantrae

The experiment was installed within a farmlet that has received superphosphate topdressing since 1973, at rates of 250 kg/ha/year between 1973-1975, and of 125 kg/ha/year between 1977-2002. Lime was also applied at rates of 1250 kg/ha in 1975 and 2500 kg/ha in 1979. Further details are described elsewhere (Lambert *et al.*, 1998). Pastures are dominated by browntop (*Agrostis capillaris* L.), while other grasses present include sweet vernal (*Anthoxanthum odoratum* L.), perennial ryegrass (*Lolium perenne*

L.) and Yorkshire fog (*Holcus lanatus* L.). Low levels of legumes are present, mainly white clover, with a sporadic presence of suckling clover and subterranean clover. Broadleaved weeds include, catsear, narrow-leaved plantain, dichondra (*Dichondra repens* Forst.), waxweed (*Hydrocotyle americana* L.), hawkbit (*Leontodon taraxacoides* (Vill.) Merat.), mouse-ear chickweed, dandelion, annual mouse-ear chickweed (*Cerastium glomeratum* Thuill.), pearlwort (*Sagina procumbens* L.), parsley piert (*Aphanes* sp.), yarrow, scotch thistle (*Cirsium vulgare* (Savi) Ten.), and Californian thistle. Breeding ewes are set stocked year-round on the paddocks.

3.2.3. Design and treatments

The three experiments had the same design and treatments but were located at the three contrasting sites: Waipawa north aspect, Waipawa south aspect and Ballantrae. All sites had low to medium soil phosphorus levels, between 13 and 15 $\mu\text{gP/ml}$, which were higher than previously expected, but still within a low range (Cornforth and Sinclair, 1984).

Four factors were selected as being the most likely to affect legume growth and persistence: cutting height, grass suppression, soil P-status and nitrogen application. The effect of soil moisture was also included by choosing the contrasting sites.

Experiments had a $2 \times 2 \times 2 \times 2$ factorial array, with two cutting heights, two pasture types, two soil phosphorus levels and two nitrogen levels. For management reasons, the factorial array was organised into a split-split plot design, with (cutting height) $\times$ (pasture type) arranged as a main plot (randomised), soil-P level as a subplot and N-level as a sub-sub plot.

Main plots were $2 \times 6\text{m}$ (12 m^2), subplots $2 \times 3\text{m}$ (6 m^2) and sub-subplots $1.5 \times 2\text{ m}$ (3 m^2), resulting in 16 treatment combinations. Each treatment had 3 replicates. The experimental sites were fenced off and managed under cutting conditions.

To ensure adequate legume population potential, plots were oversown (15 June 2000) with inoculated pelleted white clover (*cv. Tahora*) and subterranean clover (*cv. Karridale*), at rates of 6 kg/ha and 20 kg/ha, respectively. Prior to sowing, germination tests were done to ensure seed quality.

The swards were cut at two contrasting heights targeted at: 1) 3 cm (**h3**) and 2) 7 cm (**h7**), by means of a rotational mower with adjustable blade height. Plots were cut to the corresponding heights after each sampling. The adjustments of the mower generated actual cutting heights of 2.5 cm and 6.5 cm, as averages checked after cutting at the sites. Clippings were removed from the plots.

Two pasture types were tested: 1) resident naturalised pasture (**H0**) and 2) pasture treated with herbicide (**H1**) for general grass suppression and to encourage legume population. Herbicide applied was *haloxyfop* (Gallant NF), recommended for the selective control of grasses. Haloxyfop-ethoxyethyl and -methyl are a selective group of herbicides, absorbed by the foliage and roots, and hydrolyzed to haloxyfop, which is translocated to meristematic tissues and inhibits their growth (Novachem, 2000). Herbicide was applied on 25 May (Waipawa) and 6 June 2000 (Ballantrae) at a rate of 90 ml/10 l water. Herbicide was mixed with 500 ml/ 100 l water of spraying oil. Spraying was done using a Knapsack, on a wind-free day. Effects of herbicide application are depicted in Plate 3.1 .

As the experiments were imposed on low-medium P status soils, two contrasting conditions were created: 1) low soil-P status (**LP**) corresponding to the resident P level (Olsen P values of 15 in Waipawa north aspect, 13 in Waipawa south aspect and Ballantrae) and 2) high soil-P status (**HP**), which was achieved by applying 425 kg/ha triple superphosphate in Waipawa north aspect, and 475 kg/ha triple superphosphate in Waipawa south aspect and Ballantrae. An Olsen P value of 28-30 was targeted for HP plots. During general aerial topdressings at the sites, plots were covered with polythene sheets to avoid fertility changes.



Plate 3.1 General view of the experimental site at Ballantrae (summer-moist hill country) and effect of autumn herbicide application (June 2000).



Plate 3.2 Field cores during short regrowth period in the glasshouse.

Two nitrogen levels were imposed on plots: 1) one autumn application of 50 kg N/ha (N50), applied as urea on 25 May in Waipawa (both aspects) and 1 June 2000 in Ballantrae, and 2) no nitrogen application (N0). Along with the nitrogen and phosphorus applications, all plots received 20 kg S/ha (as gypsum) and 50 kg K/ha (as KCl). The pH of the sites was in all cases moderately acid (5.4-5.6).

Prior to treatment establishment, as a uniform starting point, all plots were mowed to a height of 3 cm (11 May 2000 in Waipawa, 1 June 2000 in Ballantrae). After a regrowth period of 6-7 weeks, sampling was started at monthly intervals. At some stages, intervals had to be extended due to low regrowth.

3.2.4. Measurements

At the start of the experiment, samples were taken for soil fertility determination to 75 mm depth. Also, from the start of the experiment, lamina height was measured on all plots using an HFRO sward stick (Murphy *et al.*, 1995), and continued thereafter at regular intervals, mostly related to pasture sampling dates. Ten readings were taken per plot, evenly distributed within each plot. Data were recorded using a portable tape recorder. Average slope was also measured at each site, using a digital level replicated on all plots.

Gravimetric soil moisture was determined at approximately monthly intervals at 0-50 mm and 50-100 mm depth, to monitor moisture variation within the main rooting area. Sixteen samples were taken from each site using a 2.54 cm diameter corer, cut to the appropriate depths, and wrapped individually in aluminium foil to avoid moisture loss. They were then weighed prior to and after drying at 105°C/48 h (Reynolds, 1970). Also, samples were taken to determine soil bulk density at both levels, in order to allow gravimetric to volumetric transformations. Field capacity and wilting point were also determined for each site, using soil samples taken at the 0-5 cm and 5-10 cm level and following standard procedures (Loveday, 1974), to relate soil moisture levels to available water for plant growth.

Pasture sampling was based on the use of a 10.4 cm diameter corer, which allowed processing of all samples within a manageable timeframe. Due to patchy legume distribution within plots, and taking into account the relatively small plot size, this procedure was preferred to the use of a quadrat. Three cores were taken at each sampling date from each plot, put into stackable trays and taken to the laboratory for processing. Cores were cut near ground level (approx. 0.5 cm), but allowing tiller stubble and stolons to remain. Herbage from the three cores for each plot was bulked and weighed. Samples were then separated into live grasses, white clover, subterranean clover, other legumes (mostly suckling clover), weeds and dead matter. Live sward components were dried for 48h/65°C and weighed. Total live standing biomass and absolute and relative sward components could therefore be determined, and are stated in tables.

After herbage mass sampling, all cores were taken to a glasshouse (25°C, non limiting water supply) to allow a short period of regrowth (7 days; Plate 3.2). After that period, grass tiller population density was measured from a 50 mm ring from the central area of each core. Also, for each complete core, active white clover growing points were counted, which could easily be detected by their new emerging leaves.

3.2.5. Statistical analysis

Data were analysed using the 'PROC MIXED' procedure in SAS (SAS, 1997). Proc Mixed treats the split-split plot design as a mixed model with fixed effects and random effects. PROC MIXED can compute efficient estimates of fixed effects and valid standard errors of the estimates (which for some levels are incorrectly computed by PROC GLM), while avoiding the complex error structure associated with split plot designs (Littell *et al.*, 1998). Some datasets were also used to perform regression analysis and canonical correlation multivariate procedures

3.3 RESULTS

3.3.1. General results layout

Results from the three experimental sites will be first presented separately. In each case, climate and soil moisture conditions during the experimental period will be described, followed by results on each of the main factors analysed. At the beginning of each site sub-chapter, a table with all main effects and significant interactions is presented. The analysis of effects is mostly based on the very significant (usually $p < 0.001$) *main effect x date* interaction. Particularly significant interactions for certain variables are dealt with in the corresponding *main effect* results presentation. In those cases, the means are stated and the significance level of the difference is given. Interactions are presented in one of the corresponding main effect sub-chapters only (normally at the sub-plot level).

Square root transformation of the data was necessary to comply with normality and homogeneity of variance requirements. In tables, transformed data are stated in brackets along with their corresponding standard error of the difference of means (SED). Results are presented and discussed on the original untransformed means (also presented on the tables), but all statistical significance levels are related to the transformed data.

3.3.2. Waipawa north aspect

At this site, swards were sampled five times, on 12 July, 9 August, 15 September, 25 October and 19 December 2000. For the ease of reading, dates will be hereafter referred to as July, August, September, October and December in the text and tables.

3.3.2.1. Significance of main effects and interactions

The statistical significance of main effects and some interactions of the different variables analysed at the Waipawa north aspect site are presented in Table 3.1.

Table 3.1 Summary of main effects and interaction significance. *Waipawa north aspect*.

Main effect or Interaction	Total St. biomass DM/ha	Grass DM/ha	Subt. clover DM/ha	White clover DM/ha	Other legumes DM/ha	Weeds DM/ha	All Legumes DM/ha	Sward height cm
cuth	***	*	*	NS	NS	NS	*	***
supp	*	***	NS	**	*	**	**	***
phos	NS	NS	NS	*	NS	NS	NS	NS
nitro	NS	NS	NS	NS	NS	NS	NS	NS
date	***	***	***	***	***	***	***	***
cuth x date	***	***	***	*	NS	*	***	***
supp x date	***	***	***	***	***	***	***	***
phos x date	NS	NS	NS	***	NS	NS	*	*
nitro x date	*	NS	**	NS	*	*	*	***
cuth x phos x date	NS	NS	NS	NS	*	NS	NS	NS
supp x phos x date	NS	NS	NS	NS	***	*	NS	NS
supp x nitro x date	*	NS	NS	NS	NS	NS	NS	NS
cuth x supp x date	NS	**	NS	NS	NS	*	NS	**
phos x nitro x date	NS	NS	*	NS	NS	NS	NS	NS

Main effect or Interaction	Grass %	Subt. clover %	White clover %	Other legumes %	Weeds %	All Legumes %	Tiller density till/m ²	Grow.pt. density g.p./m ²
cuth	NS	NS	NS	NS	NS	NS	**	NS
supp	***	NS	**	*	***	**	***	*
phos	NS	NS	*	NS	NS	NS	NS	NS
nitro	NS	NS	NS	*	NS	*	NS	NS
date	***	***	***	***	***	***	***	***
cuth x date	*	***	NS	*	**	NS	***	NS
supp x date	***	***	***	***	***	***	***	***
phos x date	NS	NS	**	NS	NS	NS	NS	NS
nitro x date	*	**	NS	*	*	*	NS	NS
cuth x phos x date	*	NS	NS	NS	NS	NS	NS	NS
supp x phos x date	NS	NS	NS	**	*	NS	NS	NS
cuth x supp x date	*	NS	NS	NS	*	NS	NS	*
phos x nitro x date	NS	*	NS	*	NS	NS	NS	NS

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; cuth=cutting height; supp=grass suppression; phos=phosphorus; nitro=nitrogen.

NOTE: Only interactions that were significant for at least one variable are shown in the table.

3.3.2.2. Climate conditions

Average and season rainfall and soil temperature data are presented in Table 3.2. Total rainfall in the season was only 8% lower than the 35 year average. However the distribution of rainfall was different, with a dry late autumn (May/June) with 60% of the average rainfall, a very humid July (179%), followed by a dry period between August and early November (40% and 27% of average rainfall in August and October,

respectively). September appears as a wet month, but 74% of the rainfall was concentrated in one 1-day event. Short and intense rain storm events occurred in summer, and between December and March, only February had average amounts of rainfall.

Table 3.2 Rainfall and soil temperature (10 cm) for the experimental period at Waipawa north and south aspects, and average year.

Month	Rainfall (mm)		Soil temp. 10 cm (°C)		
	<i>Waipawa</i>	<i>Waipukurau</i>	<i>Waipawa N</i>	<i>Waipawa S</i>	<i>Waipukurau</i>
	2000/01 *	Average**	2000/01 *	2000/01 *	Average **
May	46	75	14.5	10.4	9.0
June	51	85	11.1	7.8	6.3
July	163	91	11.4	8.6	5.4
August	32	81	11.2	7.1	6.5
September	95	57	13.4	10.0	8.7
October	16	59	16.2	12.9	11.9
November	99	53	16.4	14.5	15.2
December	65	83	21.4	19.2	17.6
January	50	61	21.5	19.7	18.8
February	63	60	22.5	20.9	18.3
March	21	71	20.1	16.4	15.8
April	84	71	16.7	12.5	12.4
Annual	785	847	16.4	13.3	12.2

*Data supplied by Agresearch; ** Average 1945-1980 (NZMS, 1983).

Average soil temperatures correspond to Waipukurau (40°00'S; 176°32'E), located at 8 km from the experimental sites. This station had no records for the 2000-2002 seasons, and therefore no precise comparisons with local data can be made. The season average was 1.1 °C and 4.2°C warmer at the Waipawa south and Waipawa north aspects, compared to the Waipukurau average, respectively. As expected, the north aspect had always higher soil temperatures than the south aspect, which averaged 3.6°C more in the autumn-mid spring period, and 1.9°C more in late spring-summer.

3.3.2.3. Soil moisture

The soil moisture changes over the experimental period are shown in Figure 3.1. At the dates measured during the season, volumetric moisture in the top 5 cm of the soil never reached field capacity (FC). In early November 2000, the soil went below permanent wilting point (PWP) with a recovery towards January 2001. Soil moisture was below PWP also from January until early May. Patterns observed at the 5-10 cm level were similar, with values near or below PWP from late September 2000 onwards. Percentages of available water capacity were highest in June and July (88%), falling below 50% after late August.

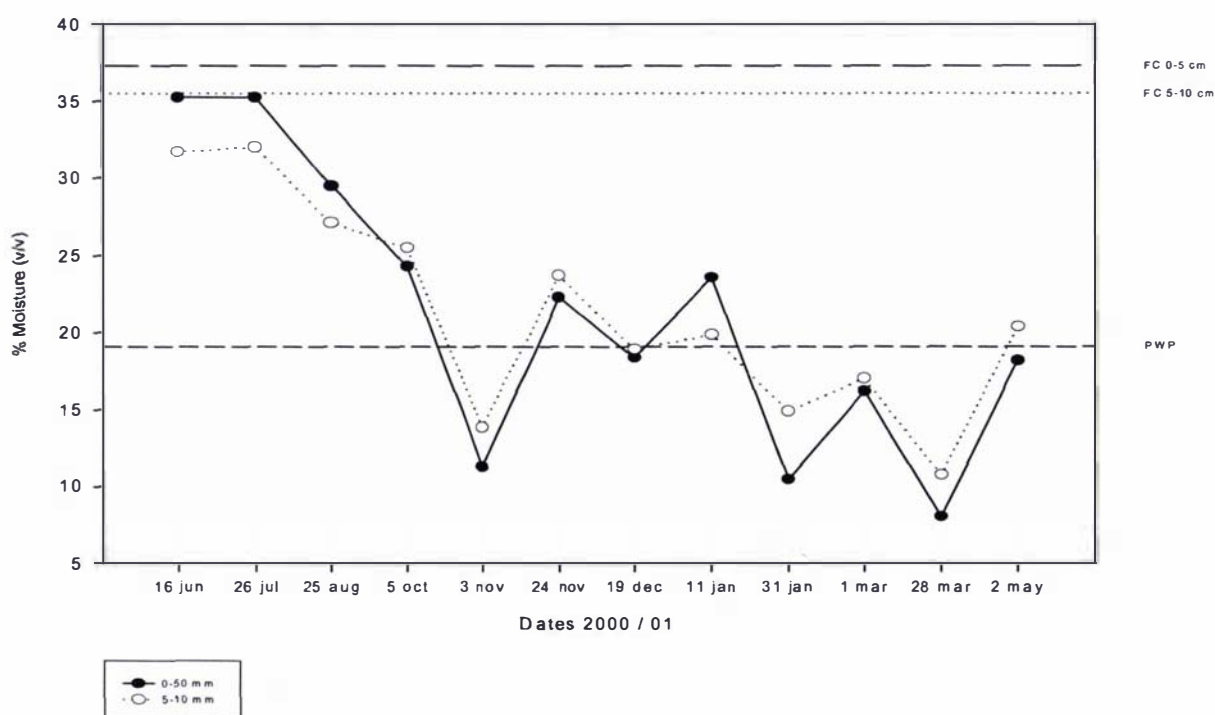


Figure 3.1 Seasonal variation of the volumetric soil moisture of the 0-50 mm and 50-100 mm soil layers in *Waipawa north aspect* (2000/01).

3.3.2.4. Effect of cutting height

3.3.2.4.1. Sward height

Cutting height had very significant effects on sward height as a seasonal average (4.9 v 6.9 cm, $p < 0.001$). Tall plots (h7) were significantly ($p < 0.001$) higher than short plots (h3) from early August to the end of the season (Table 3.3). The tallest heights were recorded in late October, where h7 plots were almost double the shorter plots. Target heights in h7 could only be achieved during spring, due to low growth in winter and summer.

Table 3.3 Average sward height (cm) for different main effects of cutting height, grass suppression, soil-P status and nitrogen treatments, at different dates (2000/2001). *Waipawa north aspect.*

Factor	Treat	May 25	Jun 16	Jul 12	Aug 9	Sep 15	Oct 25	Nov 24	Dec 19	Feb 13	Mar 28	SED	Sign.
Cutting height	h3	4.7 (2.17)	5.3 (2.29)	5.3 (2.29)	4.3 (2.05)	4.0 (1.99)	7.1 (2.64)	4.4 (2.08)	8.0 (2.82)	2.6 (1.59)	2.9 (1.69)	(0.062)	***
	h7	4.8 (2.19)	5.4 (2.31)	5.3 (2.29)	5.8 (2.37)	6.4 (2.49)	13.1 (3.60)	7.8 (2.77)	10.8 (3.26)	4.1 (2.01)	5.0 (2.22)		
	Sign.	NS	NS	NS	***	***	***	***	***	***	***		
	SED	(0.072)											
Grass suppression	H0	4.7 (2.16)	6.3 (2.50)	6.4 (2.52)	6.5 (2.53)	6.4 (2.49)	9.0 (2.97)	6.8 (2.56)	9.0 (2.97)	3.6 (1.85)	4.1 (1.98)	(0.062)	***
	H1	4.8 (2.20)	4.4 (2.10)	4.3 (2.06)	3.6 (1.89)	4.1 (1.99)	11.2 (3.28)	5.4 (2.30)	9.8 (3.11)	3.1 (1.74)	3.8 (1.93)		
	Sign.	NS	***	***	***	***	***	***	NS	NS	NS		
	SED	(0.072)											
Phosphorus	HP	4.8 (2.20)	5.5 (2.33)	5.4 (2.30)	5.0 (2.21)	5.5 (2.30)	10.2 (3.14)	6.1 (2.43)	10.1 (3.16)	3.3 (1.78)	3.8 (1.90)	(0.062)	***
	LP	4.7 (2.17)	5.2 (2.27)	5.3 (2.28)	5.1 (2.21)	4.9 (2.18)	10.0 (3.10)	6.1 (2.43)	8.7 (2.92)	3.4 (1.82)	4.1 (2.01)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	***	NS	NS		
	SED	(0.070)											
Nitrogen	N0	4.7 (2.15)	5.4 (2.30)	5.1 (2.24)	4.5 (2.09)	4.8 (2.15)	10.1 (3.13)	6.2 (2.45)	9.5 (3.05)	3.4 (1.81)	4.0 (1.97)	(0.062)	***
	N50	4.9 (2.21)	5.4 (2.30)	5.6 (2.34)	5.6 (2.33)	5.6 (2.34)	10.1 (3.11)	6.0 (2.41)	9.3 (3.03)	3.3 (1.79)	3.9 (1.94)		
	Sign.	NS	NS	NS	***	**	NS	NS	NS	NS	NS		
	SED	(0.069)											

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding pooled SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.2.4.2. Herbage mass and botanical composition

Total standing biomass

As a seasonal average, h7 had a higher standing biomass than short plots (2684 v 1932 kg DM/ha; $p < 0.001$). Tall plots outyielded short plots by 36% in September, 70% in October and 52% in December (Table 3.4).

Grass

Tall plots (h7) had on average more grass DM than h3 plots (1534 v 1163 kg DM/ha; $p < 0.05$). The main differences were observed in October, where h7 had 92% more grass than h3 plots. In other months, differences were not significant ($p > 0.05$). Percentage of grasses in the sward declined with time (from 94.2% to 44%), but differences between cutting heights only arose in December (Table 3.5; $p < 0.05$).

A significant *cutting height x grass suppression x date* interaction ($p < 0.01$) showed further that in October and December differences in grass biomass due to cutting height were significant only on plots with no grass suppression (1333 v 2857 and 1307 v 2125 kg DM/ha on h3-H0 v h7-H0, respectively; $p < 0.01$).

Legumes

More subterranean clover (SC) was present on average in h7 (673 v 348 kg DM/ha; $p < 0.05$) than in h3. However, these differences were significant only later in the season, when h7 plots had 89% and 235% more SC than h3 plots in October and December, respectively ($p < 0.001$; Table 3.4). SC percentage in the sward increased from 2.4% in July to a peak of 37.9% in October. Differences in SC percentage between cutting heights were significant only in December ($p < 0.001$; Table 3.5).

Pasture cutting height did not affect white clover (WC) biomass or percentage in the sward for most of the season. Only in October, h7 showed higher WC biomass (42%) than h3 plots ($p < 0.05$). White clover percentage in the sward varied from 0.6% in July to a peak of 14% in October.

Other legumes (OL) present were mostly represented by suckling clover. Production of OL was mostly important in the later part of the season (October to December). Cutting height had a significant effect ($p < 0.05$) on OL participation in the sward only in October (Table 3.5).

Plots with short swards had on average a lower total legume biomass (TL) than plots with taller pasture (713 v 1100 kg DM/ha). TL biomass increased as the season progressed to reach a peak in the October harvest. In October and December, h7 had significantly ($p < 0.001$) more TL than h3 (61% and 77%, respectively; Table 3.4). TL percentage in the sward varied from 4.8% in July, peaked at 57.5% in October and was 52.4% in December.

Weeds

Weed biomass was generally low, and was affected by pasture cutting height only in December, where h3 plots had higher weed content ($p < 0.05$; Table 3.4) than h7. Also, in December weeds reached their peak on h3 (5.5%) which was significantly greater than h7 weed content (1.7%; $p < 0.01$).

However, a *cutting height x grass suppression x date* interaction ($p < 0.05$) showed that weed biomass and percentage in September was highest in h7-H1 plots (139 kg DM/ha, 7.6%) compared with h3-H1 plots (37 kg DM/ha, 2.6%). In December, h3-H1 plots had more weed biomass and weed percentage (216 kg DM/ha, 9.7%) than h7-H1 plots (113 kg DM/ha, 3.0%).

Table 3.4 Main effects of cutting height on the standing herbage mass (kg DM/ha) of different sward components, total biomass, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000). *Waipawa north aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	h3	1515 (37.6)	1297 (35.6)	1083 (32.0)	967 (30.2)	951 (29.6)	(1.64)	***
	h7	1392 (36.1)	1593 (39.4)	1533 (38.6)	1857 (39.9)	1298 (32.0)		
	Signif. SED	NS	NS	NS (2.22)	***	NS		
Subt. Clover	h3	35 (3.0)	126 (8.7)	252 (14.4)	1049 (30.3)	279 (14.6)	(1.95)	***
	h7	46 (3.1)	81 (7.3)	321 (15.3)	1987 (43.2)	935 (28.8)		
	Signif. SED	NS	NS	NS (2.31)	***	***		
White clover	h3	4 (0.7)	40 (4.6)	140 (9.4)	476 (17.5)	121 (9.8)	(1.79)	NS
	h7	7 (1.1)	45 (5.2)	152 (9.7)	678 (21.9)	140 (8.3)		
	Signif. SED	NS	NS	NS (2.16)	*	NS		
Other legumes	h3	29 (3.3)	19 (3.2)	65 (6.4)	227 (12.9)	704 (24.4)	(1.48)	***
	h7	10 (2.1)	18 (3.4)	47 (5.1)	154 (10.5)	879 (26.0)		
	Signif. SED	NS	NS	NS (1.86)	NS	NS		
Weeds	h3	27 (1.5)	32 (3.1)	19 (2.4)	81 (6.4)	122 (7.9)	(1.19)	*
	h7	3 (0.5)	29 (3.5)	69 (5.1)	86 (5.4)	60 (4.4)		
	Signif. SED	NS	NS	NS (1.47)	NS	*		
All legumes	h3	68 (5.7)	185 (12.3)	457 (19.6)	1752 (39.7)	1104 (31.6)	(1.87)	***
	h7	63 (5.3)	143 (10.9)	520 (21.0)	2820 (51.3)	1954 (41.8)		
	Signif. SED	NS	NS	NS (2.27)	***	***		
Total biomass	h3	1609 (39.0)	1514 (38.5)	1559 (39.2)	2800 (52.4)	2178 (46.3)	(1.53)	***
	h7	1457 (37.0)	1766 (41.6)	2123 (45.8)	4762 (68.7)	3312 (57.2)		
	Signif. SED	NS	NS	*** (1.71)	***	***		
Tiller popul. density	h3	6065 (60.6)	9669 (90.2)	9641 (89.4)	4290 (61.0)	4989 (66.4)	(8.16)	***
	h7	4173 (46.7)	9011 (82.1)	5283 (62.2)	1939 (36.2)	1823 (33.8)		
	Signif. SED	NS	NS	** (8.33)	**	***		
WC growing points	h3	15 (1.1)	193 (10.3)	400 (15.2)	243 (11.7)	423 (17.4)	(2.27)	***
	h7	60 (3.0)	162 (11.1)	215 (9.4)	120 (7.4)	347 (12.1)		
	Signif. SED	***	NS	NS (3.01)	NS	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.2.4.3. Tiller population density

Average season tiller population density (TPD; all grasses) was higher on h3 than h7 (6930 v 4446 tiller/m²; $p < 0.01$). TPD of short and tall plots was similar in July and August, but differed significantly thereafter ($p < 0.01$). TPD was 82% higher in September, 21% higher in October and 74% higher in December in short v tall plots, respectively (Table 3.4). On average, peak TPD occurred in August (9340 tiller/m²), with a decline afterwards.

Table 3.5 Main effects of cutting height on the proportion (%) of hill country sward components at different dates (2000). *Waipawa north aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	h3	93.1 (9.62)	86.7 (9.29)	68.2 (8.15)	40.2 (6.00)	46.5 (6.51)	(0.236)	*
	h7	95.4 (9.76)	89.2 (9.43)	72.5 (8.44)	40.4 (5.87)	41.5 (5.71)		
	Signif.	NS	NS	NS	NS	*		
	SED			(0.364)				
Subt. Clover	h3	2.3 (0.77)	6.7 (2.13)	17.2 (3.75)	34.4 (5.64)	11.8 (3.06)	(0.382)	***
	h7	2.5 (0.75)	5.0 (1.78)	13.7 (3.23)	41.3 (6.27)	27.4 (5.00)		
	Signif.	NS	NS	NS	NS	***		
	SED			(0.492)				
White clover	h3	0.2 (0.18)	2.9 (1.23)	8.6 (2.37)	14.9 (3.13)	5.9 (2.17)	(0.343)	NS
	h7	0.9 (0.36)	2.9 (1.29)	7.6 (2.16)	13.2 (3.12)	4.5 (1.47)		
	Signif.	NS	NS	NS	NS	NS		
	SED			(0.417)				
Other legumes	h3	2.6 (0.98)	1.4 (0.85)	4.7 (1.68)	7.8 (2.44)	30.3 (5.18)	(0.295)	NS
	h7	1.0 (0.61)	1.0 (0.83)	2.3 (1.14)	3.3 (1.53)	25.0 (4.48)		
	Signif.	NS	NS	NS	*	NS		
	SED			(0.387)				
Weeds	h3	1.8 (0.44)	2.2 (0.82)	1.3 (0.64)	2.6 (1.17)	5.5 (1.66)	(0.260)	**
	h7	0.2 (0.15)	1.9 (0.90)	3.8 (1.20)	1.8 (0.79)	1.7 (0.75)		
	Signif.	NS	NS	NS	NS	**		
	SED			(0.306)				
All legumes	h3	5.1 (1.58)	11.1 (3.43)	30.4 (5.08)	57.2 (7.36)	48.0 (6.72)	(0.360)	NS
	h7	4.4 (1.43)	8.9 (2.69)	23.7 (4.52)	57.8 (7.41)	56.8 (7.25)		
	Signif.	NS	NS	NS	NS	NS		
	SED			(0.466)				

*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.2.4.4. White clover growing point density

White clover growing point density (GPD) was only marginally affected by cutting height, showing a tendency of higher GPDs in h3 ($p < 0.1$), especially in September and

December (Table 3.4). At the start of the season, GPD was very low (average of 38 g.p./m²) and increased significantly towards September (308 g.p./m²), declined in October and reached a peak in December (385 g.p./m²).

3.3.2.5. *Effect of grass suppression*

3.3.2.5.1. **Sward height**

As a seasonal average, plots with grass suppression (H1) had a lower sward height than untreated plots (H0) (5.5 cm v 6.3 cm; $p < 0.001$). However, these differences varied with time. From mid June to mid September, H1 plots had lower sward heights than H0 plots ($p < 0.001$). In October this situation was reversed, H1 plots being taller than H0 plots ($p < 0.001$). Sward heights tended to converge by the end of the season (Table 3.3).

There was a significant *cutting height x grass suppression x date* interaction ($p < 0.01$; not shown), which indicated that in October h7-H0 plots had lower sward heights than h7-H1 plots (11.5 v 14.8 cm; $p < 0.001$), while heights on h3 plots were not significantly different ($p > 0.05$). On the other hand, in November, differences in sward height were only significant ($p < 0.001$) on the h7 plots, h7-H0 being higher than h7-H1 plots (9.1 v 6.6 cm).

3.3.2.5.2. **Herbage mass and botanical composition**

Total standing biomass

Total biomass was on average higher on H0 than on H1 (2404 v 2212 kg DM/ha; $p < 0.05$). There were however different responses during the season. H0 plots had more standing herbage mass than H1 from July to September (89%, 37% and 24% more, respectively). In October, H1 had 16% more standing biomass than H0 plots (Table 3.6).

Grass

On average, H0 had 109% more grass DM than H1 (1825 v 872 kg DM/ha; $p < 0.001$). H0 treatments had a higher grass herbage mass throughout the season compared to H1. Differences were most marked in October and December, where H0 plots had about three times more grass biomass than H1 plots (Table 3.6).

Grass percentage in the sward was high at the start of the season in all treatments. Differences between H0 and H1 were significant from September onwards ($p < 0.001$). Grass percentage in H1 plots dropped to levels near 20% in October and December, while in H0 grass was still the main sward component (Table 3.7).

An interaction of *cutting height x grass suppression x date* was significant ($p < 0.05$), which indicated that in September the drop of grass percentage in the sward due to grass suppression was more pronounced in h3 plots than in h7 plots (82% to 55% compared with 82% to 63 %, respectively). In December the opposite was the case, with grass in h3 plots dropping from 66 to 27%, and on h7 plots from 69% to 15%, when herbicide was applied.

Legumes

Significant differences ($p < 0.001$) in SC biomass were recorded in October and December, with 88% and 117% more SC on H1 v H0 plots (Table 3.6). SC percentages at the start of the season were low and did not differ between treatments. Only in October and December, H1 swards showed a significantly higher ($p < 0.01$) SC percentage than H0 plots. Peak SC participation in the sward was in October and reached 47.4% in H1. Percentages declined towards the end of the season (Table 3.7).

WC biomass was significantly higher in H1 v H0 treatments, with a seasonal average of 293 v 67 kg DM/ha ($p < 0.01$). Main differences were observed in the latter part of the season, with H1 plots having more than four times WC biomass than H0 plots (Table 3.6). WC levels in the sward were low at the start of the season, and increased steadily on H1 plots, to reach a peak in October with 22.6%, and decline thereafter. H0 swards showed much lower WC contents, with a maximum of 5.5% in October (Table 3.7).

OL levels in the sward were low at the start of the season and H1 swards had significantly higher OL biomass at the October ($p < 0.05$) and especially December ($p < 0.001$) harvests, where H1 plots had 176% more OL than H0 plots (Table 3.6). In

December, OL percentage in the sward reached a peak of almost 39% in H1 compared to 16% in H0 (Table 3.7).

On a seasonal average, H1 plots had 1242 v 571 kg DM/ha TL biomass compared with that in H0 ($p < 0.01$). In percentage terms this meant that H1 had an average legume sward content of 40.4% compared with 20.3% in H0 ($p < 0.01$). During the season, legume biomass differed between H0 and H1 from September onwards (Table 3.6). H1 plots had higher legume contents ($p < 0.001$) in September, October and December (Table 3.7). H1 plots peaked in October with a legume content in the sward of 76.4%.

Weeds

The weed biomass and percentage average in the season was higher ($p < 0.01$) in H1 (97 kg DM/ha, 4.2%) v H0 (8 kg DM/ha, 0.4%). H1 had more weeds than H0 from August onwards (Table 3.6). Weed percentage in H0 swards was extremely low, always under 1% of DM. Percentages were significantly higher ($p < 0.001$) in H1 from August to the last harvest in December, where weed percentage peaked at 6.4% (Table 3.7).

3.3.2.5.3. Tiller population density

Average TPD in the season was higher in H0 v H1 (8052 v 3325 tiller/m²; $p < 0.001$). After selective herbicide application in autumn, TPD in H0 was significantly ($p < 0.001$) higher than in H1. Differences were greatest at the start of the season, H0 having greater than 7 times more TPD than H1. H1 TPD recovered thereafter, but differences remained very significant until September. In October treatments did not differ and H0 plots increased in TPD at the end of the season (Table 3.6). Peak TPD in H0 and H1 was recorded in August and September, respectively.

3.3.2.5.4. White clover growing point density

GPD was significantly higher in H1 v H0 especially in September (five times more) and December (more than double; $p < 0.001$), but also in October ($p < 0.05$; Table 3.6). There was a significant ($p < 0.05$) *cutting height x grass suppression x date* interaction, which indicated that the effect of grass suppression on GPD was more marked on h7 than h3

plots. When H0 v H1 was compared, on h3 plots, GPD increased 140 v 660 g.p./m² in September, and 330 v 517 g.p./m² in December. On h7 plots, GPD increased 33 v 397 g.p./m² in September and from 27 to 667 g.p./m² in December.

Table 3.6 Main effects of autumn grass suppression on the standing herbage mass (kg DM/ha) of different sward components, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000). *Waipawa north aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	H0	1912 (43.0)	1740 (41.5)	1662 (40.5)	2095 (44.8)	1716 (40.8)	(1.64)	***
	H1	995 (30.8)	1150 (33.5)	954 (30.2)	729 (25.3)	532 (20.8)		
	Signif.	***	*	***	***	***		
	SED			(2.22)				
Subt. Clover	H0	59 (4.2)	110 (9.3)	283 (14.9)	1053 (30.6)	383 (17.2)	(1.95)	***
	H1	22 (1.9)	98 (6.7)	290 (14.8)	1983 (42.9)	831 (26.3)		
	Signif.	NS	NS	NS	***	***		
	SED			(2.31)				
White clover	H0	4 (1.0)	20 (3.7)	58 (5.7)	207 (11.3)	48 (5.1)	(1.79)	***
	H1	6 (0.8)	64 (6.0)	234 (13.3)	947 (28.1)	213 (13.0)		
	Signif.	NS	NS	***	***	***		
	SED			(2.16)				
Other legumes	H0	25 (3.1)	20 (3.8)	33 (4.4)	132 (9.9)	421 (18.2)	(1.48)	***
	H1	14 (2.2)	17 (2.9)	79 (7.1)	250 (13.6)	1163 (32.3)		
	Signif.	NS	NS	NS	*	***		
	SED			(1.86)				
Weeds	H0	4 (0.8)	7 (1.5)	1 (0.3)	10 (1.3)	18 (2.3)	(1.19)	***
	H1	25 (1.3)	53 (5.1)	88 (7.2)	157 (10.5)	164 (10.0)		
	Signif.	NS	*	***	***	***		
	SED			(1.47)				
All legumes	H0	88 (6.9)	150 (11.6)	374 (17.8)	1392 (35.8)	851 (27.9)	(1.87)	***
	H1	42 (4.1)	179 (11.7)	604 (22.8)	3180 (55.2)	2207 (45.5)		
	Signif.	NS	NS	*	***	***		
	SED			(2.27)				
Total biomass	H0	2004 (44.1)	1898 (43.4)	2036 (44.8)	3497 (58.0)	2586 (50.3)	(1.53)	***
	H1	1062 (31.9)	1382 (36.8)	1646 (40.1)	4065 (63.1)	2904 (53.2)		
	Signif.	***	***	**	**	NS		
	SED			(1.71)				
Tiller popul. density	H0	9128 (91.9)	14281 (117.2)	9669 (95.5)	3317 (53.1)	3865 (60.0)	(8.16)	***
	H1	1111 (15.5)	4399 (55.1)	5256 (56.1)	2912 (44.1)	2946 (40.3)		
	Signif.	***	***	***	NS	*		
	SED			(8.33)				
WC growing points	H0	35 (2.1)	103 (8.4)	87 (6.6)	112 (6.3)	178 (8.7)	(2.27)	***
	H1	40 (2.0)	252 (13.1)	528 (18.0)	252 (12.8)	592 (20.8)		
	Signif.	NS	NS	***	*	***		
	SED			(3.01)				

*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.7 Main effects of autumn grass suppression on the proportion (%) of hill country sward components at different dates (2000). *Waipawa north aspect*

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	H0	94.5 (9.71)	91.5 (9.56)	81.9 (9.03)	61.1 (7.76)	67.3 (8.15)	(0.236)	***
	H1	93.9 (9.67)	84.4 (9.16)	58.9 (7.56)	19.5 (4.11)	20.6 (4.07)		
	Signif.	NS	NS	***	***	***		
	SED			(0.364)				
Subt. Clover	H0	3.0 (0.96)	6.0 (2.17)	13.3 (3.30)	28.3 (5.17)	13.2 (3.26)	(0.382)	***
	H1	1.8 (0.56)	5.7 (1.74)	17.6 (3.68)	47.4 (6.74)	26.1 (4.80)		
	Signif.	NS	NS	NS	**	**		
	SED			(0.492)				
White clover	H0	0.3 (0.26)	1.1 (0.88)	3.0 (1.31)	5.5 (1.86)	2.4 (1.12)	(0.343)	***
	H1	0.9 (0.28)	4.7 (1.64)	13.3 (3.22)	22.6 (4.39)	8.1 (2.52)		
	Signif.	NS	NS	***	***	***		
	SED			(0.417)				
Other legumes	H0	1.8 (0.80)	1.0 (0.86)	1.8 (1.03)	4.8 (1.82)	16.4 (3.63)	(0.295)	***
	H1	1.8 (0.78)	1.5 (0.82)	5.2 (1.80)	6.4 (2.15)	38.9 (6.03)		
	Signif.	NS	NS	*	NS	***		
	SED			(0.387)				
Weeds	H0	0.4 (0.22)	0.4 (0.33)	0.0 (0.06)	0.4 (0.26)	0.8 (0.47)	(0.260)	***
	H1	1.7 (0.37)	3.7 (1.38)	5.1 (1.78)	4.1 (1.70)	6.4 (1.95)		
	Signif.	NS	***	***	***	***		
	SED			(0.306)				
All legumes	H0	5.1 (1.65)	8.1 (2.69)	18.1 (3.97)	38.6 (6.09)	31.9 (5.50)	(0.360)	***
	H1	4.4 (1.36)	11.9 (3.13)	36.0 (5.63)	76.4 (8.68)	73.0 (8.47)		
	Signif.	NS	NS	***	***	***		
	SED			(0.466)				

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.2.6. Effect of soil phosphorus status

3.3.2.6.1. Sward height

On most dates recorded (Table 3.3), sward height was not different between high (HP) and low (LP) soil-P status ($p > 0.05$). Only in December did the HP treatment have a taller sward height than LP (10.1 v 8.7 cm; $p < 0.001$).

3.3.2.6.2. Herbage mass and botanical composition

Total standing biomass

Total standing biomass was not significantly affected by soil-P status ($p>0.05$), as can be seen from Table 3.8.

Grass

Grass biomass was not affected by soil-P status (Table 3.8). However, a significant ($p<0.05$) *cutting height* $\times$ *P* $\times$ *date* interaction indicated that, in December, grass percentage in the sward was higher on LP than HP in the h3 plots (55.8 v 37.1%), but not in the h7 plots (42.6 v 40.4%).

Legumes

The average of the season for WC biomass was 215 v 146 kg DM/ha ($p<0.05$), in HP v LP swards. HP plots had 48% more WC biomass present in October and 38% in December, compared with LP plots (Table 3.9). WC percentage at the start of the season was below 1%. Peak WC percentage in the sward occurred in October both in HP and LP plots (17.4 v 10.7%; $p<0.01$). In December, HP swards had still higher WC content than LP plots ($p<0.05$). The season average for WC content in the sward was 7.3% in HP v 5.0% in LP ($p<0.05$).

Phosphorus status of the soil did not influence SC standing biomass or SC proportion in the sward (Table 3.8 and Table 3.9).

A significant ($p<0.001$) *grass suppression* $\times$ *P* $\times$ *date* interaction showed that in December HP had higher OL biomass than LP (618 v 222 kg DM/ha; $p<0.001$) in the H0 plots, while on the H1 treatment, HP had lower biomass than LP (966 v 1359 Kg DM/ha; $p<0.05$). The same interaction was significant for OL content in the sward. HP plots on H0 swards had higher OL content than LP plots in December (22.9 v 9.8%; $p<0.001$). On H1 plots differences were not significant ($p>0.05$). A *cutting height* $\times$ *soil-*

P $\times$ *date* interaction was significant, indicating that in December in h3 plots, HP had more OL biomass than LP (869 v 539 kg DM/ha), with no differences on h7 plots.

On average, TL content was not different ($p < 0.05$) between HP and LP (31.6 v 29.1%). However, average TL content in the season was higher on HP plots than on LP plots under no grass suppression (23.7% v 16.9% in H0-HP v H0-LP, respectively; $p < 0.05$), as obtained from a *grass suppression* $\times$ *P* interaction (not shown). In December, HP plots had more legume content than LP plots ($p < 0.05$; Table 3.9).

Weeds

Weed content was generally low, and did not respond to soil-P status, apart from a particular response in August, where LP plots had higher weed biomass and percentage than HP plots (16 v 90 kg DM/ha; 1.6 v 5.9%), but only in H1 plots ($p < 0.05$).

3.3.2.6.3. Tiller population density

Under the conditions of the present experiment, TPD did not respond to soil-P status changes.

3.3.2.6.4. White clover growing point density

GPD did not respond to soil-P status at this site, however there was a tendency for HP plots to have higher GPD than LP by December ($p < 0.1$).

Table 3.8 Main effects of soil phosphorus status on the standing herbage mass (kg DM/ha) of different sward components, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000). *Waipawa north aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	HP	1391 (36.2)	1376 (36.7)	1255 (34.5)	1449 (35.4)	1033 (30.0)	(1.64)	*
	LP	1516 (37.6)	1514 (38.3)	1361 (36.1)	1374 (34.6)	1215 (31.6)		
	Signif. SED	NS	NS	NS (1.92)	NS	NS		
Subt. Clover	HP	39 (3.0)	83 (7.1)	294 (15.1)	1417 (36.2)	637 (21.9)	(1.95)	***
	LP	42 (3.1)	124 (8.9)	279 (14.6)	1619 (37.3)	578 (21.6)		
	Signif. SED	NS	NS	NS (2.12)	NS	NS		
White clover	HP	3 (0.9)	38 (4.9)	161 (10.2)	689 (23.3)	183 (10.9)	(1.79)	***
	LP	7 (1.0)	47 (4.9)	131 (8.8)	465 (16.1)	77 (7.2)		
	Signif. SED	NS	NS	NS (1.91)	***	*		
Other legumes	HP	24 (2.8)	22 (3.6)	45 (5.2)	236 (12.6)	793 (26.6)	(1.48)	***
	LP	15 (2.6)	15 (3.0)	67 (6.3)	146 (10.8)	791 (23.9)		
	Signif. SED	NS	NS	NS (1.72)	NS	NS		
Weeds	HP	4 (0.6)	11 (2.4)	46 (4.2)	87 (5.9)	123 (6.4)	(1.19)	*
	LP	26 (1.4)	49 (4.2)	43 (3.4)	80 (5.9)	59 (5.8)		
	Signif. SED	NS	NS	NS (1.47)	NS	NS		
All legumes	HP	67 (5.6)	142 (10.8)	500 (20.7)	2342 (46.8)	1612 (38.7)	(1.87)	***
	LP	64 (5.4)	186 (12.4)	478 (19.9)	2230 (44.2)	1446 (34.7)		
	Signif. SED	NS	NS	NS (2.15)	NS	NS		
Total biomass	HP	1462 (37.2)	1530 (38.7)	1801 (41.9)	3879 (61.5)	2769 (52.0)	(1.53)	***
	LP	1605 (38.8)	1750 (41.4)	1881 (43.1)	3684 (59.6)	2720 (51.5)		
	Signif. SED	NS	NS	NS (1.71)	NS	NS		
Tiller popul. density	HP	4954 (51.8)	10731 (92.6)	6564 (71.9)	3097 (50.0)	3145 (48.4)	(8.16)	***
	LP	5283 (55.7)	7949 (79.6)	8360 (79.6)	3132 (47.1)	3666 (51.9)		
	Signif. SED	NS	NS	NS (8.32)	NS	NS		
WC growing points	HP	35 (2.1)	147 (10.3)	265 (11.4)	247 (11.6)	460 (17.1)	(2.27)	***
	LP	40 (2.0)	208 (11.1)	350 (13.2)	117 (7.5)	310 (12.4)		
	Signif. SED	NS	NS	NS (2.70)	NS	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.9 Main effects of soil phosphorus status on the proportion (%) of hill country sward components at different dates (2000). *Waipawa north aspect*

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	HP	94.7 (9.72)	90.1 (9.49)	69.5 (8.24)	38.2 (5.82)	38.8 (5.82)	(0.236)	***
	LP	93.8 (9.66)	85.8 (9.23)	71.3 (8.35)	42.3 (6.05)	49.2 (6.40)		
	Signif. SED	NS	NS	NS (0.322)	NS	NS		
Subt. Clover	HP	2.8 (0.82)	4.8 (1.79)	15.9 (3.57)	35.8 (5.85)	20.5 (4.02)	(0.382)	***
	LP	2.0 (0.70)	6.9 (2.12)	15.0 (3.40)	39.9(6.06)	18.7(4.04)		
	Signif. SED	NS	NS	NS (0.397)	NS	NS		
White clover	HP	0.3 (0.23)	2.6 (1.26)	9.2 (2.46)	17.4 (3.71)	7.2 (2.17)	(0.343)	***
	LP	0.9 (0.31)	3.3 (1.27)	7.0 (2.07)	10.7 (2.54)	3.3 (1.47)		
	Signif. SED	NS	NS	NS (0.357)	**	*		
Other legumes	HP	1.9 (0.79)	1.6 (0.94)	2.7 (1.29)	6.3 (2.06)	29.0 (5.12)	(0.295)	***
	LP	1.7 (0.80)	0.9 (0.74)	4.3 (1.54)	4.8 (1.91)	26.2 (4.54)		
	Signif. SED	NS	NS	NS (0.336)	NS	NS		
Weeds	HP	0.3 (0.18)	0.9 (0.66)	2.7 (1.02)	2.3 (0.95)	4.6 (1.23)	(0.260)	*
	LP	1.7 (0.41)	3.1 (1.06)	2.4 (0.82)	2.2 (1.01)	2.6 (1.18)		
	Signif. SED	NS	NS	NS (0.306)	NS	NS		
All legumes	HP	5.0 (1.52)	9.0 (2.76)	27.8 (4.94)	59.5 (7.56)	56.7 (7.36)	(0.360)	***
	LP	4.5 (1.50)	11.0 (3.06)	26.3 (4.66)	55.5 (7.21)	48.2 (6.60)		
	Signif. SED	NS	NS	NS (0.374)	NS	*		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.2.7. Effect of nitrogen application

3.3.2.7.1. Sward height

Plots that received 50 kg nitrogen in autumn (N50) had taller swards than those where N was not applied (N0), but only in August and September (Table 3.3). During the rest of the season, there was no statistical difference between heights on the two treatments ($p > 0.05$).

3.3.2.7.2. Herbage mass and botanical composition

Total standing biomass

Total biomass was higher on N50 plots compared to N0 swards only in July (Table 3.10). Differences were mostly due to the H0-N50 plots yielding 40% more compared to the H0-N0 plots (2342 v 1666 kg DM/ha; $p < 0.05$) at the first harvest. On H1 plots, there were no differences due to nitrogen application.

Grass

On average, N50 swards had 19% more grass biomass at the first harvest (July), compared to N0 plots, but differences did not achieve statistical significance ($p < 0.1$; Table 3.10). Grass percentage in the sward was higher in the N50 plots than in the N0 plots only in December ($p < 0.05$; Table 3.11).

Legumes

Biomass of SC on N0 plots was 31% higher in October and 34% in December, compared to N50 plots (Table 3.10). SC content in the sward tended to be higher on N0 plots from September onwards ($p < 0.1$), but was significantly ($p < 0.05$) so in October and December. Peak differences occurred in October, with 42.9% in N0 plots and 32.9% in N50 plots (Table 3.11). There was also an indication of a $P \times N \times date$ interaction ($p < 0.05$) for SC content in the sward. In August there was a positive nitrogen effect on LP plots only, where SC content in the sward increased from 3.9% in LP-N0 to 9.8% in LP-N50. The opposite occurred in December, where a negative effect was recorded on HP plots only, whereby HP-N0 swards averaged 30% SC compared to 11% in HP-N50 plots. As a seasonal average, a significant *cutting height x nitrogen* interaction ($p < 0.05$) showed that negative nitrogen effects on SC biomass and percentage were seen to be significant ($p < 0.05$) in h3 swards, but not in h7 plots (456 v 239 kg DM/ha and 18.2% v 10.7% in h3-N0 v h3-N50).

Nitrogen application did not have any effects on WC biomass or WC content in the sward. WC was generally, together with weeds, only a small proportion of total biomass.

On average, OL biomass and OL content were higher on N0 plots compared to N50 plots, but only in the unsuppressed swards (H0) (175 v 77 kg DM/ha; 6.9 v 3.4%; H0-N0 v H0-N50; $p < 0.05$). Significant differences for OL biomass and OL percentage between N0 and N50 were recorded only in December (Table 3.10 and Table 3.11). These differences were related also to the soil-P status, because the decline in OL content in December was mainly observed in LP plots, where OL content dropped ($p < 0.05$) from 30.7% (LP-N0) to 22.1% (LP-N50).

As a seasonal average, TL content in the sward was higher in N0 v N50 (32.8% v 27.9%; $p < 0.05$). Also on a season basis, a significant *cutting height* $\times$ *N* interaction ($p < 0.05$) indicated a decline in TL biomass on h3 plots (848 v 579 kg DM/ha) and TL content (35.2% v 25.6%), when h3-N0 and h3-N50 were compared, while no decline occurred on h7 swards. The interaction *grass suppression* $\times$ *N* was also significant ($p < 0.05$), showing that N application had negative overall effects on TL biomass and TL content on the H0 plots (696 v 446 kg DM/ha; 24.6% v 16.1%, in H0-N0 v H0-N50) compared to the treated H1 plots, where no differences were recorded. Main differences between nitrogen treatments were observed in October and December, where N0 presented 16% more ($p < 0.05$) TL biomass than N50 (Table 3.10). A trend for N0 having higher TL content in the sward than N50 started in September ($p < 0.1$), which became significant ($p < 0.01$) in December (Table 3.11).

Table 3.10 Main effects of an autumn nitrogen application on the standing herbage mass (kg DM/ha) of different sward components, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000). *Waipawa north aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	N0	1329 (35.4)	1433 (37.3)	1170 (33.4)	1376 (34.8)	1039 (29.7)	(1.64)	NS
	N50	1578 (38.4)	1458 (37.8)	1446 (37.2)	1448 (35.3)	1210 (32.0)		
	Signif. SED	NS	NS	NS (1.84)	NS	NS		
Subt. Clover	N0	26 (2.3)	72 (7.0)	309 (15.7)	1722 (40.0)	696 (24.1)	(1.95)	***
	N50	55 (3.9)	136 (9.1)	264 (14.0)	1313(33.6)	519(19.4)		
	Signif. SED	NS	NS	NS (2.12)	**	*		
White clover	N0	3 (0.7)	52 (5.7)	141 (9.7)	509 (19.0)	109 (8.2)	(1.79)	***
	N50	8 (1.2)	32 (4.1)	151 (9.3)	645 (20.4)	151 (9.9)		
	Signif. SED	NS	NS	NS (1.76)	NS	NS		
Other legumes	N0	26 (3.2)	14 (3.1)	65 (6.3)	228 (13.0)	836 (26.9)	(1.48)	***
	N50	13 (2.1)	23 (3.6)	47 (5.1)	154 (10.4)	747 (23.5)		
	Signif. SED	NS	NS	NS (1.65)	NS	*		
Weeds	N0	5 (1.0)	33 (3.7)	32 (3.0)	67 (5.2)	62 (4.8)	(1.19)	*
	N50	24 (1.1)	28 (3.0)	56 (4.5)	100 (6.7)	120 (7.4)		
	Signif. SED	NS	NS	NS (1.27)	NS	*		
All legumes	N0	54 (5.1)	138 (11.03)	515 (21.1)	2459 (47.9)	1641 (39.1)	(1.87)	***
	N50	76 (5.9)	191 (12.2)	462 (19.5)	2113 (43.1)	1417 (34.3)		
	Signif. SED	NS	NS	NS (2.15)	*	*		
Total biomass	N0	1388 (36.2)	1604 (39.6)	1717 (41.0)	3902 (61.8)	2742 (52.0)	(1.53)	***
	N50	1678 (39.8)	1676 (40.5)	1964 (44.0)	3660 (59.4)	2747 (51.5)		
	Signif. SED	*	NS	NS (1.71)	NS	NS		
Tiller popul. density	N0	4667 (51.5)	9703 (88.2)	7380 (75.0)	3084 (47.6)	3406 (51.3)	(8.16)	***
	N50	5571 (55.9)	8977 (84.1)	7545 (76.6)	3145 (49.5)	3406 (49.0)		
	Signif. SED	NS	NS	NS (8.18)	NS	NS		
WC growing points	N0	40 (2.5)	220 (11.7)	253 (12.1)	215 (10.1)	345 (15.1)	(2.27)	***
	N50	35 (1.6)	135 (9.7)	362 (12.6)	148 (9.0)	425 (14.4)		
	Signif. SED	NS	NS	NS (2.46)	NS	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Weeds

Weed biomass and proportion in the sward was lower in N0 v N50 plots only in December ($p<0.05$). Weeds in N50 were almost double the amount in N0, but with a low proportion in the total biomass present (only 2.4 v 4.8%; Table 3.11).

3.3.2.7.3. Tiller population density

Nitrogen application did not show any effects on tiller population density during the season.

3.3.2.7.4. White clover growing point density

No influence of nitrogen application was encountered for white clover growing point density in this experiment.

Table 3.11 Main effects of an autumn nitrogen application on the proportion (%) of hill country sward components at different dates (2000). *Waipawa north aspect*

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	SED	Signif.
Grasses	N0	94.9 (9.73)	88.5 (9.39)	67.9 (8.14)	36.8 (5.71)	38.8 (5.76)	(0.236)	***
	N50	93.5 (9.65)	87.3 (9.33)	72.8 (8.44)	43.8 (6.15)	49.2 (6.46)		
	Signif. SED	NS	NS	NS (0.273)	NS	*		
Subt. Clover	N0	1.7 (0.62)	4.5 (1.74)	17.9 (3.82)	42.9 (6.41)	23.6 (4.52)	(0.382)	***
	N50	3.0 (0.90)	7.2 (2.17)	12.9 (3.16)	32.9 (5.50)	15.6 (3.54)		
	Signif. SED	NS	NS	NS (0.397)	*	*		
White clover	N0	0.2 (0.19)	3.7 (1.48)	8.1 (2.34)	12.0 (2.98)	4.4 (1.65)	(0.343)	***
	N50	0.9 (0.34)	2.1 (1.05)	8.2 (2.18)	16.0 (3.27)	6.0 (1.98)		
	Signif. SED	NS	NS	NS (0.342)	NS	NS		
Other legumes	N0	2.6 (1.01)	0.9 (0.78)	4.1 (1.60)	6.4 (2.17)	30.8 (5.21)	(0.295)	***
	N50	1.0 (0.58)	1.6 (0.90)	3.0 (1.23)	4.8 (1.81)	24.4 (4.45)		
	Signif. SED	NS	NS	NS (0.320)	NS	*		
Weeds	N0	0.5 (0.32)	2.4 (0.99)	2.0 (0.75)	1.9 (0.85)	2.4 (0.94)	(0.260)	*
	N50	1.5 (0.27)	1.7 (0.72)	3.1 (1.08)	2.6 (1.11)	4.8 (1.47)		
	Signif. SED	NS	NS	NS (0.275)	NS	*		
All legumes	N0	4.6 (1.51)	9.1 (2.83)	30.1 (5.14)	61.3 (7.70)	58.9 (7.50)	(0.360)	***
	N50	4.9 (1.50)	10.9 (2.99)	24.1 (4.46)	53.6 (7.08)	46.0 (6.46)		
	Signif. SED	NS	NS	NS (0.374)	NS	**		

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.3. Waipawa south aspect

At this site, swards were sampled six times during the season, on 12 July, 9 August, 15 September, 25 October, 19 December 2000 and 13 February 2001. For the ease of reading, dates will be hereafter referred to as July, August, September, October, December and February in the text and tables.

3.3.3.1. Significance of main effects and interactions

A summary of the significance of main effects and interaction for the Waipawa south aspect site is presented in Table 3.12.

Table 3.12 Summary of main effects and interactions significance. *Waipawa south aspect.*

Main effect or interaction	Total biomass DM/ha	Grass DM/ha	Subt. clover DM/ha	White clover DM/ha	Other legumes DM/ha	Weeds DM/ha	All legumes DM/ha	Sward height cm
cuth	**	**	NS	NS	NS	NS	NS	***
supp	***	***	NS	NS	NS	**	***	**
phos	NS	NS	NS	NS	NS	NS	*	NS
nitro	**	**	NS	NS	NS	NS	NS	***
date	***	***	***	***	***	***	***	***
cuth x date	***	***	**	NS	***	NS	*	***
supp x date	**	***	*	***	***	***	***	***
phos x date	***	NS	*	***	*	NS	***	***
nitro x date	**	***	*	NS	***	NS	**	***
supp x phos x date	NS	NS	NS	NS	NS	NS	NS	**
supp x nitro x date	NS	NS	NS	NS	NS	NS	NS	**
cuth x supp x date	NS	NS	NS	NS	***	NS	***	NS
Main effect or interaction	Grass %	Subt. clover %	White clover %	Other legumes %	Weeds %	All legumes %	TPD tiller/m ²	WC GPD pt. density gp/m ²
cuth	NS	NS	NS	NS	NS	NS	NS	NS
supp	***	*	*	*	•	***	NS	*
phos	NS	NS	NS	NS	NS	NS	NS	NS
nitro	NS	NS	NS	**	NS	NS	**	NS
date	***	***	***	***	***	***	***	***
cuth x date	**	**	NS	NS	NS	**	**	NS
supp x date	***	**	***	***	***	***	***	***
phos x date	*	NS	**	NS	NS	**	NS	**
nitro x date	**	*	NS	**	NS	**	***	*
cuth x phos x date	NS	NS	NS	NS	NS	NS	*	NS
supp x nitro x date	NS	*	NS	NS	NS	NS	NS	NS
cuth x supp x date	***	NS	NS	***	NS	**	NS	NS
phos x nitro x date	NS	*	NS	NS	NS	NS	NS	NS

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; cuth=cutting height; supp=grass suppression; phos=phosphorus; nitro=nitrogen. NOTE: Only interactions that were significant for at least one variable are shown in the table.

3.3.3.2. *Climate conditions*

Average rainfall and rainfall during the experimental period, along with soil temperatures (10 cm) (Table 3.2) were presented in Section 3.3.2.2.

3.3.3.3. *Soil moisture*

The soil moisture changes over the experimental period are shown in Figure 3.2. Volumetric moisture in the top 5 cm of the soil was above field capacity (FC) during the winter and up to the beginning of October. Between that date and early November 2000, the soil went below permanent wilting point (PWP). From that moment, soil moisture showed a pattern of re-wetting (always to levels lower than 50% available water capacity) and drying-out in response to rainfall events. In January 2001 there was a sharp decline to below PWP levels. Only in May 2001 did soil moisture recover to levels above FC. Patterns observed at the 5-10 cm level followed the trends observed at the top layer, but showed usually lower moisture levels.

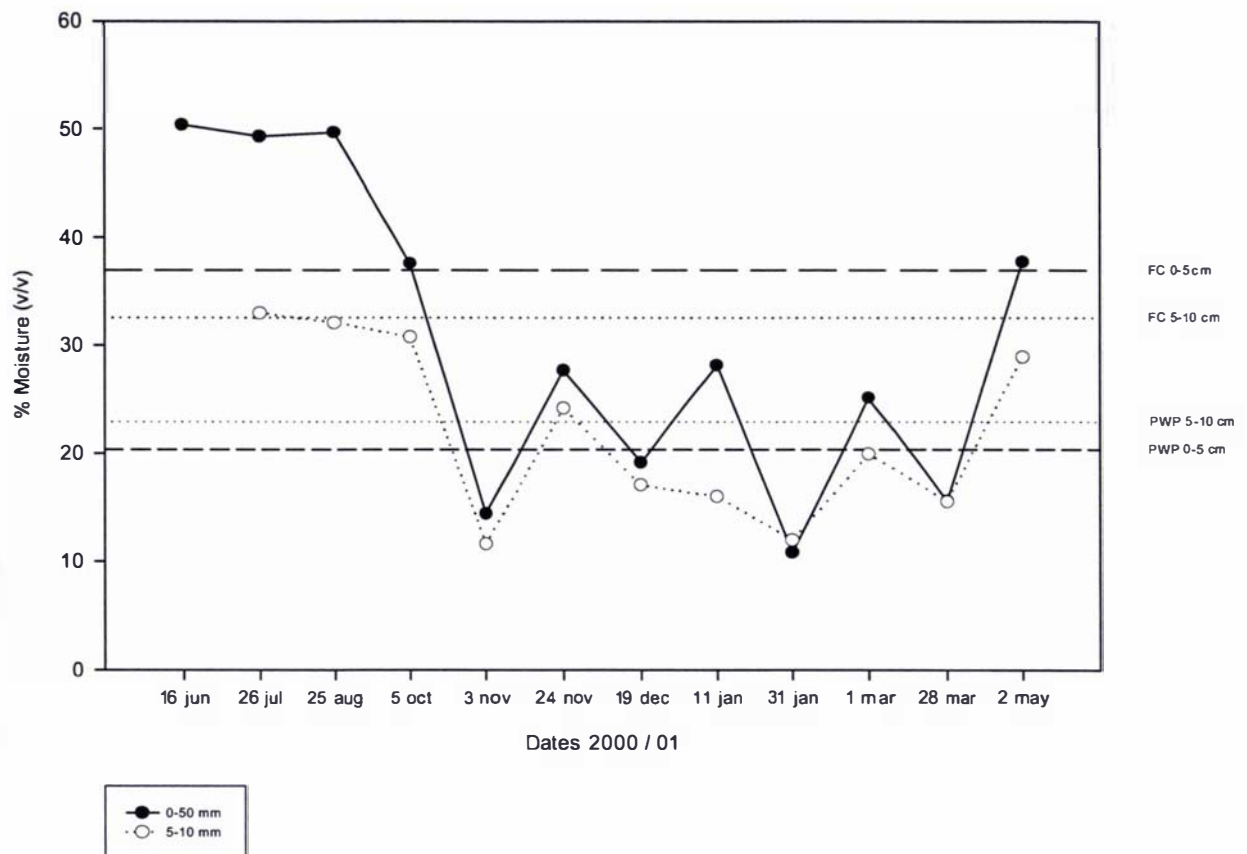


Figure 3.2 Average seasonal variation of the volumetric soil moisture of the 0-50 mm and 50-100 mm soil layers in *Waipawa south aspect* (2000/01).

Table 3.13 Average sward height (cm) for different cutting height and grass suppression treatments, and interaction of grass suppression x soil-P status, and grass suppression x nitrogen, at different dates (2000/01). *Waipawa south aspect*.

Factor or interaction	Treat./ interaction	May 25	Jun 16	Jul 12	Aug 9	Sep 15	Oct 25	Nov 24	Dec 19	Feb 13	Mar 28	SED	Sign.
Cutting height	h3	4.6 (2.14)	4.5 (2.11)	3.8 (1.95)	3.3 (1.79)	2.7 (1.62)	3.0 (1.73)	3.6 (1.88)	7.2 (2.64)	2.4 (1.53)	4.0 (1.98)	(0.048)	***
	h7	4.5 (2.12)	4.7 (2.16)	4.0 (1.96)	4.5 (2.08)	4.2 (1.98)	4.9 (2.17)	6.3 (2.48)	10.7 (3.25)	4.4 (2.10)	6.5 (2.53)		
	Sign. SED	NS	NS	NS	***	**	***	***	***	***	***		
Grass suppression	H0	4.7 (2.16)	4.5 (2.12)	4.7 (2.14)	4.9 (2.20)	4.8 (2.16)	5.3 (2.28)	5.8 (2.38)	9.5 (3.05)	3.4 (1.80)	5.2 (2.24)	(0.048)	***
	H1	4.4 (2.09)	4.7 (2.16)	3.2 (1.77)	2.8 (1.67)	2.1 (1.43)	2.6 (1.61)	4.0 (1.98)	8.5 (2.84)	3.4 (1.83)	5.3 (2.26)		
	Sign. SED	NS	NS	***	***	***	***	***	**	NS	NS		
supp x phos	H0 x HP	4.8 (2.17)	4.5 (2.11)	4.6 (2.12)	5.0 (2.22)	4.7 (2.14)	5.4 (2.29)	5.9 (2.40)	9.5 (3.06)	3.6 (1.85)	5.4 (2.28)	(0.067)	***
	H0 x LP	4.6 (2.15)	4.5 (2.13)	4.8 (2.16)	4.9 (2.19)	4.8 (2.17)	5.3 (2.27)	5.7 (2.36)	9.5 (3.04)	3.2 (1.74)	5.1 (2.20)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
	H1 x HP	4.5 (2.13)	4.4 (2.10)	3.4 (1.85)	2.7 (1.63)	2.1 (1.43)	2.6 (1.59)	4.3 (2.04)	10.4 (3.14)	3.8 (1.94)	6.0 (2.42)		
	H1 x LP	4.3 (2.06)	4.9 (2.22)	2.9 (1.71)	2.9 (1.71)	2.1 (1.44)	2.7 (1.63)	3.8 (1.92)	6.6 (2.54)	3.0 (1.72)	4.5 (2.11)		
supp x nitro	Sign. SED	NS	NS	NS	NS	NS	NS	NS	***	*	***	(0.085)	
	H0 x N0	4.5 (2.11)	4.4 (2.09)	3.8 (1.95)	4.1 (2.02)	4.1 (2.01)	4.9 (2.19)	5.8 (2.38)	9.4 (3.04)	3.3 (1.79)	4.7 (2.15)	(0.067)	***
	H0 x N50	4.9 (2.21)	4.7 (2.15)	5.5 (2.33)	5.8 (2.39)	5.4 (2.30)	5.8 (2.37)	5.8 (2.37)	9.5 (3.06)	3.4 (1.80)	5.7 (2.34)		
	Sign.	NS	NS	***	***	***	*	NS	NS	NS	*		
	H1 x N0	4.5 (2.11)	4.8 (2.18)	3.2 (1.78)	2.6 (1.62)	1.9 (1.36)	2.5 (1.56)	3.6 (1.88)	7.5 (2.69)	3.2 (1.77)	5.0 (2.20)		
	H1 x N50	4.3 (2.07)	4.6 (2.13)	3.2 (1.76)	3.0 (1.71)	2.3 (1.51)	2.8 (1.67)	4.4 (2.08)	9.4 (2.98)	3.7 (1.90)	5.5 (2.33)		
	Sign. SED	NS	NS	NS	NS	NS	NS	***	***	NS	NS	(0.078)	

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.3.4. Effect of cutting height

3.3.3.4.1. Sward height

As a season average, h7 plots were higher than h3 plots (5.5 v 3.9 cm; $p < 0.01$). Sward height was significantly higher in h7 v h3 plots from August onwards. Peak sward height was achieved in December (Table 3.13) on both treatments.

3.3.3.4.2. Herbage mass and botanical composition

Total standing biomass

Average standing biomass in the season was higher in h7 v h3 (1512 v 1125 kg DM/ha; $p < 0.01$). Differences were recorded between August and the end of the season in February. Table 3.14 shows that taller (h7) plots had more biomass than short plots (h3) in August (22%), September (35%), October (34%), December (34%) and February, where differences were greatest (94%).

Grass

Grass biomass was on average higher in h7 than h3 (1296 v 942 kg DM/ha; $p < 0.01$). Tall plots had more biomass from August onwards. Greatest differences were recorded in February, where h7 had 117% more grass biomass than h3 plots (Table 3.14). The grass content in the sward was generally high, especially at the start and end of the season. Tall (h7) plots had higher grass percentages in the sward than h3 plots in September and February (Table 3.15).

Legumes

SC biomass was generally low at this site. Effects of cutting height on SC biomass were significant ($p < 0.01$) only in October, where h3 was more than double h7. In relative terms, h3 swards had 2.9 and 5.2% SC in September and October, compared to 0.7 and 1.6% in h7 (Table 3.15). SC was not present in the sward after December.

WC biomass or percentage in the sward was not significantly affected by cutting height treatments. OL doubled biomass levels in h7 v h3 in December (Table 3.14).

TL biomass present in the sward was only significantly higher (42%) in h7 v h3 plots in December (Table 3.14). However, there was a higher proportion of TL in h3 v h7 in September and December (Table 3.15). TL percentage peaked in December, with an average of 26.8%.

Weeds

Weed biomass and percentage was very low, and did not differ between cutting height treatments.

Table 3.14 Main effects of cutting height on the standing herbage mass (kg DM/ha) of different hill country sward components, tiller population density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Waipawa south aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	h3	886 (28.9)	951 (30.3)	709 (25.9)	966 (30.6)	1388 (36.7)	754 (27.0)	(1.14)	***
	h7	802 (27.5)	1153 (33.5)	1000 (30.9)	1379 (36.2)	1801 (41.5)	1639 (39.9)		
	Sign.	NS	*	**	***	**	***		
	SED			(1.52)					
White Clover	h3	3 (0.6)	9 (2.0)	14 (2.6)	59 (5.6)	282 (14.5)	144 (9.3)	(1.07)	***
	h7	3 (0.6)	13 (2.7)	10 (2.0)	50 (5.5)	303 (14.4)	107 (9.2)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(1.76)					
Subt. clover	h3	3 (0.9)	2 (1.0)	17 (3.0)	68 (6.0)	22 (3.0)	-	(0.76)	***
	h7	2 (0.6)	2 (1.1)	6 (1.5)	26 (3.6)	27 (2.9)	-		
	Sign.	NS	NS	NS	**	NS			
	SED			(0.83)					
Other legumes	h3	4 (1.2)	9 (2.5)	30 (5.1)	179 (12.5)	168 (11.1)	-	(1.07)	***
	h7	17 (2.6)	15 (3.0)	24 (4.1)	255 (13.7)	338 (16.0)			
	Sign.	NS	NS	NS	NS	***			
	SED			(1.36)					
Weeds	h3	16 (1.3)	3 (0.8)	7 (1.3)	38 (3.4)	12 (1.8)	6 (1.2)	(0.81)	**
	h7	3 (0.8)	5 (1.2)	8 (1.6)	41 (4.0)	35 (3.0)	5 (0.4)		
	Sign.	NS	NS	NS	NS	NS			
	SED			(1.00)					
All legumes	h3	10 (2.3)	20 (4.1)	61 (7.2)	306 (16.6)	472 (20.6)	144 (9.3)	(1.13)	***
	h7	22 (3.5)	31 (5.1)	40 (5.8)	332 (16.8)	668 (23.8)	107 (9.2)		
	Sign.	NS	NS	NS	NS	*	NS		
	SED			(1.29)					
Total biomass	h3	911 (29.4)	973 (30.7)	777 (27.4)	1312 (35.9)	1872 (42.9)	904 (29.7)	(1.08)	***
	h7	828 (28.1)	1189 (34.1)	1047 (31.8)	1752 (41.5)	2504 (49.7)	1751 (41.4)		
	Sign.	NS	*	**	***	***	***		
	SED			(1.49)					
Tiller popul. density	h3	7236 (77.4)	9655 (94.6)	14932 (119.7)	9881 (98.1)	12842 (111.4)	10642 (100.2)	(6.11)	***
	h7	6044 (69.9)	10909 (99.3)	12499 (109.8)	9593 (93.6)	8984 (92.1)	9724 (96.5)		
	Sign.	NS	NS	NS	NS	**	NS		
	SED			(6.87)					
WC growing points	h3	135 (6.6)	213 (9.9)	262 (12.1)	412 (16.3)	-	855 (22.1)	(2.40)	**
	h7	337 (13.1)	198 (10.6)	177 (10.2)	342 (14.9)	-	727 (23.0)		
	Sign.	NS	NS	NS	NS	-	NS		
	SED			(4.27)					

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.15 Main effects of cutting height on the proportion (%) of hill country sward components at different dates (2000/01). *Waipawa south aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	h3	96.7 (9.83)	96.9 (9.85)	87.9 (9.35)	73.0 (8.49)	73.5 (8.53)	84.9(9.15)	(0.146)	***
	h7	94.9 (9.73)	96.4 (9.82)	94.1 (9.69)	75.8 (8.64)	70.6 (8.32)	92.6 (9.62)		
	Sign.	NS	NS	*	NS	NS	**		
	SED			(0.166)					
White Clover	h3	0.5 (0.25)	1.3 (0.73)	2.2 (1.00)	5.0 (1.61)	14.2 (3.32)	14.5 (3.06)	(0.258)	***
	h7	0.5 (0.24)	1.2 (0.81)	1.0 (0.64)	3.1 (1.35)	12.2 (2.91)	7.0 (2.31)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(0.456)					
Subt. clover	h3	0.3 (0.30)	0.3 (0.37)	2.9 (1.22)	5.2 (1.67)	1.4 (0.74)	-	(0.202)	***
	h7	0.4 (0.27)	0.2 (0.32)	0.7 (0.54)	1.6 (0.88)	1.1 (0.59)	-		
	Sign.	NS	NS	**	***	NS			
	SED			(0.231)					
Other legumes	h3	0.6 (0.44)	1.1 (0.86)	5.3 (2.03)	13.6 (3.47)	10.1 (2.68)	-	(0.282)	***
	h7	3.6 (1.07)	1.7 (0.98)	3.0 (1.41)	16.9 (3.48)	14.6 (3.31)	-		
	Sign.	NS	NS	NS	NS	NS			
	SED			(0.387)					
Weeds	h3	1.9 (0.46)	0.4 (0.30)	1.7 (0.62)	3.3 (1.00)	0.8 (0.44)	0.7 (0.42)	(0.235)	*
	h7	0.7 (0.34)	0.5 (0.37)	1.2 (0.60)	2.6 (1.02)	1.5 (0.64)	0.4 (0.13)		
	Sign.	NS	NS	NS	NS	NS			
	SED			(0.307)					
All legumes	h3	1.4 (0.83)	2.7 (1.42)	10.3 (2.87)	23.7 (4.64)	25.7 (4.82)	14.5 (3.06)	(0.316)	***
	h7	4.5 (1.42)	3.1 (1.56)	4.8 (1.93)	21.6 (4.21)	27.9 (4.88)	7.0 (2.31)		
	Sign.	NS	NS	**	NS	NS	*		
	SED			(0.356)					

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.3.4.3. Tiller population density

The effect of cutting height on TPD was significant only in December, where h3 plots had 42% more tillers per square meter than h7 swards (Table 3.14).

3.3.3.4.4. White clover growing point density

No differences between cutting height treatments were recorded for GPD at this site.

3.3.3.5. *Effect of grass suppression*

3.3.3.5.1. **Sward height**

Swards with no grass suppression were, on average, taller than H1 swards (5.3 v 4.1 cm; $p < 0.01$). Differences between treatments were maintained between July and December. After December, H0 and H1 sward heights did not differ significantly ($p > 0.05$; Table 3.13).

3.3.3.5.2. **Herbage mass and botanical composition**

Total standing biomass

Average standing biomass in the season was 41% higher on H0 than H1 plots (1541 v 1095 kg DM/ha; $p < 0.001$). At the start of the season (July), differences were greatest (102%) and declined thereafter, especially in December and February (19% and 30% respectively; Table 3.16). Total biomass peaked in December in both treatments.

Grass

Average grass biomass and percentage in the season were higher in H0 v H1 (1426 v 812 kg DM/ha, and 93.2 v 79.7%, respectively; $p < 0.001$). Differences in standing biomass remained significant throughout the season, with peaks in July and October (113 and 108% difference, respectively; Table 3.16). Grass percentage in the sward remained high (85-98%) in H0 plots throughout the experiment, while a decline was observed in H1 plots from August (86%) to December (59%), with a recovery in February. Differences became significant ($p < 0.001$) from September onwards (Table 3.17).

A significant *cutting height x grass suppression x date* interaction showed that grass percentages fell more sharply on h3 than h7 plots when H0 and H1 plots were compared, both in September (95.3 v 80.6% in h3-H0 v h3-H1 ($p < 0.001$) and 97.3 v 90.9% in h7-H0 v h7-H1 ($p > 0.05$)) and February (92.7 v 77.0% in h3-H0 v h3-H1 ($p < 0.001$) and 96.1 v 89.0% in h7-H0 v h7-H1 ($p > 0.05$)).

Legumes

Very low amounts of SC biomass were present at this site. SC biomass was higher in H1 v H0 plots from September to December (Table 3.16). SC reached a peak percentage in the sward in October (5% in H1). H1 plots had higher SC contents from September onwards (Table 3.17), and higher overall SC percentage (1.8 v 0.5%; $p < 0.05$). No SC was present in the swards in the February harvest.

On average, WC percentage for the season was higher on H1 v H0 (7.8 v 2.6%; $p < 0.05$). WC biomass was higher in H1 v H0 plots in December (172%) and February (164%). There was about three times more WC on H1 plots than H0 plots on those dates (Table 3.17).

On average, OL percentage for the season was higher on H1 v H0 (8.2 v 3.5%; $p < 0.05$). In October and December, OL biomass on H1 plots was more than double that on H0 swards (Table 3.16). OL percentage in the sward was significantly higher on H1 v H0 in October and December (Table 3.17).

Substantial differences ($p < 0.001$) were observed on average TL biomass and percentage in the sward, when H0 and H1 are compared. TL biomass was higher in H1 v H0 in October (106%), December (148%) and February (163% more) (Table 3.16). H1 had higher TL percentage in the sward than H0 from September onwards, with a peak in December (Table 3.17).

A *cutting height x grass suppression x date* interaction showed that suppression effects on TL biomass were more marked on h7 than h3 plots, especially in October (347 v 265 kg DM/ha in h3-HO v h3-H1; NS; and 151 v 512 kg DM/ha in h7-HO v h7-H1; $p < 0.001$) and December (368 v 575 kg DM/ha in h3-HO v h3-H1; $p < 0.01$; and 286 v 1049 kg DM/ha in h7-HO v h7-H1; $p < 0.001$). The same interaction was present for TL percentage in the sward, whereby sharper increases in TL percentage due to grass suppression were observed on the h7 than h3 plots in October (17.1 v 30.3% in h3-HO

v h3-H1; $p < 0.01$; and 7.7 v 35.5% in h7-HO v h7-H1; $p < 0.001$), and December (18.1 v 33.3% in h3-HO v h3H1; $p < 0.01$; and 11.6 v 44.1% in h7-HO v h7H1; $p < 0.001$).

Weeds

Low weed biomass and percentage was present in the swards, but on a seasonal average H1 had higher weed biomass (27 v 3 kg DM/ha; $p < 0.01$) and higher TL content (2.4 v 0.2%; $p < 0.05$) than H0 plots. Weed biomass in the sward was higher in H1 v H0 from September to December (Table 3.16), while weed percentage was higher in October and December only (Table 3.17).

3.3.3.5.3. Tiller population density

TPD was higher in H0 v H1 in July and August. Differences disappeared afterwards, and both treatments peaked with a similar TPD in September. In February, the opposite was the case, H1 having a higher TPD compared to H0 (58% more; Table 3.16). The relative high TPD observed on H1 plots consisted mostly of small chewings fescue (*Festuca rubra*) tillers. Reduced plant activity due to low soil temperatures during and after herbicide treatment may have lowered the effectiveness of application.

3.3.3.5.4. White clover growing point density

Grass suppression influenced GPD from August onwards, H1 showing higher GPD than H0. By the end of the season (February) H1 had 3.5 times more white clover growing points than H0 (Table 3.16). In December GPD was not recorded because cores were damaged.

Table 3.16 Main effects of autumn grass suppression on the standing herbage mass (kg DM/ha) of different hill country sward components, tiller population density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Waipawa south aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	H0	1149 (33.6)	1239 (34.8)	1109 (32.9)	1585 (39.3)	2045 (44.6)	1430 (36.8)	(1.14)	***
	H1	539 (22.8)	865 (29.0)	599 (23.9)	760 (27.4)	1144 (33.6)	964 (30.1)		
	Sign.	***	***	***	***	***	***		
	SED			(1.52)					
White Clover	H0	2 (0.4)	5 (1.5)	7 (1.6)	35 (4.6)	157 (10.9)	69 (7.0)	(1.07)	***
	H1	3 (0.8)	16 (3.3)	17 (3.0)	75 (6.4)	427 (18.0)	182 (11.5)		
	Sign.	NS	NS	NS	NS	***	*		
	SED			(1.76)					
Subt. clover	H0	3 (0.7)	2 (1.1)	5 (1.4)	32 (3.7)	11 (2.0)	-	(0.76)	***
	H1	2 (0.8)	3 (1.1)	17 (3.2)	62 (5.8)	37 (3.9)	-		
	Sign.	NS	NS	*	*	*			
	SED			(0.83)					
Other legumes	H0	9 (2.2)	12 (2.8)	24 (4.1)	141 (10.0)	158 (10.9)	-	(1.07)	***
	H1	12 (1.6)	12 (2.7)	30 (5.1)	293 (16.1)	348 (16.2)	-		
	Sign.	NS	NS	NS	***	***			
	SED			(1.36)					
Weeds	H0	1 (0.3)	3 (0.7)	0 (0.3)	7 (1.1)	2 (0.6)	2 (0.5)	(0.81)	***
	H1	18 (1.8)	5 (1.3)	15 (2.7)	73 (6.3)	45 (4.3)	8 (1.2)		
	Sign.	NS	NS	*	***	***	NS		
	SED			(0.89)					
All legumes	H0	14 (3.0)	20 (3.9)	36 (5.4)	208 (13.2)	327 (17.0)	69 (7.0)	(1.13)	***
	H1	18 (2.8)	31 (5.2)	64 (7.6)	430 (20.2)	812 (27.4)	182 (11.5)		
	Sign.	NS	NS	NS	***	***	***		
	SED			(1.29)					
Total biomass	H0	1165 (33.8)	1261 (35.1)	1146 (33.5)	1800 (42.1)	2374 (48.3)	1501 (37.8)	(1.08)	***
	H1	575 (23.6)	901 (29.6)	678 (25.7)	1262 (35.3)	2001 (44.3)	1154 (33.3)		
	Sign.	***	***	***	***	***	***		
	SED			(1.49)					
Tiller popul. density	H0	9024 (90.9)	13198 (113.5)	14397 (119.2)	8504 (90.4)	10361 (100.4)	7880 (87.8)	(6.11)	***
	H1	4256 (56.4)	7366 (80.4)	13034 (110.4)	10971 (101.4)	11464 (103.0)	12485 (108.9)		
	Sign.	***	***	NS	NS	NS	**		
	SED			(6.87)					
WC growing points	H0	167 (9.2)	120 (7.0)	80 (6.4)	177 (10.7)	-	348 (14.5)	(2.40)	***
	H1	305 (10.5)	292 (13.5)	358 (15.9)	577 (20.4)	-	1233 (30.6)		
	Sign.	NS	*	*	*		***		
	SED			(4.27)					

*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.17 Main effects of autumn grass suppression on the proportion (%) of hill country sward components at different dates (2000/01). *Waipawa south aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	H0	98.4 (9.92)	98.0 (9.90)	96.3 (9.81)	87.1 (9.32)	85.0 (9.20)	94.5 (9.71)	(0.146)	***
	H1	93.1 (9.63)	95.4 (9.77)	85.7 (9.23)	61.7 (7.81)	59.1 (7.64)	83.0 (9.05)		
	Sign.	NS	NS	***	***	***	***		
	SED			(0.166)					
White Clover	H0	0.2 (0.11)	0.4 (0.41)	0.6 (0.46)	2.1 (1.11)	6.9 (2.28)	5.3 (1.92)	(0.258)	***
	H1	0.8 (0.38)	2.0 (1.13)	2.6 (1.18)	6.0 (1.84)	19.5 (3.95)	16.1 (3.46)		
	Sign.	NS	NS	NS	NS	***	***		
	SED			(0.456)					
Subt. clover	H0	0.2 (0.19)	0.2 (0.28)	0.6 (0.44)	1.8 (0.89)	0.5 (0.43)	-	(0.202)	***
	H1	0.5 (0.38)	0.4 (0.40)	3.1 (1.33)	5.0 (1.66)	2.0 (0.91)	-		
	Sign.	NS	NS	***	**	*			
	SED			(0.231)					
Other legumes	H0	1.0 (0.70)	1.3 (0.86)	2.6 (1.32)	8.5 (2.47)	7.5 (2.35)	-	(0.282)	***
	H1	3.2 (0.81)	1.5 (0.97)	5.7 (2.13)	21.9 (4.48)	17.2 (3.64)	-		
	Sign.	NS	NS	*	***	**			
	SED			(0.387)					
Weeds	H0	0.1 (0.10)	0.2 (0.19)	0.0 (0.09)	0.5 (0.28)	0.1 (0.12)	0.3 (0.16)	(0.235)	*
	H1	2.5 (0.69)	0.7 (0.48)	2.8 (1.12)	5.4 (1.73)	2.2 (0.96)	0.9 (0.39)		
	Sign.	NS	NS	**	***	**	NS		
	SED			(0.307)					
All legumes	H0	1.4 (0.92)	1.8 (1.16)	3.7 (1.68)	12.4 (3.20)	14.9 (3.60)	5.3 (1.92)	(0.316)	***
	H1	4.4 (1.32)	3.9 (1.82)	11.4 (3.12)	32.9 (5.66)	38.7 (6.11)	16.1 (3.46)		
	Sign.	NS	NS	***	***	***	***		
	SED			(0.356)					

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.3.6. Effect of soil phosphorus status

3.3.3.6.1. Sward height

A significant *grass suppression* $\times$ *P* $\times$ *date* ($p < 0.01$) indicated that sward height between HP and LP plots did not differ significantly in H0 but that, on the H1 plots, HP swards had a significantly higher sward height than LP plots from December onwards (Table 3.13).

3.3.3.6.2. Herbage mass and botanical composition

Total standing biomass

Effects of soil-P status on total standing biomass were only significant in the December harvest, when HP yielded 24% more than LP (Table 3.18).

Grass

Grass biomass was not affected by soil-P status, but a higher grass percentage in the sward was recorded in the latter part of the season (December and February), where LP swards showed higher grass percentage than HP plots (Table 3.19).

Legumes

SC biomass in the sward was higher in HP v LP plots only in December, but with very low levels of production (Table 3.18). No SC was present on the February harvest.

HP plots had higher WC biomass in December (73% more) and February (128% more; Table 3.18). WC percentage in the sward reached levels of 14-15% in the latter part of the season on HP plots, but differences with LP plots were only significant in February (Table 3.19).

OL biomass became a more significant component of the sward in October and December, not being present in February. In October, HP plots had 36% more OL biomass compared to LP swards (Table 3.18).

Average TL biomass in the season was higher in HP v LP plots (220 v 149 kg DM/ha; $p < 0.05$). TL content in the sward increased sharply from October onwards, TL biomass being higher in HP v LP plots in December (66% more) and February (129% more; Table 3.18). TL peaked in December with 30% of the total biomass in HP plots, but differences with LP plots were only significant in February (Table 3.19).

Table 3.18 Main effects of soil-P status on the standing herbage mass (kg DM/ha) of different hill country sward components, tiller population density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Waipawa south aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	HP	854 (28.4)	1023 (31.3)	867 (28.5)	1192 (33.6)	1691 (40.2)	1227 (33.9)	(1.14)	***
	LP	834 (28.0)	1081 (32.4)	842 (28.3)	1153 (33.2)	1498 (38.0)	1166 (33.0)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(1.34)					
White Clover	HP	2 (0.4)	9 (2.4)	10 (2.0)	51 (5.0)	371 (16.7)	174 (11.2)	(1.07)	***
	LP	3 (0.8)	12 (2.4)	14 (2.6)	59 (6.1)	214 (12.2)	76 (7.3)		
	Sign.	NS	NS	NS	NS	***	**		
	SED			(1.33)					
Subt. clover	HP	3 (0.9)	3 (1.4)	9 (2.0)	45 (4.4)	38 (3.9)	-	(0.76)	***
	LP	2 (0.6)	1 (0.8)	13 (2.5)	49 (5.2)	11 (2.0)	-		
	Sign.	NS	NS	NS	NS	*			
	SED			(0.75)					
Other legumes	HP	9 (1.9)	14 (2.9)	29 (4.7)	251 (14.1)	302 (14.2)	-	(1.07)	***
	LP	13 (1.9)	11 (2.6)	26 (4.5)	184 (12.0)	204 (12.8)	-		
	Sign.	NS	NS	NS	*	NS			
	SED			(1.07)					
Weeds	HP	2 (0.5)	2 (0.8)	7 (1.4)	36 (3.6)	23 (2.6)	4 (0.8)	(0.81)	**
	LP	17 (1.6)	5 (1.2)	8 (1.5)	43 (3.8)	24 (2.2)	7 (0.8)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(0.89)					
All legumes	HP	14 (2.8)	26 (4.8)	47 (6.4)	347 (17.4)	710 (24.8)	174 (11.2)	(1.13)	***
	LP	18 (2.9)	24 (4.3)	53 (6.6)	291 (16.0)	429 (19.6)	76 (7.3)		
	Sign.	NS	NS	NS	NS	***	**		
	SED			(1.25)					
Total biomass	HP	870 (28.8)	1052 (31.9)	921 (29.6)	1575 (39.3)	2425 (48.8)	1405 (36.7)	(1.08)	***
	LP	869 (28.7)	1110 (32.9)	903 (29.5)	1488 (38.2)	1951 (43.8)	1249 (34.4)		
	Sign.	NS	NS	NS	NS	***	NS		
	SED			(1.31)					
Tiller popul. density	HP	6064 (71.4)	9977 (94.8)	14219 (116.4)	10621 (100.0)	10210 (97.8)	9895 (97.6)	(6.11)	***
	LP	7216 (75.9)	10587 (99.1)	13212 (113.1)	8853 (91.7)	11615 (105.7)	10471 (99.1)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(6.87)					
WC growing points	HP	225 (9.1)	223 (11.6)	258 (12.5)	417 (15.4)	-	982 (26.8)	(2.40)	***
	LP	247 (10.6)	188 (8.9)	180 (9.8)	337 (15.7)	-	600 (18.3)		
	Sign.	NS	NS	NS	NS		**		
	SED			(3.04)					

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Weeds

No soil-P effects were observed on weed biomass at the present site.

3.3.3.6.3. Tiller population density

Soil-P status did not affect tiller population density during the season at this site.

3.3.3.6.4. White clover growing point density

Only at the end of the season (February) HP plots showed a 64% higher GPD compared to LP plots (Table 3.18).

Table 3.19 Main effects of soil-P status on the proportion (%) of hill country sward components at different dates (2000/01). *Waipawa south aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	HP	97.4 (9.87)	96.3 (9.81)	91.0 (9.53)	72.8 (8.47)	68.8 (8.22)	85.6 (9.19)	(0.146)	***
	LP	94.2 (9.69)	97.0 (9.85)	91.0 (9.52)	76.0 (8.66)	75.4 (8.63)	91.9 (9.57)		
	Sign.	NS	NS	NS	NS	*	*		
	SED			(0.180)					
White Clover	HP	0.4 (0.19)	1.2 (0.80)	1.4 (0.73)	3.7 (1.32)	14.9 (3.42)	14.0 (3.15)	(0.258)	***
	LP	0.5 (0.30)	1.2 (0.74)	1.8 (0.91)	4.4 (1.64)	11.5 (2.81)	7.4 (2.22)		
	Sign.	NS	NS	NS	NS	NS	**		
	SED			(0.324)					
Subt. clover	HP	0.4 (0.34)	0.4 (0.45)	1.5 (0.80)	3.1 (1.13)	1.8 (0.84)	-	(0.202)	***
	LP	0.3 (0.23)	0.1 (0.23)	2.2 (0.97)	3.7 (1.43)	0.7 (0.49)	-		
	Sign.	NS	NS	NS	NS	NS			
	SED			(0.201)					
Other legumes	HP	1.5 (0.70)	1.7 (0.98)	4.8 (1.81)	17.6 (3.75)	13.4 (3.00)	-	(0.282)	***
	LP	2.7 (0.82)	1.2 (0.86)	3.5 (1.63)	12.8 (3.20)	11.3 (2.99)	-		
	Sign.	NS	NS	NS	NS	NS			
	SED			(0.293)					
Weeds	HP	0.3 (0.18)	0.4 (0.31)	1.3 (0.61)	2.8 (0.98)	1.2 (0.58)	0.4 (0.28)	(0.235)	*
	LP	2.3 (0.62)	0.5 (0.36)	1.6 (0.60)	3.1 (1.03)	1.1 (0.50)	0.7 (0.27)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(0.271)					
All legumes	HP	2.3 (1.08)	3.3 (1.61)	7.7 (2.41)	24.4 (4.58)	30.0 (5.15)	14.0 (3.15)	(0.316)	***
	LP	3.5 (1.17)	2.5 (1.38)	7.4 (2.39)	20.9 (4.28)	23.5 (4.55)	7.4 (2.22)		
	Sign.	NS	NS	NS	NS	NS	**		
	SED			(0.356)					

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.3.7. *Effect of nitrogen application*

3.3.3.7.1. **Sward height**

On average, N50 plots were taller than N0 plots (5.0 v 4.4 cm ($p < 0.001$)). The interaction *grass suppression x N x date* ($p < 0.01$) showed that on H0 plots N50 swards were taller than N0 swards between July and October, while on H1 plots means did not differ during that period. On the other hand, on H1-N50 plots swards were taller than H1-N0 plots during November and December, with no differences in the H0 plots (Table 3.13).

3.3.3.7.2. **Herbage mass and botanical composition**

Total standing biomass

Average total standing biomass for the season was 12% higher on N50 than N0 (1394 v 1243 kg DM/ha; $p < 0.01$). Main differences occurred in September (21% more biomass on N50 v N0) and December (17% more; Table 3.20).

Grass

A *grass suppression x N* interaction indicated that the season average for grass biomass was higher on N50 v N0 only in the H0 swards (1582 v 1270 kg DM/ha for H0-N50 v H0-N0; $p < 0.001$), while on the H1 plots differences were not significant (838 v 786 kg DM/ha for H1-N50 v H1-N0; $p > 0.05$). A higher grass biomass was recorded in September, December and February, when N50 v N0 plots are compared. These differences were highest in December, when N50 had 30% more grass biomass than N0 (Table 3.20). Grass percentage in the sward was only significantly higher on N50 v N0 plots in December (Table 3.21).

Legumes

SC biomass was generally very low and significant differences due to nitrogen application arose only in December (Table 3.20). A *grass suppression x N x date*

interaction ($p < 0.05$) indicated that in October, N50 swards had less SC percentage than N0 plots, only in H0 conditions ($3.4 \text{ v } 0.3\%$ for H0-N0 v H0-N50). On H1 plots no differences were recorded. Also, a *soil-P x N x date* interaction ($p < 0.05$) showed that for October, SC percentage in the sward was lower only on LP-N50 compared to LP-N0 ($5.5 \text{ v } 1.9\%$).

WC biomass or percentage in the sward was not affected by nitrogen application at this site.

On average, OL biomass in the sward was higher on N0 v N50 only in the H0 plots ($87 \text{ v } 28 \text{ kg DM/ha}$; $p < 0.01$), with no differences observed on the H1 plots ($117 \text{ v } 115 \text{ kg DM/ha}$; $p > 0.05$). Average OL percentage showed similar responses, with $5.3 \text{ v } 1.7\%$ when H0-N0 v H0-N50 were compared ($p < 0.01$), while on H1 plots the effect was not significant ($8.5 \text{ v } 7.9\%$; $p > 0.05$). OL biomass (Table 3.20) and percentage in the sward (Table 3.21) were higher in N0 v N50 in October (51% more biomass) and December (42% more biomass).

Similar interactions were observed for the TL component of the sward. On average, TL biomass in the sward was higher on N0 v N50 only in the H0 plots ($153 \text{ v } 71 \text{ kg DM/ha}$; $p < 0.01$), with no differences observed on the H1 plots ($249 \text{ v } 264 \text{ kg DM/ha}$; $p > 0.05$). Average OL percentage showed similar responses, with $9.2 \text{ v } 4.0\%$ when H0-N0 v H0-N50 were compared ($p < 0.01$), while on H1 plots the effect was not significant ($17.8 \text{ v } 18.0\%$; $p > 0.05$). TL biomass was 35% higher in October and 15% higher in December, when N0 and N50 plots are compared (Table 3.20). TL percentage was also higher on N0 v N50 (Table 3.21).

Weeds

No significant responses were observed for weed biomass or weed content in the sward.

Table 3.20 Main effects of an autumn nitrogen application on the standing herbage mass (kg DM/ha) of different hill country sward components, tiller population density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Waipawa south aspect.*

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	N0	817 (28.0)	1007 (31.3)	767 (27.1)	1100 (32.4)	1388 (36.6)	1088 (32.1)	(1.14)	***
	N50	871 (28.4)	1097 (32.5)	942 (29.7)	1244 (34.3)	1801 (41.6)	1306 (34.9)		
	Sign.	NS	NS	*	NS	***	*		
	SED			(1.29)					
White Clover	N0	1 (0.2)	7 (1.8)	10 (2.0)	49 (5.7)	280 (14.5)	144 (10.1)	(1.07)	***
	N50	5 (1.0)	15 (2.9)	14 (2.6)	61 (5.4)	305 (14.4)	107 (8.4)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(1.33)					
Subt. clover	N0	3 (0.7)	3 (1.0)	10 (2.2)	56 (5.8)	32 (3.5)	-	(0.76)	***
	N50	2 (0.8)	2 (1.1)	12 (2.4)	38 (3.8)	16 (2.3)	-		
	Sign.	NS	NS	NS	NS	*			
	SED			(0.74)					
Other legumes	N0	11 (2.0)	12 (2.8)	32 (5.2)	262 (14.9)	297 (15.9)	-	(1.07)	***
	N50	11 (1.8)	12 (2.7)	23 (4.1)	173 (11.3)	209 (11.2)	-		
	Sign.	NS	NS	NS	***	***			
	SED			(1.04)					
Weeds	N0	15 (1.4)	5 (1.1)	7 (1.4)	33 (3.6)	16 (2.3)	6 (0.8)	(0.81)	**
	N50	4 (0.7)	3 (0.9)	8 (1.5)	46 (3.8)	32 (2.5)	4 (0.9)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(0.89)					
All legumes	N0	15 (2.6)	22 (4.2)	52 (6.7)	366 (18.4)	609 (23.9)	144 (10.1)	(1.13)	***
	N50	18 (3.2)	29 (5.0)	49 (6.3)	272 (15.0)	531 (20.5)	107 (8.4)		
	Sign.	NS	NS	NS	**	**	NS		
	SED			(1.25)					
Total biomass	N0	846 (28.6)	1034 (31.7)	826 (28.3)	1500 (38.3)	2012 (44.5)	1237 (34.3)	(1.08)	***
	N50	893 (28.9)	1129 (33.0)	999 (30.1)	1563 (39.2)	2363 (48.1)	1417 (36.7)		
	Sign.	NS	NS	*	NS	**	NS		
	SED			(1.24)					
Tiller popul. density	N0	6455 (72.7)	8312 (86.0)	10779 (102.1)	9429 (94.0)	10512 (99.9)	9600 (95.6)	(6.11)	***
	N50	6825 (74.6)	12252 (107.9)	16652 (127.4)	10046 (97.7)	11313 (103.5)	10765 (101.1)		
	Sign.	NS	**	***	NS	NS	NS		
	SED			(6.77)					
WC growing points	N0	257 (11.0)	197 (10.5)	182 (10.6)	312 (15.6)	-	957 (26.1)	(2.40)	***
	N50	215 (8.7)	215 (10.0)	257 (11.7)	442 (15.5)	-	625 (19.0)		
	Sign.	NS	NS	NS	NS		*		
	SED			(2.89)					

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.21 Main effects of autumn nitrogen application on the proportion (%) of hill country sward components at different dates (2000/01). *Waipawa south aspect*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Dec	Feb	SED	Sign.
Grasses	N0	95.8 (9.77)	96.9 (9.85)	91.0 (9.53)	72.0 (8.44)	68.0 (8.19)	87.5 (9.33)	(0.146)	***
	N50	95.8 (9.78)	96.4 (9.82)	91.0 (9.51)	76.8 (8.69)	76.1 (8.65)	90.0 (9.43)		
	Sign.	NS	NS	NS	NS	**	NS		
	SED			(0.166)					
White Clover	N0	0.2 (0.11)	0.8 (0.60)	1.4 (0.76)	3.5 (1.52)	14.4 (3.29)	11.9 (2.96)	(0.258)	***
	N50	0.8 (0.38)	1.7 (0.94)	1.8 (0.88)	4.5 (1.44)	12.0 (2.94)	9.6 (2.41)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(0.324)					
Subt. clover	N0	0.3 (0.24)	0.3 (0.35)	1.6 (0.86)	3.8 (1.48)	1.6 (0.80)	-	(0.202)	***
	N50	0.4 (0.32)	0.2 (0.33)	2.0 (0.90)	3.0 (1.08)	0.9 (0.53)	-		
	Sign.	NS	NS	NS	*	NS			
	SED			(0.201)					
Other legumes	N0	1.8 (0.75)	1.5 (0.94)	4.6 (1.93)	18.4 (3.98)	15.1 (3.60)	-	(0.282)	***
	N50	2.4 (0.77)	1.4 (0.90)	3.6 (1.51)	12.1 (2.98)	9.5 (2.39)	-		
	Sign.	NS	NS	NS	***	***			
	SED			(0.282)					
Weeds	N0	2.0 (0.53)	0.5 (0.35)	1.4 (0.61)	2.3 (0.96)	0.9 (0.54)	0.6 (0.26)	(0.235)	*
	N50	0.6 (0.27)	0.4 (0.33)	1.5 (0.60)	3.6 (1.05)	1.5 (0.54)	0.5 (0.30)		
	Sign.	NS	NS	NS	NS	NS	NS		
	SED			(0.270)					
All legumes	N0	2.3 (0.93)	2.6 (1.40)	7.6 (2.51)	25.7 (4.88)	31.1 (5.42)	11.9 (2.96)	(0.316)	***
	N50	3.6 (1.32)	3.2 (1.59)	7.5 (2.29)	19.6 (3.98)	22.4 (4.28)	9.6 (2.41)		
	Sign.	NS	NS	NS	*	**	NS		
	SED			(0.356)					

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.3.7.3. Tiller population density

TPD on N50 plots was on average higher than on N0 plots (11309 v 9181 tiller/m²; $p < 0.01$). Differences in TPD were mainly observed in August and September, with N50 plots having 47% and 54% more tiller/m² compared to N0 swards, respectively. Thereafter, TPD was similar on both treatments (Table 3.20).

3.3.3.7.4. White clover growing point density

White clover GPD for nitrogen treatments was only significantly different in February, when N0 plots had 1.5 times more growing points/m² than N50 plots (Table 3.20).

3.3.4. Ballantrae

At this site, swards were sampled at eight different times during the season 2000-2001, on July 19, August 22, September 18, October 19, November 21, December 22, February 15 and March 27. For the ease of reading, dates will be hereafter referred to as July, August, September, October, November, December, February and March, in the text and tables.

3.3.4.1. Significance of main effects and interactions

A summary of the main effects and significant interactions is presented in Table 3.22

Table 3.22 Summary of main effects and interaction significance. *Ballantrae*.

Main effect or Interaction	Total standing DM/ha	Grass. DM/ha	White clover DM/ha	Weeds DM/ha	All Legumes DM/ha	Sward height cm	Tiller density till/m ²	Grow.pt. density gp/m ²	Grass %	White clover %	Weed %	All Legumes %
cuth	***	**	NS	NS	NS	**	NS	NS	NS	NS	NS	NS
supp	***	***	***	***	***	***	***	***	***	***	***	***
phos	*	NS	**	NS	**	**	NS	NS	NS	*	**	**
nitro	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
date	***	***	***	***	***	***	***	***	***	***	***	***
cuth x date	***	***	NS	*	NS	***	***	**	NS	**	NS	**
supp x date	***	***	***	***	***	***	***	***	***	***	***	***
phos x date	NS	*	***	NS	***	NS	*	**	*	**	***	**
nitro x date	NS	NS	NS	NS	NS	*	NS	*	NS	NS	NS	NS
supp x phos x date	NS	NS	NS	NS	NS	**	NS	NS	●	NS	NS	NS
cuth x supp x date	NS	***	***	**	***	***	NS	NS	NS	*	NS	*

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; cuth=cutting height; supp=grass suppression; phos=phosphorus; nitro=nitrogen. NOTE: Only interactions that were significant for at least one variable are shown in the table.

3.3.4.2. Temperature and rainfall

Between May 2000 and April 2001 there was 30% less rainfall compared to an average year. Deficits were greatest in April, followed by July, November and March, with 32%, 42%, 49% and 50% of average rainfall, respectively (Table 3.23). Only December and especially February had more rainfall than average. Summer rainfall was concentrated in

a few thunderstorm events responsible for 64%, 66%, 94% and 59% of total rainfall in December, January, February and March, respectively.

Data recorded at the nearest (Pahiatua) meteorological station (40°27'S, 175°49'E), located at 15 km from Ballantrae, were used to compare soil temperature data with the average record available (1992-2002). Soil temperatures (10 cm) for the experimental season were close to average. Average soil temperature was 1.1 °C colder in November and 0.9 °C warmer in December, compared to an average year (Table 3.23). Ballantrae tended to be slightly colder than Pahiatua between November and January, similar in February and warmer in March and April (soil temperature data for March and April 2001 had to be taken from a different station at site, due to failure of original equipment, which could explain differences observed).

3.3.4.3. *Soil moisture*

Soil moisture levels exceeded field capacity in the 0-5 cm layer, from June to the end of September, and in the same period moisture was at levels of over 90% of available water capacity for the 5-10 cm soil layer. There was a drop towards early November, available water capacity falling below 40% in the top layer and averaging 50% in the lower layer of the soil. There was a recovery in late November, but moisture levels fell dramatically thereafter and were very low (under 20% of available water capacity) at the dates measured during the summer period between December and late March. Moisture levels recovered at the last date of measurement (Figure 3.3).

Table 3.23 Rainfall and soil temperature (10 cm) for the experimental period and average year at Ballantrae and Pahiatua.

Month	Rainfall (mm)		Soil temp. 10 cm (°C)		
	<i>Ballantrae</i>		<i>Ballantrae</i>	<i>Pahiatua</i> **	
	2000/01 #	Average*	2000/01 #	2000/01	Average***
May	104.4	130	11.2	10.6	10.2
June	75.4	108	8.9	7.9	7.7
July	56.0	135	8.8	7.9	7.0
August	85.6	116	8.3	7.3	7.3
September	78.6	123	9.8	9.7	9.4
October	95.6	120	11.5	11.8	11.8
November	49.6	101	11.5	12.6	13.7
December	110.6	105	16.5	17.2	16.3
January	63.4	89	16.5	17.1	17.4
February	95.8	61	17.9	18.1	17.3
March	53.0	105	18.7	15.4	15.1
April	31.8	98	15.2	11.9	12.6
Annual	899.8	1291	12.9	12.3	12.2

• Average 1970-80 from (NZMS, 1983); ** Data supplied by NIWA; *** Average 1992-2002; # Supplied by Agresearch and Hortresearch.

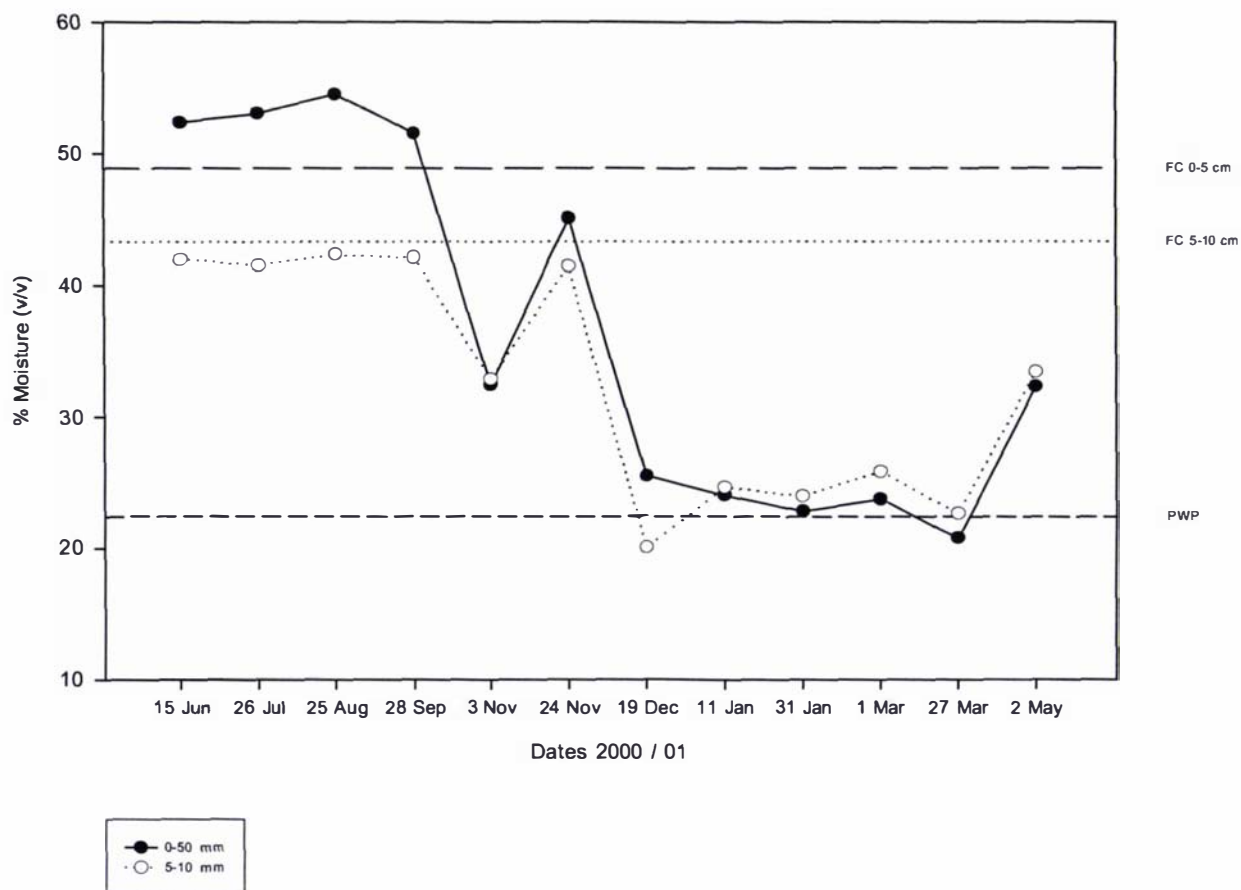


Figure 3.3 Seasonal variation of volumetric soil moisture at the 0-50 mm and 50-100 mm layers of the soil in Ballantrae (2000/01).

Table 3.24 Average sward height (cm) for different cutting height, grass suppression and nitrogen treatments, and the grass suppression x soil-P interaction, at different dates (2000/01). *Ballantrae*.

Factor	Treat	Jun 1	Jun 15	Jul 19	Aug 22	Sep 18	Oct 19	Nov 21	Dec 22	Feb 15	Mar 27	SED	Sign.
Cutting height	h3	2.4 (1.54)	2.7 (1.64)	2.8 (1.63)	2.7 (1.53)	3.1 (1.60)	3.6 (1.76)	4.1 (1.90)	5.3 (2.28)	4.6 (2.15)	3.5 (1.83)	(0.043)	***
	h7	2.4 (1.54)	2.8 (1.68)	2.7 (1.59)	3.4 (1.68)	4.5 (1.86)	5.7 (2.12)	7.1 (2.43)	9.3 (3.00)	9.0 (2.97)	6.7 (2.56)		
	Sign. SED	NS	NS	NS	NS	**	***	***	***	***	***		
Grass suppression	H0	2.5 (1.57)	2.9 (1.71)	4.1 (2.00)	5.2 (2.24)	6.8 (2.55)	8.2 (2.82)	9.4 (3.03)	9.4 (3.03)	6.6 (2.53)	6.6 (2.52)	(0.043)	***
	H1	2.3 (1.51)	2.6 (1.60)	1.5 (1.21)	0.9 (0.96)	0.8 (0.90)	1.2 (1.07)	1.8 (1.31)	5.2 (2.24)	7.1 (2.59)	3.6 (1.87)		
	Sign. SED	NS	NS	***	***	***	***	***	***	NS	**		
Grass suppression x Phosphorus	H0-HP	2.4 (1.55)	3.2 (1.77)	4.3 (2.05)	5.7 (2.35)	7.3 (2.67)	8.9 (2.95)	9.5 (3.05)	9.4 (3.05)	6.5 (2.54)	6.6 (2.53)	(0.089)	***
	H0-LP	2.5 (1.59)	2.7 (1.65)	3.9 (1.96)	4.7 (2.14)	6.3 (2.44)	7.5 (2.69)	9.4 (3.00)	9.5 (3.02)	6.6 (2.52)	6.6 (2.51)		
	Sign. SED	NS	NS	NS	*	*	**	NS	NS	NS	NS		
	H1-HP	2.4 (1.54)	2.6 (1.59)	1.5 (1.24)	1.0 (0.98)	0.9 (0.91)	1.3 (1.10)	2.1 (1.42)	5.9 (2.41)	8.4 (2.81)	4.0 (1.96)		
	H1-LP	2.2 (1.49)	2.6 (1.61)	1.4 (1.18)	0.9 (0.95)	0.8 (0.89)	1.1 (1.03)	1.5 (1.20)	4.4 (2.07)	5.7 (2.37)	3.3 (1.78)		
Nitrogen	N0	2.5 (1.56)	2.7 (1.65)	2.7 (1.59)	3.1 (1.61)	3.9 (1.75)	4.9 (1.98)	5.8 (2.21)	7.6 (2.70)	7.2 (2.63)	5.2 (2.22)	(0.043)	***
	N50	2.3 (1.52)	2.8 (1.67)	2.9 (1.63)	3.1 (1.60)	3.7 (1.70)	4.5 (1.90)	5.4 (2.12)	7.0 (2.58)	6.4 (2.49)	5.0 (2.17)		
	Sign. SED	NS	NS	NS	NS	NS	NS	NS	NS	*	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.4.4. Effect of cutting height

In the Ballantrae site, white clover was by far the main legume present. Other legumes, mainly suckling clover and very occasionally subterranean clover, were also present on a very erratic basis. Tables will be analysed using the “White clover” category, but bearing in mind that occasionally very small amounts (normally under 1% of DM) of other legumes were also present. The “All legumes” category was also inserted in the tables, and occasional differences with the white clover category indicate presence of

other legumes. The erratic appearance within the season and patchy distribution at the site, along with the very low amounts present, did not allow an individual analysis of the “Other legumes” category.

3.3.4.4.1. Sward height

Season average sward height was higher in h7 v h3 (5.4 v 3.5 cm; $p < 0.01$). Heights in the sward were significantly different between cutting heights from September onwards (Table 3.24). Sward heights in h7 were below target heights due to low growth. The interaction *cutting height x grass suppression x date* ($p < 0.001$) indicated that sward height differences were observed between September and November on H0-h3 v H0-h7 plots (5.4 v 8.2, 6.2 v 10.2, and 6.7 v 12.2 cm, for September, October and November, respectively; $p < 0.001$), but not on H1-h3 v H1-h7 plots (0.8 v 0.9, 1.1 v 1.2, and 1.6 v 2.0 cm, for September, October and November, respectively; $p > 0.05$).

3.3.4.4.2. Herbage mass and botanical composition

Total standing biomass

Average total standing biomass was higher in h7 v h3 in the season (2244 v 1634 kg DM/ha; $p < 0.001$). The h7 swards had higher total biomass than h3 plots from September to March, with the exception of October, where treatments did not differ significantly (Table 3.25). Biomass in h7 was highest in February, but differences between h7 and h3 were greatest in December (65%) and March (62%) .

Grass

Grass biomass was, as a season average, 69% higher on h7 v h3 (1482 v 1023; $p < 0.01$). Differences between h7 and h3 plots were significant from December onwards ($p < 0.001$; Table 3.25). However, a significant *cutting height x grass suppression x date* interaction ($p < 0.001$) showed that between November and February differences in grass biomass between h3 and h7 plots only were significant on H0-h7 v H0-h3 plots (2196 v 2832, 2171 v 3876, and 2527 v 4279 kg DM/ha, for November, December and February, respectively; $p < 0.001$) and not on H1 plots.

Legumes

Cutting height effects on WC were not significant up to November. In December, h3 plots had a higher proportion of WC than h7 swards (Table 3.26). Thereafter, effects of cutting height on WC biomass ($p < 0.001$) and percentage ($p < 0.05$) could be seen on a particular *cutting height x grass suppression x date* interaction that was significant only in February and March. The h7-H0 v h3-H0 plots had lower WC biomass (229 v 360 kg DM/ha; $p < 0.01$) in February and similar biomass in March (255 v 194 kg DM/ha; $p > 0.05$). On the other hand, h7-H1 had more WC biomass than h3-H1 plots on both dates (1406 v 890 kg DM/ha, and 839 v 622 kg DM/ha, respectively; $p < 0.001$). In relative terms, h3-H0 had a higher WC percentage in the sward than h7-H0 in February and March (12.3 v 4.9%, and 9.0% v 4.0%, respectively; $p < 0.05$), while there were no significant differences on H1 plots due to cutting height.

Weeds

Weed biomass was higher in h7 v h3 plots only in December (Table 3.25). However, these differences for December were mostly due to a significant 95% increase of weed biomass in H1-h7 v H1-h3 plots (1248 v 2430 kg DM/ha; $p < 0.001$), while on H0 plots the two cutting heights had similar weed biomass.

Table 3.25 Main effects of cutting height on the standing herbage mass (kg DM/ha) of different sward components, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	h3	808 (23.3)	691 (20.4)	645 (18.9)	802 (21.8)	1120 (26.4)	1171 (29.5)	1406 (33.0)	1541 (35.9)	(1.08)	***
	h7	692 (21.8)	760 (21.1)	847 (21.2)	980 (23.1)	1433 (29.1)	2014 (36.7)	2317 (41.3)	2809 (48.1)		
	Sign.	NS	NS	NS	NS	NS	***	***	***		
	SED	(1.65)									
White clover	h3	26 (4.7)	24 (4.2)	38 (5.5)	54 (6.4)	97 (9.1))	294 (15.3)	625 (23.9)	438 (19.8)	(0.74)	***
	h7	28	23	42	47 (1.1)	103 (5.2)	245 (9.7)	818 (21.9)	516 (8.3)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(1.06)									
Weeds	h3	36 (5.6)	80 (7.5)	222 (12.2)	429 (16.6)	622 (19.2)	652 (20.9)	806 (22.2)	409 (16.3)	(1.39)	***
	h7	41 (6.0)	137 (9.7)	278 (12.7)	477 (17.1)	649 (19.4)	1244 (27.5)	872 (24.0)	541 (19.5)		
	Sign.	NS	NS	NS	NS	NS	***	NS	NS		
	SED	(1.64)									
All legumes	h3	30 (5.1)	26 (4.5)	39 (5.7)	55 (6.6)	107 (9.6)	312 (15.7)	628 (23.9)	438 (19.8)	(0.76)	***
	h7	33 (5.4)	26 (4.7)	46 (5.9)	54 (6.4)	112 (8.8)	259 (13.9)	818 (25.5)	516 (20.8)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(1.08)									
Total biomass	h3	873 (25.7)	797 (25.7)	905 (28.7)	1287 (35.2)	1850 (42.5)	2135 (45.9)	2839 (53.1)	2388 (48.4)	(1.38)	***
	h7	766 (24.5)	922 (27.9)	1171 (32.5)	1511 (37.7)	2194 (45.9)	3517 (58.9)	4006 (63.0)	3866 (61.3)		
	Sign.	NS	NS	*	NS	*	***	***	***		
	SED	(1.58)									
Tiller popul. density	h3	14801 (88.3)	17111 (99.2)	13746 (90.0)	9977 (83.2))	4392 (60.2)	9107 (88.2)	9189 (82.5)	8216 (83.3)	(4.88)	***
	h7	15713 (89.1)	15596 (92.3)	10354 (73.8)	6304 (66.9)	4214 (59.6)	6023 (69.7)	5770 (63.0)	5023 (64.0)		
	Sign.	NS	NS	*	*	NS	*	**	**		
	SED	(7.49)									
WC growing points	h3	1103 (31.4)	1427 (34.0)	1345 (32.5)	1538 (34.3)	1448 (34.0)	2219 (41.9)	3564 (56.3)	3809 (58.3)	(2.32)	***
	h7	1218 (32.7)	1638 (38.6)	1138 (29.8)	1160 (29.2)	1313 (30.0)	1503 (32.0)	3252 (51.8)	2962 (48.1)		
	Sign.	NS	NS	NS	NS	NS	**	NS	**		
	SED	(3.68)									

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.4.4.3. Tiller population density

TPD was higher on h3 v h7 plots from September to March, with the exception of November, where TPD was similar for both cutting heights (Table 3.25).

3.3.4.4.4. White clover growing point density

GPD in h3 v h7 swards was 47% higher in December and 29% higher in March and showed similar densities in February (Table 3.25).

Table 3.26 Main effects of cutting height on the proportion (%) of different hill country sward components at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	h3	69.5 (8.12)	56.6 (6.31)	49.3 (5.36)	49.2 (5.57))	49.9 (5.74)	51.1 (6.29)	48.4 (6.17)	57.9 (7.16)	(0.240)	***
	h7	67.1 (7.95)	54.5 (6.24)	50.1 (5.38)	48.8 (5.38)	50.3 (5.68)	51.0 (5.99)	52.2 (6.34)	62.7 (7.46)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(0.328)									
White clover	h3	11.6 (2.76)	8.2 (2.13)	6.3 (2.18)	4.8 (1.89)	6.2 (2.25)	14.6 (3.39)	22.1 (4.50)	21.2 (4.24)	(0.253)	***
	h7	13.4 (2.97)	6.0 (1.99)	9.4 (2.24)	4.5 (1.80)	6.3 (2.04)	8.0 (2.41)	22.7 (4.18)	17.4 (3.67)		
	Sign.	NS	NS	NS	NS	NS	**	NS	NS		
	SED	(0.338)									
Weeds	h3	17.1 (3.36)	34.4 (4.47)	44.2 (5.31)	45.9 (5.34)	43.2 (5.03)	33.3 (4.71)	29.4 (4.24)	20.9 (3.63)	(0.284)	***
	h7	17.7 (3.50)	38.4 (4.91)	39.6 (4.73)	46.2 (5.31)	42.8 (4.95)	40.5 (4.94)	25.0 (4.02)	20.0 (3.59)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(0.284)									
All legumes	h3	13.4 (2.98)	9.0 (2.25)	6.5 (2.22)	4.9 (1.93)	6.9 (2.37)	15.6 (3.50)	22.2 (4.51)	21.2 (4.24)	(0.262)	***
	h7	15.3 (3.19)	7.1 (2.18)	10.3 (2.35)	5.0 (1.89)	6.9 (2.13)	8.5 (2.47)	22.7 (4.18)	17.4 (3.67)		
	Sign.	NS	NS	NS	NS	NS	**	NS	NS		
	SED	(0.346)									

*, p<0.05; **, p<0.01; *** p<0.001; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.4.5. *Effect of grass suppression*

3.3.4.5.1. **Sward height**

On average, sward height was greater in H0 v H1 plots (6.2 v 2.7 cm; $p < 0.001$). Heights were different from July onwards, to the end of the season, with the exception of February. Peak sward heights were achieved in November and December (9.4 cm) in the H0 plots, while the maximum height on H1 plots was recorded in February (7.1 cm). Very low sward heights were observed on H1 plots up to November (Table 3.24).

3.3.4.5.2. **Herbage mass and botanical composition**

Total standing biomass

On average, during the season, total biomass was 75% higher on H0 v H1 plots (2469 v 1410 kg DM/ha; $p < 0.001$). Grass suppression was almost complete at this site, and therefore differences were observed throughout the season. At the start of the season, H0 plots had almost 11 times more biomass than H1 plots. Total biomass peaked in February for both treatments, when differences between H0 and H1 were least (21%) (Table 3.27).

Grass

Average grass biomass and grass percentage in the sward were higher on H0 v H1 plots (2335 v 169 kg DM/ha, and 94.9% v 13.7%; $p < 0.001$). Table 3.25 shows that differences remained for the whole season, grass biomass present increasing in the latter part of the season. Grass content in the sward declined rapidly in H1 plots in July and dropped thereafter to levels well below 5% between September and November. In H0 plots, grass percentage was very high (>90%) (Table 3.28).

Legumes

WC average biomass was 3.5 times higher in H1 v H0 (333 v 94 kg DM/ha; $p < 0.001$) and there was 3.3% v 19.5% WC in the H0 v H1 swards ($p < 0.001$), also on average. WC biomass was higher in H1 from October onwards, compared with H0 swards. Peak

productions were achieved in February, and differences observed between WC biomass in H1 v H0 were 64%, 262%, 361%, 290% and 224%, for October, November, December, February and March, respectively (Table 3.27).

H1 plots had always higher WC percent in the sward, compared with H0 plots (Table 3.28), although WC biomass in the sward was low until November. During the main WC growing season (December to March), H1 plots peaked at 36.2% WC, while H0 plots only achieved 8.6%.

Weeds

Grass suppression had a very significant ($p < 0.001$) overall effect on weed biomass. Weed biomass and weed percentage in the sward on H1 plots was higher than on H0 plots (898 v 38 kg DM/ha; 65.6% v 1.8%).

Differences occurred throughout the season, and weed biomass increased steadily from July to December on the H1 plots and declined thereafter (Table 3.27). On H0 plots, weeds were a minor component of the sward, normally ranging between 1-2% of the biomass present, while on H1 plots weeds reached up to 90% of the sward composition (Table 3.28).

3.3.4.5.3. Tiller population density

TPD was significantly higher ($p < 0.001$) on the H0 v H1 plots (17879 v 1562 tiller/m²). Differences in TPD were recorded at all dates. TPD in H0 was initially high (>30000 tiller/m²), while H1 densities show the effective grass suppression by herbicide. TPD in H0 declined after August, with a sharp drop in November and a recovery towards the end of the season, but at much lower densities than at the start of the season. H1 TPD increased between July and December, but showed still much lower values (3.8 times) in March than H0 plots (Table 3.27).

Table 3.27 Main effects of grass suppression on the standing herbage mass (kg DM/ha) of different sward components, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	H0	1447 (37.9)	1420 (37.5)	1476 (38.0)	1769 (41.6)	2514 (49.8)	3024 (54.2)	3403 (57.7)	3629 (59.4)	(1.08)	***
	H1	53 (7.2)	31 (4.0)	16 (2.1)	13 (3.3)	39 (5.7)	162 (12.0)	319 (16.6)	722 (24.6)		
	Sign.	***	***	***	***	***	***	***	***		
	SED	(1.65)									
White clover	H0	21 (4.4)	18 (3.9)	26 (4.6)	28 (4.7)	43 (5.7)	96 (8.9)	294 (16.3)	225 (14.3)	(0.74)	***
	H1	33 (5.3)	29 (4.7)	54 (6.6)	74 (7.9)	156 (11.9)	443 (20.0)	1148 (33.0)	730 (26.3)		
	Sign.	NS	NS	NS	**	***	***	***	***		
	SED	(1.06)									
Weeds	H0	29 (5.1)	27 (4.5)	29 (4.6)	27 (4.6)	20 (3.7)	57 (6.6)	61 (6.5)	57 (6.6)	(1.39)	***
	H1	47 (6.5)	189 (12.8)	471 (20.3)	879 (29.0)	1251 (35.0)	1839 (41.8)	1617 (39.7)	893 (29.2)		
	Sign.	NS	***	***	***	***	***	***	***		
	SED	(1.63)									
All legumes	H0	25 (4.8)	18 (4.0)	27 (4.8)	29 (4.8)	45 (5.8)	96 (8.9)	295 (16.3)	225 (14.3)	(0.76)	***
	H1	38 (5.7)	33 (5.1)	57 (6.8)	80 (8.2)	174 (12.5)	475 (20.7)	1150 (33.1)	730 (26.3)		
	Sign.	NS	NS	NS	*	***	***	***	***		
	SED	(1.08)									
Total biomass	H0	1501 (38.6)	1466 (38.1)	1533 (38.8)	1825 (42.3)	2579 (50.5)	3177 (55.7)	3759 (60.8)	3910 (61.8)	(1.38)	***
	H1	138 (11.6)	253 (15.4)	544 (22.3)	973 (30.6)	1465 (37.9)	2475 (49.1)	3087 (55.3)	2344 (47.9)		
	Sign.	***	***	***	***	***	***	***	***		
	SED	(1.57)									
Tiller popul. density	H0	30391 (172.9)	32268 (178.2)	23737 (151.4)	15028 (118.5)	6249 (77.0)	11162 (103.5)	13732 (115.1)	10471 (100.5)	(4.88)	***
	H1	123 (4.5)	438 (13.3)	363 (12.5)	1254 (31.5)	2357 (42.9)	3967 (54.3)	1226 (30.4)	2768 (46.9)		
	Sign.	***	***	***	***	***	***	***	***		
	SED	(7.49)									
WC growing points	H0	915 (28.6)	983 (29.9)	535 (21.2)	455 (18.5)	350 (16.2)	498 (19.3)	1428 (35.6)	1447 (34.4)	(2.32)	***
	H1	1407 (35.5)	2082 (42.7)	1948 (41.0)	2243 (45.0)	2411 (47.9)	3224 (54.6)	5387 (72.5)	5324 (71.9)		
	Sign.	NS	***	***	***	***	***	***	***		
	SED	(3.68)									

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.28 Main effects of grass suppression on the proportion (%) of hill country sward components at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	H0	96.2 (9.81)	96.7 (9.83)	95.8 (9.78)	96.5 (9.82)	97.3 (9.86)	94.6 (9.72)	89.9 (9.48)	92.0 (9.59)	(0.240)	***
	H1	40.4 (6.26)	14.4 (2.73)	3.6 (0.96)	1.6 (1.13)	3.0 (1.56)	7.6 (2.55)	10.7 (3.03)	28.6 (5.04)		
	Sign.	***	***	***	***	***	***	***	***		
	SED	(0.328)									
White clover	H0	1.5 (1.15)	1.2 (1.01)	1.9 (1.23)	1.6 (1.12)	1.8 (1.15)	3.5 (1.66)	8.6 (2.75)	6.5 (2.37)	(0.253)	***
	H1	23.5 (4.57)	13.0 (3.10)	13.8 (3.19)	7.7 (2.57)	10.8 (3.14)	19.0 (4.14)	36.2 (5.93)	32.1 (5.54)		
	Sign.	***	***	***	***	***	***	***	***		
	SED	(0.338)									
Weeds	H0	2.1 (1.34)	2.1 (1.21)	2.2 (1.23)	1.8 (1.15)	0.8 (0.76)	1.9 (1.21)	1.5 (1.05)	1.6 (1.08)	(0.284)	***
	H1	32.7 (5.51)	70.7 (8.17)	81.7 (8.81)	90.2 (9.49)	85.2 (9.22)	71.9 (8.44)	53.0 (7.21)	39.3 (6.14)		
	Sign.	***	***	***	***	***	***	***	***		
	SED	(0.314)									
All legumes	H0	1.7 (1.26)	1.2 (1.05)	2.0 (1.28)	1.6 (1.16)	1.9 (1.19)	3.5 (1.67)	8.6 (2.75)	6.5 (2.38)	(0.262)	***
	H1	27.0 (4.90)	14.9 (3.38)	14.7 (3.29)	8.2 (2.66)	11.8 (3.30)	20.6 (4.30)	36.3 (5.94)	32.1 (5.54)		
	Sign.	***	***	***	***	***	***	***	***		
	SED	(0.346)									

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.4.5.4. White clover growing point density

On average, GPD in H1 plots was higher than H0 plots (3003 v 826 g.p./m²; $p < 0.001$). There were more WC growing points on H1 plots compared to H0 plots, from August onwards, and an increase was observed especially in the latter part of the season. In March, H1 swards had 3.7 times more WC growing points than H0 swards (Table 3.27).

3.3.4.6. Effect of soil phosphorus status

3.3.4.6.1. Sward height

On average, HP swards had higher heights than LP swards (4.7 v 4.2 cm; $p < 0.01$). There was a *grass suppression* $\times$ *P* $\times$ *date* interaction that affected the P responses for most of the season ($p < 0.01$). On H0, HP plots had higher sward heights than LP plots from August to October, but not thereafter. On H1, HP and LP plots did not differ significantly between August and October, but did so from November to the end of the season in March (Table 3.24).

3.3.4.6.2. Herbage mass and botanical composition

Total standing biomass

Only average season total biomass was slightly (7%) but significantly ($p < 0.05$) higher on HP v LP plots (2001 v 1878 kg DM/ha, Table 3.29).

Grass

Phosphorus effects on grass biomass were generally non-significant ($p > 0.05$), with the exception of September, where HP had 19% more grass biomass than LP (Table 3.29). Grass percentage in the HP swards was significantly higher in August and September and the opposite was the case in March (Table 3.30). However, a significant *grass suppression* $\times$ *P* $\times$ *date* interaction showed that differences in grass percentage in March were largely due to effects observed on H1 plots (34.6% v 22.6%, for H1-LP v H1-HP; $p < 0.05$), while on H0 plots grass percentages in the sward were similar.

Legumes

There was a *grass suppression* $\times$ *P* interaction ($p < 0.05$), which indicated for the season average, that WC biomass was higher on H1-HP v H1-LP plots (419 v 248 kg DM/ha), but similar on the H0 plots. WC biomass was higher in HP v LP swards in December (94% more), February (56%) and March (76%) (Table 3.29). On those same dates, WC percentage in the sward was higher in HP v LP (Table 3.30).

Weeds

Weed percent in the sward was higher on average in LP v HP plots (36.5 v 30.9%; $p < 0.01$). Differences were significant only in August and September. Weed percentage in the sward declined towards the end of the season (Table 3.30).

3.3.4.6.3. Tiller population density

Soil-P status did not have significant ($p > 0.05$) effects on TPD, with the exception of December and March, where LP plots had 18% and 23% more tiller density than HP plots, respectively (Table 3.29).

3.3.4.6.4. White clover growing point density

GPD on HP plots was higher than on LP plots in the latter part of the season. HP plots had 63%, 56% and 48% more GPD than LP plots in December, February and March, respectively (Table 3.29).

Table 3.29 Main effects of soil-P status on the standing herbage mass (kg DM/ha) of different sward components, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	HP	795 (23.1)	751 (21.6)	812 (21.6)	895 (22.7)	1292 (28.0)	1621 (33.3)	1827 (36.6)	2115 (40.7)	(1.08)	***
	LP	705 (21.9)	700 (19.9)	680 (18.5)	886 (22.2)	1261 (27.5)	1564 (33.0)	1895 (37.7)	2234 (43.3)		
	Sign.	NS	NS	*	NS	NS	NS	NS	NS		
	SED	(1.55)									
White clover	HP	27 (4.8)	23 (4.2)	44 (5.8)	57 (6.7)	114 (9.5)	356 (16.9)	880 (27.2)	608 (23.1)	(0.74)	***
	LP	27 (5.0)	24 (4.4)	36 (5.4)	44 (5.9)	86 (8.0)	183 (11.9)	563 (22.2)	346 (17.5)		
	Sign.	NS	NS	NS	NS	NS	***	***	***		
	SED	(1.06)									
Weeds	HP	30 (5.2)	78 (7.3)	223 (11.5)	493 (17.2)	686 (19.8)	920 (23.7)	823 (22.3)	481 (17.9)	(1.39)	***
	LP	46 (6.4)	138 (9.9)	277 (13.4)	413 (16.4)	585 (18.8)	975 (24.7)	855 (23.9)	469 (18.0)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(1.41)									
All legumes	HP	32 (5.3)	26 (4.6)	48 (6.1)	64 (7.0)	125 (9.9)	379 (17.4)	880 (27.2)	608 (23.1)	(0.76)	***
	LP	30 (5.3)	26 (4.5)	37 (5.5)	46 (6.0)	95 (8.5)	192 (12.3)	565 (22.2)	346 (17.5)		
	Sign.	NS	NS	NS	NS	NS	***	***	***		
	SED	(1.07)									
Total biomass	HP	857 (25.6)	855 (26.5)	1082 (31.0)	1452 (37.4)	2103 (45.2)	2921 (53.3)	3530 (59.1)	3204 (55.6)	(1.38)	***
	LP	781 (24.6)	864 (27.1)	994 (30.2)	1346 (35.5)	1941 (43.1)	2731 (51.5)	3315 (57.0)	3050 (54.1)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(1.43)									
Tiller popul. density	HP	15809 (89.4)	16021 (96.7)	11560 (81.5)	7887 (72.4)	4324 (58.9)	6955 (73.2)	6928 (68.9)	5927 (68.1)	(4.88)	***
	LP	14705 (88.1)	16686 (94.8)	12540 (82.3)	8394 (77.6)	4283 (60.9)	8175 (84.7)	8031 (76.6)	7312 (79.2)		
	Sign.	NS	NS	NS	NS	NS	*	NS	NS		
	SED	(5.34)									
WC growing points	HP	1088 (30.9)	1588 (36.7)	1277 (31.0)	1390 (31.9)	1518 (33.2)	2309 (41.8)	4152 (60.5)	4045 (58.8)	(2.32)	***
	LP	1233 (33.2)	1477 (35.8)	1207 (31.2)	1308 (31.5)	1243 (30.8)	1413 (32.1)	2664 (47.6)	2725 (47.6)		
	Sign.	NS	NS	NS	NS	NS	**	***	**		
	SED	(3.40)									

*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.30 Main effects of soil-P status on the proportion (%) of hill country sward components at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	HP	68.4 (8.04)	60.3 (6.75)	51.7 (5.72)	49.3 (5.50)	50.3 (5.72)	50.1 (6.04)	49.1 (6.11)	56.5 (6.96)	(0.240)	***
	LP	68.1 (8.03)	50.8 (5.81)	47.7 (5.02)	48.8 (5.45)	50.0 (5.71)	52.0 (6.23)	51.5 (6.40)	64.1 (7.67)		
	Sign.	NS	**	*	NS	NS	NS	NS	*		
	SED	(0.328)									
White clover	HP	13.7 (2.91)	9.0 (2.25)	10.4 (2.43)	5.1 (1.92)	6.8 (2.27)	15.1 (3.39)	26.2 (4.69)	23.9 (4.45)	(0.253)	***
	LP	11.3 (2.82)	5.2 (1.86)	5.4 (2.00)	4.2 (1.77)	5.8 (2.02)	7.5 (2.41)	18.6 (3.99)	14.7 (3.47)		
	Sign.	NS	NS	NS	NS	NS	**	*	**		
	SED	(0.307)									
Weeds	HP	15.4 (3.19)	29.0 (4.13)	37.1 (4.62)	45.2 (5.19)	42.3 (4.89)	33.8 (4.63)	24.7 (3.84)	19.6 (3.54)	(0.284)	***
	LP	19.4 (3.67)	43.8 (5.25)	46.8 (5.42)	46.9 (5.45)	43.8 (5.09)	40.0 (5.02)	29.8 (4.42)	21.3 (3.68)		
	Sign.	NS	***	**	NS	NS	NS	NS	NS		
	SED	(0.308)									
All legumes	HP	16.2 (3.18)	10.7 (2.49)	11.3 (2.54)	5.5 (2.00)	7.5 (2.36)	16.1 (3.48)	26.3 (4.69)	23.9 (4.45)	(0.262)	***
	LP	12.5 (2.98)	5.4 (1.94)	5.5 (2.03)	4.3 (1.82)	6.3 (2.13)	8.0 (2.48)	18.7 (4.00)	14.7 (3.47)		
	Sign.	NS	NS	NS	NS	NS	**	*	**		
	SED	(0.309)									

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.3.4.7. Effect of nitrogen application

3.3.4.7.1. Sward height

Nitrogen application had no effect on sward height at this site, apart from February, where N0 was taller than N50 (Table 3.24).

3.3.4.7.2. Herbage mass and botanical composition

Total standing biomass, grass and weeds

Nitrogen application had no significant effect ($p > 0.05$) on total standing biomass, grass biomass, weed biomass, and grass- and weed percentage in the sward (Table 3.31, Table 3.32).

Legumes

Nitrogen application had only an overall average season effect on WC biomass and WC percentage in the sward, which was given by a $P \times N$ interaction ($p < 0.05$). According to that, LP-N50 plots had lower WC biomass than LP-N0 plots (133 v 195 kg DM/ha) and also lower WC percentage (7.6% v 10.5%). In February, N0 plots had slightly but significantly ($p < 0.05$) more WC biomass than N50 plots.

3.3.4.7.3. Tiller population density

No effects of nitrogen application were observed on tiller population density at the present site.

3.3.4.7.4. White clover growing point density

N0 plots had higher white clover GPD than N50 plots, but only in November (47% more) and March (23% more) (Table 3.31).

Table 3.31 Main effects of a late autumn nitrogen application on the standing herbage mass (kg DM/ha) of different sward components, tiller density (tiller/m²) and white clover growing point density (g.p./m²), at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	N0	761 (22.7)	724 (20.7)	743 (20.2)	870 (22.2)	1276 (28.0)	1556 (32.9)	1882 (38.1)	2130 (41.5)	(1.08)	***
	N50	739 (22.4)	727 (20.8)	749 (19.9)	912 (22.7)	1277 (27.6)	1630 (33.3)	1841 (36.2)	2220 (42.5)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(1.49)									
White clover	N0	26 (4.8)	24 (4.2)	50 (6.3)	45 (6.2)	118 (9.7)	276 (15.1)	759 (25.7)	486 (20.7)	(0.74)	***
	N50	28 (4.9)	23 (4.3)	30 (4.9)	56 (6.4)	82 (7.9)	262 (13.8)	683 (23.7)	469 (19.9)		
	Sign.	NS	NS	NS	NS	NS	NS	*	NS		
	SED	(0.98)									
Weeds	N0	39 (5.8)	91 (7.9)	258 (12.5)	436 (16.1)	660 (19.4)	964 (24.4)	835 (23.5)	461 (17.7)	(1.39)	***
	N50	37 (5.7)	125 (9.4)	242 (12.3)	471 (17.6)	611 (19.3)	931 (24.0)	842 (22.8)	489 (18.1)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(1.40)									
All legumes	N0	30 (5.2)	26 (4.5)	52 (6.5)	47 (6.3)	127 (10.1)	284 (15.3)	760 (25.7)	486 (20.7)	(0.76)	***
	N50	33 (5.4)	26 (4.6)	33 (5.1)	62 (6.7)	92 (8.3)	287 (14.3)	686 (23.7)	469 (19.9)		
	Sign.	NS	NS	NS	NS	NS	NS	*	NS		
	SED	(0.97)									
Total biomass	N0	829 (25.2)	841 (26.3)	1052 (30.9)	1353 (35.9)	2063 (44.8)	2805 (52.3)	3477 (58.5)	3077 (54.4)	(1.38)	***
	N50	809 (25.0)	878 (27.3)	1024 (30.2)	1445 (37.0)	1981 (43.6)	2848 (52.5)	3369 (57.7)	3177 (55.3)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(1.42)									
Tiller popul. density	N0	15260 (91.0)	16295 (96.8)	11471 (81.0)	8017 (75.3)	4194 (59.1)	8182 (82.4)	7435 (73.8)	6188 (71.5)	(4.88)	***
	N50	15254 (86.5)	16412 (94.6)	12629 (82.8)	8264 (74.8)	4413 (60.8)	6948 (75.4)	7524 (71.6)	7051 (75.9)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED	(5.31)									
WC growing points	N0	1182 (32.2)	1485 (35.1)	1452 (33.8)	1415 (33.0)	1643 (35.6)	1874 (37.7)	3377 (54.6)	3739 (56.4)	(2.32)	***
	N50	1140 (31.9)	1580 (37.4)	1032 (28.4)	1283 (30.4)	1118 (28.4)	1849 (36.2)	3439 (53.5)	3032 (50.0)		
	Sign.	NS	NS	NS	NS	*	NS	NS	*		
	SED	(3.18)									

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

Table 3.32 Main effects of a late autumn nitrogen application on the proportion (%) of hill country sward components at different dates (2000/01). *Ballantrae*.

Sward Component	Treat	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	SED	Sign.
Grasses	N0	69.0 (8.09)	57.3 (6.39)	50.2 (5.47)	49.3 (5.49)	50.3 (5.75)	51.2 (6.17)	50.2 (6.38)	59.5 (7.28)	(0.240)	***
	N50	67.6 (7.98)	53.8 (6.17)	49.2 (5.28)	48.8 (5.46)	50.0 (5.67)	50.9 (6.11)	50.4 (6.13)	61.1 (7.35)		
	Sign.	NS	NS	NS		NS	NS	NS	NS		
	SED				(0.328)						
White clover	N0	11.5 (2.80)	7.4 (2.08)	8.4 (2.41)	4.3 (1.83)	7.5 (2.35)	10.8 (2.99)	22.9 (4.47)	20.3 (4.09)	(0.253)	***
	N50	13.5 (2.93)	6.8 (2.03)	7.3 (2.01)	5.0 (1.86)	5.1 (1.94)	11.7 (2.81)	21.9 (4.22)	18.2 (3.83)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED				(0.300)						
Weeds	N0	18.0 (3.51)	34.1 (4.47)	41.1 (5.00)	46.2 (5.24)	41.7 (4.86)	37.6 (4.88)	26.9 (4.15)	20.2 (3.62)	(0.284)	***
	N50	16.7 (3.34)	38.7 (4.91)	42.7 (5.04)	45.8 (5.41)	44.3 (5.12)	36.2 (4.77)	27.6 (4.1)	20.7 (3.6)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED				(0.308)						
All legumes	N0	13.0 (2.97)	8.5 (2.22)	8.7 (2.48)	4.4 (1.87)	8.0 (2.46)	11.2 (3.02)	22.9 (4.47)	20.3 (4.09)	(0.262)	***
	N50	15.7 (3.20)	7.5 (2.20)	8.1 (2.09)	5.4 (1.95)	5.7 (2.04)	12.9 (2.94)	22.0 (4.23)	18.2 (3.83)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
	SED				(0.298)						

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SED, standard error of the difference of means. Values in brackets are square-root transformations with corresponding SED values also in brackets. Values without brackets are original (untransformed) means.

3.4 DISCUSSION

The magnitude of treatment effects on legume abundance in the sward during the season 2000-2001 was different for the four factors considered. A summary of responses is given in Table 3.33. The main aspects of these responses are discussed for each of the main factors considered.

Table 3.33 Summary of the magnitude of treatment effects on the sward legume content and white clover growing point density at the three experimental sites.

Factor		White clover			Subt. clover		Other legumes		All legumes			WC Growing point density		
Site →		WpN	WpS	Ball	WpN	WpS	WpN	WpS	WpN	WpS	Ball	WpN	WpS	Ball
low cut		0	0	+	---	+	+	0	0	+	+	0	0	+
gr. Supp		+++	++	++++	+++	+	+++	+++	+++++	+++	++++	++++	+++++	+++++
P applic.		++	+	++	0	0	0	0	++	++	++	0	++	+++
N applic.		0	0	0	--	0	-	--	--	0	0	0	-	-

WpN=Waipawa north aspect; WpS=Waipawa south aspect; Ball=Ballantrae. Magnitude of responses based on change of average legume percentage points and WC-GPD change by effect of treatments (0=not sign.; + or - =<5%; ++ or -- = 5-10%; +++ or --- = 10-20%; ++++ or ---- = 20-30%; +++++ or ----- = >30%) during the main legume growing period at each site (WpN=Sep-Dec; WpS=Oct-Feb; Ball=Dec-Mar).

3.4.1. Grass suppression

Grass suppression had the strongest effects of all treatments, and the same pattern of response of legume abundance was recorded at all three sites (see Plate 3.3 and Plate 3.4). Grass suppression increased legume abundance by factors of 2.0, 2.7, and 6.1 (i.e. season average legume content changed from 20.2% to 40.4%, 6.6% to 17.9%, and 3.4% to 20.7%) in Waipawa north aspect, Waipawa south aspect, and Ballantrae, respectively (season average; p<0.001).



Plate 3.3 Grass suppression effect at the Waipawa site (north aspect). Spaces colonized by subterranean clover (September 2000).



Plate 3.4 Grass suppression effect at the Ballantrae site. White clover dominance in H1 plots. (March 2001)

The existence of relationships between grass and legume variables was explored using multivariate canonical correlation analysis. This analysis showed a strong relationship between a canonical variable defined by grass biomass, tiller population density and sward height at different dates, and a second canonical variable defined separately by legume species biomass or white clover growing point density during the main legume growing season. Grass biomass, tiller population density and sward height (especially in spring) had negative relationships with legume biomass or white clover growing point density in the sward, which was given by negative correlations between individual dependent variables and their canonical variate. The average of these squared individual correlations is the corresponding canonical redundancy coefficient, which is given for each group of dependant canonical variables in Table 3.34. The correlations were strongly negative in Ballantrae (-0.80 to -0.95) and lesser so in the Waipawa sites (-0.20 to -0.50).

Table 3.34 Relationship between an *independent canonical variable** composed by grass related individual variables, and *dependent canonical (CAN) variables*** defined by legume related variables, for each of the experimental sites, as obtained from canonical correlation analysis.

	Waipawa north aspect		Waipawa south aspect		Ballantrae	
Dependent Canonical variable**	Canonical r^2 #	Canonical redundancy coefficient ##	Canonical r^2 #	Canonical redundancy coefficient ##	Canonical r^2 #	Canonical redundancy coefficient ##
CAN-WC	0.782 ($p < 0.001$)	0.444	0.731 ($p < 0.05$)	0.502	0.965 ($p < 0.01$)	0.787
CAN-SC	0.888 ($p < 0.001$)	0.374	n/a	n/a	n/a	n/a
CAN-OL	0.726 ($p < 0.05$)	0.272	0.852 ($p < 0.001$)	0.669	n/a	n/a
CAN-TL	0.951 ($p < 0.001$)	0.482	0.823 ($p < 0.001$)	0.489	0.965 ($p < 0.01$)	0.787
CAN-GPD	0.659 ($p < 0.05$)	0.381	0.792 ($p < 0.01$)	0.531	0.957 ($p < 0.05$)	0.832

* Independent canonical variable defined by the following individual original variables: Grass biomass, tiller population density, weed biomass (Only Ballantrae) and sward height at different dates.

** Canonical variable defined by legume related original individual variables within the main legume-growing season at each site:

WC, white clover biomass; SC, subterranean clover biomass; OL, other legumes biomass; TL, total (all) legumes biomass; GPD, white clover growing point density.

Proportion of variance in the dependent canonical variable explained by the independent canonical variable.

Proportion of variance of the individual dependent variables explained by the independent canonical variable.

n/a, not analysed due to low presence of species at a particular site.

The grass-legume relationship was stronger in the denser sward at Ballantrae compared to the sparser Waipawa sites. An indication of this can be obtained from the canonical correlation analysis, where canonical variables constructed with grass-related individual variables always had high canonical relationships (r^2) with canonical variables based on legume-related individual variables. Also, as indicated by the canonical redundancy coefficient (Table 3.34), the canonical “grass” variables were able to predict generally much more of the variance in the individual “legume” variables at Ballantrae, followed by Waipawa south aspect, and least in Waipawa north aspect. For example, while at Ballantrae the canonical variable composed by grass-related variables was able to predict on average 78.7% of the variation in white clover biomass, it only predicted on average 44.4% of the variation observed at Waipawa north aspect. The analysis also showed a more homogeneous relationship for the variables over the season in Ballantrae than at Waipawa. At the Waipawa north aspect, the relationship between grass and legume variables tended to break down at the start of the summer period. At this particular site, low soil moisture by December was limiting growth, and the main legume component was composed of annuals, which were ending their seasonal life cycle. Although in Ballantrae moisture levels also fell to low available water capacity levels during summer, it is likely that soil moisture determinations did not reflect concentrated rainfall events that occurred between sampling dates, especially in February 2001. This may have led to an underestimation of available water for pasture growth at this site.

Apart from the presence of the grass component, other factors, like low soil moisture or the presence of bare ground may have had influence on legume abundance, especially at the Waipawa north aspect. At this site, both on H0 and H1 plots, TPD was low from October onwards. At low TPD (under 5000 grass tiller/m²), little grass competition occurs in ryegrass/white clover swards (Brereton *et al.*, 1985), while severe effects on WC stolon growth occur in late spring and early summer by soil moisture stress, especially on rotationally grazed pastures, where lower grass tiller populations provide

less protection from radiation and higher soil temperature (Woodfield and Caradus, 1996). Legume abundance and persistence is limited in areas of severe moisture deficits (Chapman *et al.*, 1986).

The general increase in legume content in the sward via grass suppression at all sites, was probably connected to early removal of grass competition which generated open spaces that could in turn be colonized by legumes, either through germination and establishment of new seedlings, or appearance of new white clover growing points. Higher GPD and clover branching were observed on swards under autumn grass suppression and it is suggested that the main effect on WC was to allow buds to develop, by allowing light to penetrate to the base of the sward (Patterson *et al.*, 1995). The importance of the light environment around the developing buds of WC has also been established (Thompson, 1993, Teuber and Laidlaw, 1996). More WC growing points at the beginning of spring on plants that were free from grass competition improved the ability of WC to survive (Hay *et al.*, 1984), while increased contribution of WC to dry matter production was available in swards where bare ground was available for colonization (Lambert *et al.*, 1986a).

Only at the Ballantrae site and during the main legume growing season (December to March), were significant ($p < 0.001$) curvilinear relationships found between grass and legume variables (Table 3.35). Legume abundance seemed to be closely linked to grass biomass and density especially at this site. Although weed biomass and percentage also tended to increase significantly in the grass-suppressed swards, relationships between these and WC abundance expressed as biomass or sward content were not significant ($p > 0.05$), and WC density and WC content in the sward was more related to the presence of the grass component. The close relationship observed between GPD and WC biomass and content in the sward stresses the need of pastures to have sufficient numbers of growing points to sustain adequate white clover production.

Table 3.35 Relationships between grass tiller population density and WC growing point density (GPD); WC biomass and WC content in the sward; grass biomass and GPD; GPD and WC biomass; and GPD and WC content; during the main legume-growing period in Ballantrae (Dec-Mar).

Variables	Equation	r and n
TPD v GPD	$GPD = 5205.1 - 0.253 (TPD)$	(r = -0.82; n=32) p<0.001
TPD v WC biomass	$WC = 2991.1 - 297.48 \ln (TPD)$	(r = -0.81; n=32) p<0.001
TPD v WC%	$WC\% = 93.93 - 9.189 \ln (TPD)$	(r = -0.80; n=32) p<0.001
grass DM v GPD	$GPD = 0.0003 (DM)^2 - 2.024 (DM) + 4700$	(r = -0.79; n=32) p<0.001
GPD v WC biomass	$WC = 0.00005 (GPD)^2 + 0.0063 (GPD) + 84.79$	(r = 0.92; n=32) p<0.001
GPD v WC%	$\%WC = 0.0067 (GPD) - 0.892$	(r = 0.96; n=32) p<0.001

Herbicide application generally decreased total standing biomass, especially in Ballantrae, and the increase in legumes could normally not compensate for the decline in grass biomass, at least in the short-term (see Table 3.6, Table 3.16, Table 3.27). It is of interest to establish the patterns of response in a second growth season. However, on the drier north-facing aspect at Waipawa, subterranean clover became the dominant legume species, and swards with grass suppression had both more legume and total biomass in October, and more legume and similar total biomass by late December, compared to unsuppressed pasture (Table 3.6). It is likely that under the cutting conditions of this experiment SC establishment and growth was favoured, due to the absence of grazing animals. Sheep have been reported to select SC from swards, affecting its competitiveness in relation to other species present (Broom and Arnold, 1986). At the same site, a decline of SC in the sward has been reported and attributed to grazing management being unsuitable for SC (Gillingham *et al.*, 1998).

3.4.2. Soil-P status

Soil-P status also affected legume abundance, but effects were less pronounced than those of grass suppression. The most P-responsive species was white clover, while subterranean clover and other legumes were generally non-responsive or had a low response. Since white clover was the dominant legume species in Ballantrae, with higher relative importance compared to the other sites, the impact of P on legume abundance was most marked at that site (Table 3.30, Table 3.33). From average season responses in Ballantrae, there was a suggestion that P effects on white clover were higher on grass suppressed swards, which may indicate that P responses are subordinate to grass competition factors. A sward dominated by low fertility tolerant grasses (as in this experiment), is less suited to coexistence with legumes than e.g. ryegrass, and application of P fertilizer to stimulate legume growth would be less effective (Lambert *et al.*, 1986a). The effects of P on total legume biomass were mostly a reflection of responses on the white clover component. On the Waipawa south aspect, and especially at Ballantrae, P application also produced higher GPD, which is also linked to higher white clover abundance (Table 3.35).

The dry conditions experienced during the main legume growing season, especially at Waipawa, may have contributed to the limited P response observed. During a substantial part of the season, the surface soil especially on the north aspect of the Waipawa site was near or under PWP, which would reduce P uptake. Reduced P responses under low soil moisture have been reported elsewhere (Simpson and Pinkerton, 1989, Dodd *et al.*, 1992), especially when surface soil moisture is limiting (Pinkerton and Simpson, 1986). Lower response to P application has been observed especially on dry north-facing aspects compared to south aspects, which may make P application policies less profitable (Gillingham *et al.*, 1998). Growth of WC was more adversely affected than that of browntop at low P supply, by reducing P availability through direct competition and decreasing soil moisture (Jackman and Mouat, 1973).

3.4.3. Cutting height

The magnitude of the cutting height effect on legume abundance was less than the previously discussed factors. In the cases where cutting height had significant effects, short swards usually had higher legume percentages, however the opposite was the case with subterranean clover in the Waipawa north aspect (especially in December; Table 3.5). Under the cutting conditions of this experiment, SC seemed to compete more successfully with the grasses than other legumes. Higher competitiveness of SC when grown together with grasses has been reported (Du and King, 1999, Lodge, 2000). At Ballantrae, WC content was higher on short swards during late spring and summer, mostly in the H0 treatments, linking the lower legume content to the presence of a taller grass component and higher grass biomass in h7 v h3 plots at that time. Higher cutting generally also produced swards with lower tiller population density at the three sites, especially during the spring-summer period. At Waipawa, GPD was unaffected by cutting height, but in the denser Ballantrae swards there were more white clover growing points on the shorter swards, which in turn may explain the higher WC abundance on those plots. Increased defoliation frequency is associated with higher tiller density and lower canopy height and usually higher WC branching density (Brock and Hay, 1996).

3.4.4. Nitrogen application

At the Waipawa north aspect, nitrogen applied in late autumn affected legume abundance in the sward mostly through negative responses of annual legumes, which produced an overall decrease in total legume biomass and content at that site. These responses were observed on plots without grass suppression, where nitrogen induced an increase of 40% higher total biomass at the first harvest (July), which was mostly composed of extra grass growth. At this stage, this may have triggered greater competition between grasses and establishing subterranean clover seedlings, and consequently affected legume biomass and content in the sward later in the season. In

mixed swards, grasses usually outcompete legumes in their ability to absorb nitrogen (Munoz and Weaver, 1999) and legume content in the sward is negatively affected (Barker *et al.*, 1993a, Gillingham *et al.*, 1998). However, the lack of a negative effect on total legume biomass in H1 plots (grass-suppressed) means that there was no direct effect of the autumn nitrogen application on legumes.

In the Waipawa south aspect, grass responses to nitrogen application occurred later in the season, with up to 30% more grass on non-suppressed swards only. On those plots, the “other legumes” component (mainly suckling clover), but also the low contributing subterranean clover, were reduced in contribution to herbage biomass. Higher TPD along with higher grass biomass on the N50 plots may explain to some extent the lower total legume abundance observed.

At the Ballantrae site, nitrogen application did not have significant impacts on grass biomass and consequently on legume biomass or content in the sward. This is surprising, since in the same environment, previous workers have encountered increased pasture production due to late autumn – early winter N application (Ball *et al.*, 1976, Lambert and Clark, 1986). However, in another study little effect of N applied in autumn on total sward- or white clover dry weight was observed, when using 25 kg N/ha (Caradus *et al.*, 1993). The winter period in Ballantrae had about 40% less rainfall than average, which may have delayed the N responses in winter, and subsequent mineralisation in spring may have annulated N effects. White clover abundance was virtually unaffected by nitrogen application at all sites, but GPD was reduced on N50 plots in the Waipawa south aspect and in Ballantrae. This may be related to grass competition factors in the Waipawa south aspect, but the explanation is less clear at Ballantrae, due to the lack of grass response to nitrogen at this site. Soil nitrogen levels were not recorded in these experiments, but higher soil-N levels may explain part of the lack of response to N fertiliser, especially in Ballantrae, where the dense grass-dominant pasture may be a reflection of the higher N-status of the soil (Lambert *et al.*, 1982).

3.5 CONCLUSIONS

The previous experiments showed short-term responses of legume abundance in the sward to major factors that have been seen to encourage or discourage legume growth. The relative impact of the factors analysed has been highlighted (Table 3.33).

Grass suppression had the greatest impact on legume abundance at all sites, with an increase in legume standing biomass and legume content in the sward when the grass component was initially removed. Soil-P levels also had a significant influence, especially on white clover abundance, and most importantly at the Ballantrae site. Both cutting height and nitrogen application had lower impact, compared to the previous factors, although no direct negative effect on legumes was observed in grass-suppressed swards.

However, it is of interest to establish the continuity of the effects of the main factors (especially grass suppression, under both soil-P regimes), and to observe how these contrasting swards develop in a second season of growth. Moreover, these experiments were evaluated under cutting conditions, and the effect of defoliation by grazing animals is potentially important, since it is likely to have an impact on persistence of legume components in the sward.

Seasonal effects producing different moisture patterns, related to inter-annual variation in rainfall and its distribution probably also play a role in legume abundance and responses may vary under different rainfall regimes. It is therefore of interest to evaluate the highlighted main factor effects for a second season.

Results from the present experiments, together with those of the following experiments, will be contrasted and discussed at the end of Chapter 4, under a broader perspective of a two-year evaluation period for the two most contrasting sites (Waipawa north aspect and Ballantrae). Further, an inter-site comparison will be included in the General Discussion (Chapter 6).

CHAPTER 4

EFFECTS OF GRAZING AND GRASS SUPPRESSION ON LEGUME ABUNDANCE AND PRODUCTION UNDER HIGH AND LOW SOIL-P LEVELS IN SUMMER-MOIST AND SUMMER-DRY HILL COUNTRY

4.1 INTRODUCTION

The production and abundance of legumes in hill country pastures is affected by factors like climatic constraints, grass competition, soil fertility, grazing management, and others, which are most likely to interact. The previous set of experiments (Chapter 3) indicated that, under cutting conditions, suppression of grasses played a major role in stimulating short-term legume abundance in the sward, while soil-P status significantly affected white clover presence. Nitrogen application and cutting height, at least at the levels used, had relatively less impact on legume abundance in the pastures studied.

As a contrast to cutting management conditions, sheep grazing can lead to a reduction in clover content in the sward, by effects of selective grazing, treading and/or excretal return (Frame and Newbould, 1986). White clover productivity under rotational grazing is enhanced by generating a pasture structure with reduced grass tiller density, which allows more space for the expression of white clover, especially if grass competition can be controlled (Brock and Hay, 1996). Variation in frequency and severity of defoliation, and differential grass and legume utilization can occur under grazing conditions, which will in turn also affect legume production and abundance in the sward.

Two experiments, located at the summer-dry and summer-moist sites of Waipawa and Ballantrae, respectively, were adapted and evaluated during the season June 2001-March 2002. The rationale was to select the two most influential factors from the experiments

in the previous year. Therefore, an additional grass suppression treatment was included, while residual effects were tested on the previous year's H1 plots. Soil-P was repeated as a factor. To incorporate grazing effects, an additional factor looking at cutting v grazing was also included. The general objective was to test the effects of simulated rotational grazing and cutting managements on legume abundance and production, under different grass suppression and soil-P regimes, in environmentally contrasting locations. The residual response of legumes to the effects of grass suppression was also tested at each of these hill sites.

4.2 MATERIALS AND METHODS

4.2.1. Sites

The more contrasting sites at Waipawa north aspect (summer-dry) and Ballantrae (summer-moist) were selected for this second set of experiments. The previous year's experimental area at each site was modified to impose the new treatments. The sites and previous management were described in Chapter 3 (Sections 3.2.1 and 3.2.2).

4.2.2. Design and treatments

The two experiments had the same design and treatments, one at each site. The experimental sites had to be adapted to accommodate contrasts in grazing and cutting management, differential grass suppression, and soil-P status.

To measure the effect of grazing, each site was divided into two areas, one being enclosed by a fence (cutting management) and the other defined by a movable electric fence, which allowed intermittent access by sheep to simulate rotational grazing management. The split of grazing and cutting areas required that a balanced set of plots (in relation to year 1 treatments) had to be kept on either area. To check the validity of subdivision, homogeneity of variance was tested for a series of variables measured in Year 1 (e.g. Total biomass, grass biomass and content, legume biomass and content,

etc.). All tests indicated that equality of variance could be assumed. Some spare plots, which were included within the same experimental area in the previous season, had to be added to the present design to allow a balanced set of treatments.

Experiments were analysed as a completely randomised design with a 2 x 3 x 2 factorial array, with two management regimes, three grass suppression levels, and two soil phosphorus levels. Plot size was 1.5 x 2m (3 m²) and each treatment had 4 replicates.

The swards were managed under two contrasting management regimes: 1) Cutting (**C**) by means of a rotary mower with adjustable blade cutting height; and 2) Grazing (**G**) by sheep, in each case after a regrowth period (usually 1 month). After pasture sampling, C plots were cut to a height of 2.5 cm after each harvest. For G plots, the electric fence was removed and pasture was grazed by ewes aiming at similar residual heights compared to C plots. In Waipawa, where paddocks around the experimental area were rotationally grazed, a mob of sheep was introduced to the surrounding paddock when required, and grazing was completed overnight (see Plate 4.1 and Plate 4.2). In Ballantrae, where the surrounding paddock was set-stocked and lower numbers of ewes were available, grazing took 24-48 h, depending on herbage mass.

Three grass suppression levels were tested: 1) resident naturalised pasture (**H0**); 2) pasture treated with herbicide in autumn 2000 (**H1**); and 3) pasture treated with herbicide in autumn 2001 (**H2**). Herbicide applied in 2001 was the same as in the previous season (*haloxyfop*). Herbicide was applied on 31 May (Waipawa) and 1 June 2001 (Ballantrae) using the same procedure described in Chapter 3 (Section 3.2.3).

The same soil-P contrasts used in the first year were maintained: 1) low soil-P status (**LP**) corresponding to the resident P level (initial average Olsen P value of 12.2 µgP/g in Waipawa and 14.1 µgP/g in Ballantrae) and 2) high soil-P status (**HP**). The initial average Olsen P level for the HP plots was 24.9 µgP/g in Waipawa and 25.8 µgP/g in Ballantrae. At the start of the experiment, an extra 15 kg P/ha was applied to all HP plots as triple superphosphate (1 June 2001).

In March 2001 plots were cut to a uniform sward height of 2.5 cm. Prior to treatment establishment in late May 2001, G plots were subjected to grazing and C plots were again cut to a height of 2.5 cm. After an initial regrowth period of 4 weeks, sampling was started at monthly intervals. At some stages, intervals had to be adjusted due to low regrowth.

4.2.3. Measurements

At the start of the experiment, samples were taken for soil fertility determination at 75 mm depth. Gravimetric soil moisture was determined at approximately monthly intervals at 0-50 mm and 50-100 mm depth, using the methodology described in Chapter 3 (gravimetric). To have a more complete description of the soil moisture patterns during the potentially drier period, from September onwards probes were inserted in the soil at different depths at each site, for volumetric soil moisture determination using Time Domain Reflectometry (TDR). At five points around the experimental area of each location, TDR probes of 10, 20, 30 and 40 cm length were inserted into the soil and kept for fortnightly measurements. Accuracy of TDR readings at 10 cm levels were checked with gravimetric determinations.

From the start of the experiment, pre-cutting and pre-grazing grass lamina and legume leaf height was measured on all plots using an HFRO sward stick, and continued thereafter at regular intervals. On G plots, post-grazing grass lamina and post-grazing legume leaf height was also measured. For C plots, a general post-cutting sward height was recorded. Ten readings were taken per plot for each component.

Pasture sampling was based on the procedure described in Chapter 3. Three cores were taken at each sampling date from each plot and taken to the laboratory for processing. To allow herbage accumulation to be estimated, post cutting/grazing herbage mass was also measured, by taking one core per plot. Total and partial herbage accumulation, as well as absolute and relative sward components could therefore be determined. As described in Chapter 3, grass tiller population density (TPD), active white clover



Plate 4.1 Rotational grazing with sheep at the Waipawa north aspect (Spring 2001)



Plate 4.2 Waipawa north aspect. Rotational grazing in summer 2002.

growing point density (GPD), and subterranean clover plant density (SCPD) and SC seedling density, was established from counts from the regrowth of core samples under glasshouse conditions.

Once during the main legume growing period in Waipawa (early October) and Ballantrae (late December), the distribution of root biomass was measured for two contrasting grass suppression treatments. From the grazed area, five 6.1 cm diameter cores at H0-HP (grass dominated) plots, and five cores at H1-HP (legume dominated) plots were taken at 0-40 cm depth. Each core was further cut into eight sub-samples (layers): 0-2.5 cm, 2.5-5 cm, 5-7.5 cm, 7.5-10 cm, 10-15 cm, 15-20 cm, 20-30 cm, and 30-40 cm. All samples were subjected to a root-washing procedure based on the hydropneumatic elutriation system developed by Smucker (1982). Remaining soil particles and non-root material were manually removed.

At the same time, soil samples were taken for the determination of P distribution within the surface soil profile. Contrasting H0 and H1 plots (at HP and LP levels) were selected for sampling, and two samples per plot were obtained, using a 1-inch soil corer, to a depth of 15 cm. Each core was cut into 5 layers: 0-2.5 cm, 2.5-5 cm, 5-7.5 cm, 7.5-10 cm, and 10-15 cm. Sub-samples from each core were bulked for corresponding layers, air-dried, and prepared for available phosphorus determination by extraction with sodium bicarbonate, as described by Olsen (1954).

To have an estimate of earthworm populations at each site, 1 core (7.85 cm diameter) was taken from each H1 plot at each site, to a depth of 30 cm. Cores were disaggregated and extended on a white tray. Earthworms were manually picked, counted, washed and weighed.

4.2.4. Statistical analysis

Data were analysed by analysis of variance (ANOVA) using the general linear model (GLM) procedure (SAS, 1990). Variables generated through sequential sampling over

time, were analysed using also the 'repeated measures' option of SAS. Data were checked for normality and homogeneity of variance, and where assumptions were not met, adequate adjustment of data was made by square-root or natural logarithm transformation.

4.3 RESULTS

4.3.1. General results layout

Results from the two experimental sites are presented separately. As in the previous chapter, climatic conditions and seasonal soil moisture patterns during the experimental period are presented. Results on pasture responses are presented according to main effects. Tables are generally based on these main effect responses, while particular interactions are presented and discussed normally in the text, as they refer usually only to a particular period within the season.

On many occasions data transformation was necessary to comply with normality and homogeneity of variance requirements. When tables contain transformed data, these are stated in brackets, with the corresponding standard error of the mean (SEM), also in brackets. Results are presented and discussed on the original untransformed means, which also appear on the tables, but all statistical significance levels are related to the transformed data.

4.3.2. Waipawa

At this site, swards were sampled seven times, on 1 July, 5 September, 10 October, 21 November, 18 December 2001, and 13 February and 28 March 2002. Pre-harvest standing biomass, botanical composition of the standing biomass and other measurements, are presented on a monthly basis, and for the ease of reading, dates in these cases will be hereafter referred to as July, September, October, November, December, January, February and March, in the text and tables. Since pre- and post-

harvest herbage mass measurements were available, data for herbage mass accumulation and botanical composition of the accumulated herbage could also be generated and these were organised into three periods within the season and are presented as: *Winter* (July to September; 96 days), *Spring* (September to December; 104 days), and *Summer* (December to March, 100 days). Cumulative herbage mass for a particular period was defined as $\{\Sigma (\text{pre harvest herbage mass}_{(n+1)}) - (\text{post harvest herbage mass}_{(n)})\}$.

4.3.2.1. *Climate conditions*

The year 2001/02 had 23% more total rainfall than the previous year (2000/01), and 14% more precipitation than the 35-year average. The autumn period was 12% below average, while the winter period had near-normal rainfall, but uneven distribution, June being 19% above average and September 40% below average. The spring season had very high rainfall (69% above average), especially in October and December, both with almost twice the normal rainfall. The summer period had also more rainfall than average (32% more), January and February having both 80% more rain than the 35-year average, while March was dry (49% below average) (Table 4.1).

Soil temperatures followed similar patterns as the previous season, July being in average 2°C colder, and both December and February were 2.8°C colder than the previous year (Table 4.1). On average, the 2001/02 season was 0.8°C colder than the previous season. As mentioned in Chapter 3, comparisons with 35-year average data from Waipukurau are not precise, as no soil temperature data are available for the present season at that location. In all months, soil temperatures measured at the Waipawa site are higher than the averages corresponding to Waipukurau, especially during the winter, autumn and spring periods, which is probably related to the Waipawa site being located on a north facing aspect.

4.3.2.2. *Soil moisture*

Starting soil moisture levels in autumn were near PWP, but recovered quickly by early June and rose to near FC by the end of July 2001, especially on the surface layer of the soil. Lower-than-normal rainfall in August and September reduced soil volumetric moisture content, reaching a season minimum by the end of September, but never dropping below PWP. High rainfall in October and December made soil moisture levels recover and the surface soil layers were above 50% available water capacity for that period. Surface soil moisture dropped sharply in January, and continued to decrease in the 0-50mm layer until early March. Although rainfall in January and February was well above average, soil moisture in the first 5 cm was recorded below PWP at the dates indicated (Figure 4.1). Between measurement dates, heavy rainfall events occurred on 13 January (59 mm), 10-14 February (100 mm). Evapotranspiration loss from the soil surface may play a major role during the summer period (Grayson *et al.*, 1997). Soil moisture at the 50-100 mm level was much more stable during the same period, and did not reach PWP. Moisture levels recovered slightly in March but declined again in April due to low rainfall.

Table 4.1 Rainfall and soil temperature (10 cm) for the experimental period at Waipawa and average year.

Month	Rainfall (mm)		Soil temperature 10 cm (°C)		
	<i>Waipawa</i>	<i>Waipukurau</i>	<i>Waipawa</i>		<i>Waipukurau</i>
	2001/02 *	Average**	2000/01*	2001/02 *	Average **
May	63	75	14.5	14.3	9.0
June	57	85	11.1	10.6	6.3
July	108	91	11.4	9.4	5.4
August	73	81	11.2	11.1	6.5
September	34	57	13.4	13.7	8.7
October	119	59	16.2	16.6	11.9
November	49	53	16.4	16.4	15.2
December	161	83	21.4	18.6	17.6
January	109	61	21.5	20.8	18.8
February	108	60	22.5	19.7	18.3
March	36	71	20.1	19.8	15.8
April	47	71	16.7	16.3	12.4
Annual	964	847	16.4	15.6	12.2

● Data supplied by Agresearch; ** Average 1945-1980 (NZMS, 1983).

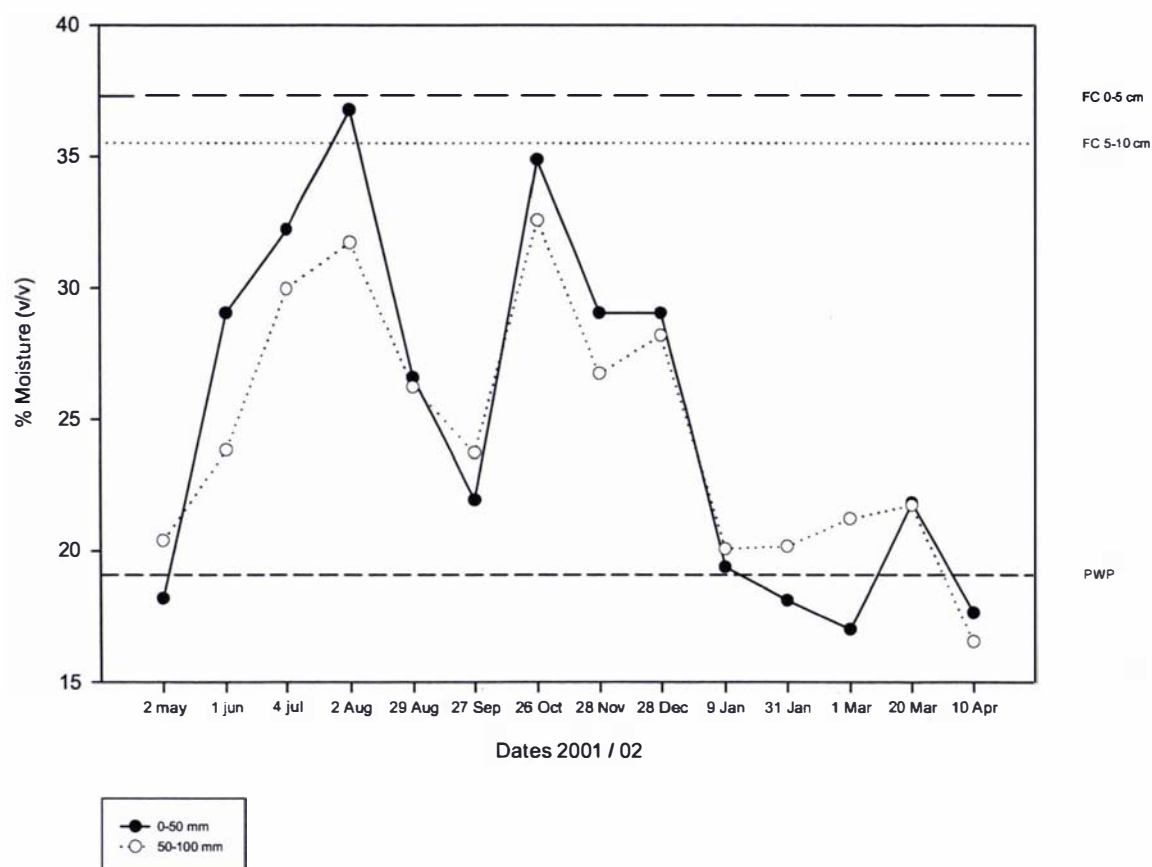


Figure 4.1 Seasonal variation of the volumetric soil moisture of the 0-50 mm and 50-100 mm soil layers in *Waipawa north aspect* (2001/02).

Figure 4.2 shows the patterns of soil moisture variation at different soil depths (measured by TDR) during the spring-summer period in Waipawa. The soil moisture in layers closer to the surface tended to follow the patterns of short term previous rainfall (7 d). Intermediate layers, like the 20-30 cm strata at this site showed a much more stable soil moisture reading during the spring-summer period, and tended to respond more to the amounts of previous 14 or 28 d of rainfall. This layer showed an adequate soil moisture content throughout the summer period, when the surface layers showed limiting moisture contents, especially as seen in Figure 4.1. The 30-40 cm strata showed

a pattern closer to that of the surface layer, which may be related to more free-draining textures at that level.

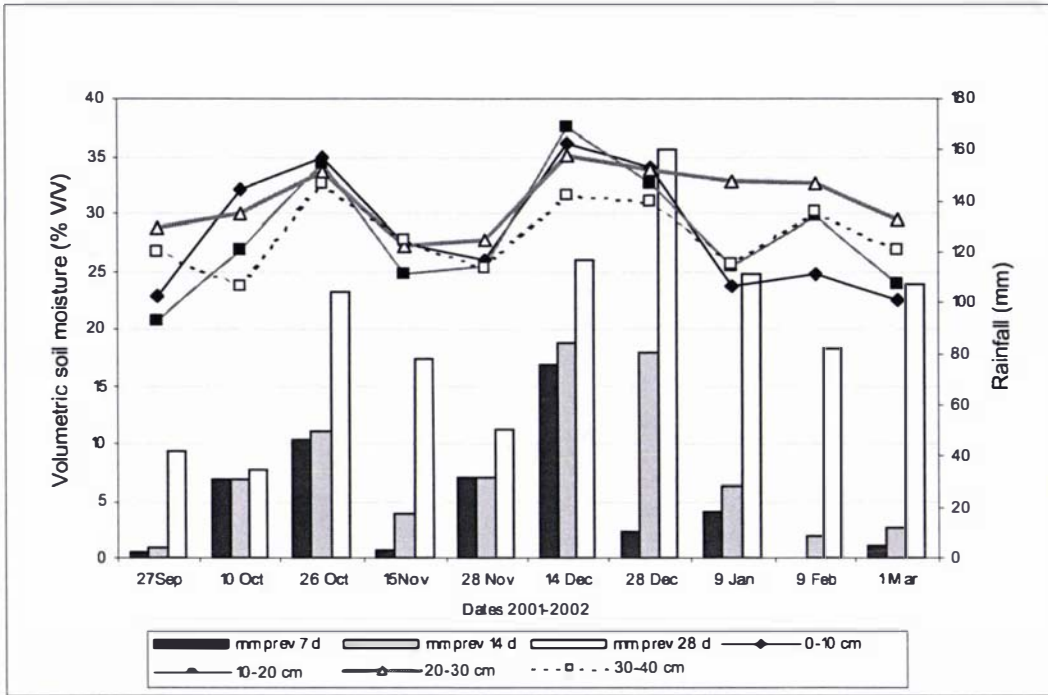


Figure 4.2 Seasonal variation of the TDR volumetric soil moisture (%) at different depths within the 0-40 cm layer during spring and summer, and relationship with rainfall in the previous 7, 14 and 28 days. *Waipawa*

4.3.2.3. Significance of main effects and interactions

The statistical significance of main effects and some interactions of the different variables analysed at the *Waipawa* site are presented in Table 4.2.

Table 4.2 Summary of main effects (Management (*manag*), grass suppression (*supp*) and soil-P status (*phos*)), and interactions statistical significance. *Waipawa*.

Main effect or Interaction	Total .	Grass	Subt. clover	White clover	Other legumes	Weeds	All Leg	Sward height cm	Tiller dens till/m ²
manag	NS	***	***	***	***	**	***	***	NS
supp	***	***	***	***	***	***	***	***	***
phos	***	***	NS	***	NS	NS	***	***	*
date	***	***	***	***	***	***	***	***	***
manag x date	***	***	***	***	***	***	***	***	NS
supp x date	***	***	***	***	***	***	***	***	***
phos x date	***	***	NS	***	NS	**	***	***	***
manag x supp x date	NS	NS	**	***	***	NS	NS	***	NS
manag x phos x date	**	NS	NS	***	NS	NS	**	NS	NS
supp x phos x date	NS	**	***	NS	*	NS	**	NS	NS

Main effect or Interaction	Grass %	Subt. clover %	White clover %	Other legumes %	Weeds %	All Legumes %	Grow.pt. density g.p./m ²	SC density pl/m ²	SC seedl dens
manag	***	***	***	***	***	***	NS	NS	NS
supp	***	***	***	***	***	***	***	NS	NS
phos	***	**	***	*	NS	***	**	NS	NS
date	***	***	***	***	***	***	***	***	***
manag x date	***	***	***	***	***	***	*	*	***
supp x date	***	***	***	***	***	***	***	**	**
phos x date	***	NS	***	**	**	***	*	*	*
manag x supp x date	NS	***	**	NS	NS	NS	NS	NS	NS
manag x phos x date	**	NS	**	NS	NS	NS	NS	NS	NS
supp x phos x date	***	***	NS	NS	NS	***	NS	NS	NS

Main effect or Interaction	Total .	Grass	Subt. clover	White clover	Other legumes	Weeds	All Legumes
manag	***	***	*	**	***	**	*
supp	*	***	***	***	***	***	***
phos	***	NS	NS	***	NS	*	***
date	***	***	***	***	***	***	***
manag x date	***	***	*	***	***	***	**
supp x date	***	***	***	***	***	***	***
phos x date	**	NS	NS	***	NS	*	***
manag x supp x date	NS	NS	NS	***	***	NS	NS
manag x phos x date	**	NS	*	**	NS	NS	***
supp x phos x date	NS	**	***	**	NS	NS	NS

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; date refers to "season" (winter, spring, summer) for herbage accumulation data or "month" (Jul – Mar) for standing biomass, botanical composition and plant density data. Botanical composition by percent is based on standing biomass data. NOTE: Interactions are listed if significant ($p < 0.05$) at least for one variable.

4.3.2.4. Effect of grazing

4.3.2.4.1. Sward height

The main differences between sward heights prior to defoliation were recorded in the spring period. Grass height was greater under cutting management only in October, while grazed plots were taller than cut plots from November to January. Legume pre-cutting height was significantly greater ($p < 0.001$) than pre-grazing height, especially in September and October, but lower in November. Thereafter, legume pre-harvest heights did not differ between treatments (Table 4.3).

Table 4.3 Effect of grazing and cutting management on average pre-defoliation grass and legume height (cm), at different dates (2001/2002). *Waipawa*.

		Factor	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
GRASS	PRE	cutting	3.2	3.6	7.0	15.8	5.9	3.8	8.2	5.8	0.21	***
		grazing	2.8	3.1	4.7	20.1	7.1	4.7	8.3	6.7		
		SEM	0.15	0.22	0.27	0.31	0.25	0.16	0.32	0.23		
		Sign.	NS	NS	***	***	**	***	NS	**		
LEGUME	PRE	cutting	2.2	6.7	11.5	15.5	5.2	3.1	8.1	4.7	0.27	***
		grazing	2.2	3.5	6.1	19.3	5.3	2.6	7.0	4.6		
		SEM	0.12	0.26	0.37	0.46	0.32	0.21	0.44	0.21		
		Sign	NS	***	***	***	NS	NS	NS	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean.

Plots under cutting conditions did not differ significantly in post-defoliation sward height ($p > 0.05$). After grazing, H2 plots had lower grass heights, compared to H0 and H1 that had similar heights, especially from November to the end of the season ($p < 0.001$). From October onwards, the post-grazing height of legumes in H1 and H2 plots was significantly lower than that of H0 swards (Table 4.4).

Table 4.4 Effect of cutting and grazing management, and grass suppression on average post-grazing grass and legume height (cm), and general post-cutting sward height, at different dates (2001/2002). *Waipawa*.

Factor		Treat	Jul	Sep	Oct	Nov	Dec	Feb	Mar	SEM	Sign.
GENERAL	cutting	H0	n/a	1.7	1.8	2.4	2.6	2.4	2.4		
	cutting	H1	n/a	1.6	1.5	2.1	2.5	2.4	2.1		
	cutting	H2	n/a	1.3	1.6	2.0	2.3	2.3	2.4	0.13	***
	SEM			0.11	0.13	0.20	0.17	0.23	0.22		
	Sign.			NS	NS	NS	NS	NS	NS		
GRASS	grazing	H0	n/a	1.6	2.5	4.5	3.8	4.9	4.1		
	grazing	H1	n/a	2.1	2.6	4.1	3.5	4.8	3.2		
	grazing	H2	n/a	1.7	1.8	2.6	2.1	2.9	2.4	0.13	***
	SEM			0.11	0.13	0.20	0.17	0.23	0.22		
	Sign.			*	*	***	***	***	***		
LEGUMES	grazing	H0	0.6	0.9	1.8	3.1	2.6	3.2	2.0		
	grazing	H1	0.5	0.8	1.4	2.2	1.5	1.8	0.7		
	grazing	H2	0.7	0.8	1.0	1.6	1.1	1.2	0.8	0.13	***
	SEM		0.07	0.08	0.18	0.19	0.18	0.26	0.13		
	Sign.		NS	NS	•	***	**	***	**		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. n/a, not available.

4.3.2.4.2. Standing herbage mass and sward composition

Total biomass

Average seasonal standing biomass was similar on C and G plots (2113 v 2087 kg DM/ha, respectively; $p > 0.05$). However, C plots had higher ($p < 0.001$) pre-harvest biomass than G plots in September (+40%) and October (+26%), while the reverse occurred thereafter, where G plots had more standing biomass than C plots in November (+18%), December (+43%) and March (+15%) (Table 4.5).

Grass

On season average, grass standing biomass was 29% higher on G v C plots (686 v 531 kg DM/ha; $p < 0.001$). On a monthly basis, significant differences between G and C occurred in October (+41%), November (+55%) and March (+56%) (Table 4.5).

Overall, pre-harvest grass content was slightly but significantly higher on G v C plots (32.6% v 29.2%; $p < 0.001$). In October, and especially in February and March, grass content in the standing biomass was significantly higher ($p < 0.001$) on G v C plots. C plots had higher grass content than G plots only in December (Table 4.6).

Legumes

Average season WC pre-harvest biomass was significantly higher (15%) on G v C plots (518 v 450 kg DM/ha; $p < 0.001$). At individual dates, differences in WC biomass between G and C were significant only in July (+91%; $p < 0.01$) and October (+70%; $p < 0.001$). At other dates, WC biomass was similar between treatments (Table 4.5). However, a *management x grass suppression x date* interaction showed that in September, November and December, on H1 plots only, G plots had more WC standing biomass than C plots (579 v 870, 1546 v 2172, and 929 v 1282 kg DM/ha, for C-H1 v G-H1, in September ($p < 0.05$), November ($p < 0.001$) and December ($p < 0.05$), respectively).

Overall, G plots had significantly higher WC content in the standing biomass than C plots (25.0 v 21.4%; $p < 0.001$). However, this was mostly from July to October. Thereafter, WC contents were similar between C and G treatments. WC content peaked in December, with a general average of 35.4% (Table 4.6).

SC standing biomass was on average 69% higher on C v G plots (973 v 576 kg DM/ha; $p < 0.001$) during the season. At all dates (except for December, where SC biomass was very low), C plots had higher SC biomass than G plots. Most contrasting differences occurred in September and October, when C plots had 117% and 105% more SC biomass than G plots ($p < 0.001$). After the general decline in SC biomass by December, there was a recovery during the summer period, where C plots showed also higher SC biomass than G plots (Table 4.5). A *management x grass suppression x date* interaction showed that in September C plots had higher SC standing biomass only on H1 (1758 v 563 kg DM/ha, for C-H1 v G-H1; $p < 0.001$) and H2 plots (1276 v 623 kg DM/ha, for C-

H2 v G-H2; $p < 0.001$), but not in H0 plots. The same interaction indicated that in March, SC biomass was higher in C v G plots only at the H0 level (840 v 334 kg DM/ha, for C-H0 v G-H0, respectively, $p < 0.001$).

SC content of the standing biomass was on average significantly higher on C v G plots (41.8% v 28.9%; $p < 0.001$). For all dates, except December, C plots had higher SC content than G plots. Peak SC participation in the standing biomass occurred in October, with 73.2% on C plots v 46.2% on G plots. At the end of the season, SC content on C plots recovered to a level representing one third of the standing biomass at that time (Table 4.6). In September, a *management x grass suppression* interaction showed that SC percentage in the sward was higher on C v G plots only in H1 (62.5 v 27.1%, for C-H1 v G-H1; $p < 0.001$).

The spring average for OL standing biomass was higher (146%) on G v C plots (499 v 203 kg DM/ha; $p < 0.001$). However, OL standing biomass in the sward was important only in November and December, when G plots had 134% and 165% more OL biomass than C plots, respectively. At other dates, OL abundance was very low (Table 4.5). Differences in OL standing biomass between G and C plots were mostly significant in H0 and H2 plots (572 v 1842 and 451 v 1003, for C-H2 v G-H2, and 550 v 927 and 126 v 561 kg DM/ha, for C-H0 v G-H0, in November and December, respectively; $p < 0.001$), and not in H1 plots, as shown by a *management x grass suppression x date* interaction for those dates.

OL content of the standing biomass on G plots reached levels of 23.3% in November and 36% in December, both significantly higher ($p < 0.001$) than those recorded on C plots. At other dates, the OL component was very low, representing less than 1% of the standing biomass (Table 4.6).

TL standing biomass was on season average 15% higher on C v G plots (1509 v 1310 kg DM/ha; $p < 0.001$). At particular dates, however, the comparison varied. In September and October, C plots had 61% and 52% more TL biomass than G plots ($p < 0.001$); while

in November and December, G plots had 8% ($p<0.05$) and 58% ($p<0.01$) more TL biomass than C plots, respectively. In March, C plots had again more TL biomass compared to G plots (+22%; $p<0.05$) (Table 4.5).

Overall, C plots had higher TL content in the standing biomass than G plots (67.4% v 62.6%; $p<0.01$). At individual dates, TL content was always high, and significant ($p<0.001$) differences between treatments (C v G) occurred mostly in October and March (Table 4.6).

Weeds

Overall weed standing biomass was low during the season and, on average G plots had 29% higher weed biomass than C plots (91 v 70 kg DM/ha; $p<0.01$). A higher weed biomass in G v C plots was observed for most of the season, except for July and February, where it was similar (Table 4.5).

Weed content in the standing biomass was on average higher on G v C plots (4.8% v 3.3%; $p<0.001$). Weed content was generally low, and tended to slightly increase in summer (Table 4.6).

Table 4.5 Effect of cutting and grazing management on standing biomass and biomass components (kg DM/ha) at different dates. *Waipawa* (2001-2002).

Component	Treat.	Dates							SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Feb	Mar		
Grass	C	422 (19.1)	414 (18.4)	405 (18.1)	613 (22.7)	361 (17.9)	769 (26.2)	730 (24.7)	(0.83)	***
	G	338 (16.8)	410 (17.7)	570 (21.4)	953 (28.3)	428 (18.2)	967 (29.5)	1140 (31.4)		
	SEM	(0.90)	(0.99)	(1.00)	(1.40)	(0.94)	(1.52)	(1.02)		
	Sign.	NS	NS	*	**	NS	NS	***		
White clover	C	81 (6.6)	271 (14.1)	332 (15.6)	757 (23.4)	466 (18.6)	817 (26.0)	425 (19.0)	(0.80)	***
	G	155 (9.6)	382 (16.5)	564 (21.6)	900 (25.4)	538 (19.1)	650 (24.0)	435 (19.9)		
	SEM	(0.62)	(0.90)	(1.11)	(1.19)	(1.17)	(1.07)	(0.96)		
	Sign.	**	NS	***	NS	NS	NS	NS		
Subt. clover	C	432 (20.3)	1364 (35.4)	2130 (45.7)	1714 (39.6)	62 (7.0)	440 (19.1)	671 (24.0)	(0.97)	***
	G	307 (16.5)	630 (24.0)	1040 (31.2)	1268 (34.3)	83 (7.10)	247 (13.8)	454 (19.7)		
	SEM	(0.86)	(1.33)	(1.32)	(1.30)	(0.74)	(1.35)	(1.13)		
	Sign.	**	***	***	**	NS	**	*		
Other legumes	C	0	5	8 (2.0)	405(17.0)	197(10.8)	7	1	(0.81)	***
	G	0	4	25 (3.6)	949(26.7)	522(18.5)	1	13		
	SEM			(0.36)	(1.33)	(0.95)				
	Sign.			**	***	***				
All legumes	C	513 (22.1)	1640 (38.7)	2470 (49.4)	2876 (53.2)	724 (25.5)	1241 (30.2)	1098 (32.7)	(0.93)	***
	G	462 (20.1)	1017 (31.3)	1629 (40.0)	3117 (55.7)	1144 (32.0)	897 (29.1)	902 (29.7)		
	SEM	(0.81)	(1.25)	(0.93)	(0.67)	(1.35)	(2.10)	(0.83)		
	Sign.	NS	***	***	*	**	NS	*		
Weeds	C	34 (4.1)	41 (4.9)	20 (3.3)	102 (7.9)	17 (3.0)	218 (10.9)	62 (5.7)	(0.78)	***
	G	59 (5.2)	72 (7.1)	100 (8.0)	149(10.6)	9 (1.8)	111 (7.6)	133 (10.2)		
	SEM	(0.77)	(0.55)	(0.60)	(0.87)	(0.35)	(1.62)	(0.70)		
	Sign.	NS	**	***	*	*	NS	***		
Total	C	969	2095	2895	3590	1102	2250	1888	98.9	***
	G	859	1498	2300	4219	1581	1975	2175		
	SEM	53.1	116.4	105.1	145.4	82.1	146.9	88.4		
	Sign.	NS	***	***	**	***	NS	**		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for total herbage standing biomass (no transformation needed). Other legumes data for Jul-Sep and Feb-Mar, were not analysed, due to very low and erratic appearance.

Table 4.6 Effect of cutting and grazing management on botanical composition of the standing biomass (% by weight) at different dates. *Waipawa* (2001-2002).

Component	Treat.	Jul	Sep	Oct	Dates Nov	Dec	Feb	Mar	SEM	Sign.
Grass	C	40.1	22.8	14.0	17.9	37.6	36.6	35.0	1.63	***
	G	39.7	23.9	23.8	21.2	24.7	48.0	46.5		
	SEM	3.21	1.48	1.29	1.51	2.04	2.60	1.71		
	Sign.	NS	NS	***	NS	***	**	***		
White clover	C	7.6 (2.18)	11.9 (3.11)	11.8 (2.93)	20.3 (3.88)	36.7 (5.42)	33.1 (5.46)	28.3 (4.75)	(0.160)	***
	G	14.2 (3.10)	23.7 (4.24)	24.3 (4.52)	21.4 (3.92)	34.0 (4.93)	33.1 (5.50)	24.1 (4.55)		
	SEM	(0.193)	(0.226)	(0.219)	(0.224)	(0.315)	(0.205)	(0.229)		
	Sign.	**	**	***	NS	NS	NS	NS		
Subt. clover	C	49.4	63.1	73.2	47.5	6.4	20.0	33.0	1.75	***
	G	39.4	46.4	46.2	30.6	4.8	12.7	22.3		
	SEM	3.05	1.84	2.53	2.03	0.59	2.18	2.01		
	Sign.	*	***	***	***	NS	*	***		
Other legumes	C	0.0	0.4	0.3 (0.38)	11.5 (2.84)	17.5 (3.32)	0.4	0.1	(0.157)	***
	G	0.0	0.4	1.2 (0.78)	23.3 (4.17)	36.0 (4.85)	0.0	0.5		
	SEM			(0.080)	(0.211)	(0.233)				
	Sign.			**	***	***				
All legumes	C	57.0 (7.48)	75.4 (8.55)	85.3 (9.22)	79.4 (8.89)	60.6 (7.60)	52.6 (7.14)	61.4 (7.74)	(0.149)	***
	G	53.6 (7.15)	70.4 (8.34)	71.6 (8.41)	75.4 (8.64)	74.7 (8.16)	45.9 (6.67)	46.9 (6.68)		
	SEM	(0.242)	(0.085)	(0.074)	(0.104)	(0.318)	(0.174)	(0.145)		
	Sign.	NS	NS	***	NS	NS	NS	***		
Weeds	C	2.9 (1.26)	1.8 (1.04)	0.7 (0.62)	2.7 (1.30)	1.8 (0.99)	9.8 (2.67)	3.7 (1.42)	(0.185)	***
	G	6.7 (1.86)	5.6 (1.93)	4.6 (1.73)	3.4 (1.61)	0.6 (0.49)	6.1 (1.76)	6.6 (2.25)		
	SEM	(0.258)	(0.137)	(0.115)	(0.129)	(0.106)	(0.343)	(0.156)		
	Sign.	NS	***	***	NS	**	NS	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass and subclover (no transformation needed). Other legumes data for Jul-Sep and Feb-Mar were not analysed, due to very low and erratic appearance.

4.3.2.4.3. Population density

Tiller population density did not differ significantly ($p > 0.05$) between C and G treatments. From an initial average of 5951 tiller/m², TPD declined to a minimum of 1294 tiller/m² in November, remained low in December and recovered in summer (Table 4.7).

White clover GPD was higher ($p<0.05$) on G plots by 71% in October and 130% in November, compared to C plots. During the remainder of the season, GPD on both treatments were similar. Maximum GPD were achieved in February (Table 4.7).

Subterranean clover plant density (SCPD) was significantly higher ($p<0.05$) on C v G plots from July to November, with the exception of September, where SCPD did not achieve significant differences. SCPD was very low in December and recovered thereafter to similar values to those recorded in winter and early spring (Table 4.7).

Table 4.7 Effect of grazing and cutting management on grass tiller population density (TPD; tiller/m²), white clover growing point density (GPD; g.p./m²), subterranean clover plant density (SCPD; pl/m²) at different dates, and summer SC seedling density (SC seedl./m²). *Waipawa* (2001/2002).

Factor	Treat	Jul	Sep	Oct	Nov	Dec	Feb	Mar	SEM	Sign.
TPD	C	5569 (61.6)	5456 (62.3)	3774 (52.6)	1463 (29.2)	2806 (46.0)	5188 (59.9)	6234 (70.0)	(4.92)	***
	G	6333 (65.7)	5788 (65.1)	6707 (68.9)	1124 (26.2)	1986 (34.0)	5159 (58.2)	4290 (59.9)		
	SEM	(6.19)	(6.19)	(6.05)	(4.09)	(4.57)	(6.62)	(5.66)		
	Sign.	NS	NS	NS	NS	NS	NS	NS		
GPD	C	662 (19.1)	972 (25.8)	1108 (25.9)	845 (21.5)	1320 (31.0)	2287 (41.0)	1710 (33.7)	(3.38)	***
	G	1342 (26.4)	1580 (31.4)	1899 (37.0)	1945 (31.3)	1425 (26.2)	2257 (41.8)	1878 (37.4)		
	SEM	(3.19)	(3.11)	(3.35)	(3.87)	(3.14)	(3.96)	(5.11)		
	Sign.	NS	NS	*	*	NS	NS	NS		
SCPD	C	328 (5.650)	263 (5.240)	205 (5.190)	130 (4.510)	13 (0.540)	510 (5.540)	443 (4.950)	(0.3190)	***
	G	197 (4.790)	163 (4.590)	147 (4.400)	92 (3.680)	5 (0.340)	428 (4.970)	202 (4.160)		
	SEM	(0.2470)	(0.281)	(0.2830)	(0.3030)	(0.2810)	(0.3830)	(0.4590)		
	Sign.	*	NS	*	*	NS	NS	NS		
SC seedl.	C					500 (5.686)	2642 (7.514)	95 (2.802)	(0.3980)	***
	G					345 (5.193)	772 (4.944)	40 (2.127)		
	SEM					(0.2652)	(0.3403)	(0.5061)		
	Sign.					NS	***	NS		

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations either square root (TPD and GPD) or log (SCPD and SC seedl. density), with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

The wet summer conditions at this site triggered SC germination in December, and SC seedlings density was recorded over the summer period. C plots had almost 2.5 times more SC seedling density in February ($p < 0.001$), compared to G plots. Both treatments had similar seedling densities in December and March. At this last date, SC seedling density was very low.

4.3.2.4.4. Herbage accumulation

Total herbage accumulation

Total herbage accumulation was 34% higher on G plots compared to C plots. Differences were greatest in spring (50% more DM/ha) but were also apparent in summer (23% more). No significant differences ($p > 0.05$) were observed during the winter period (Table 4.8).

Grass

Swards under grazing produced significantly ($p < 0.001$) more grass than those under cutting in spring (123% more) and summer (73% more). Total grass accumulation on G plots was 85% more than that on C plots (Table 4.8). In relative terms, based on herbage accumulated, grass content in G swards was significantly higher in spring ($p < 0.01$) and summer ($p < 0.001$), and as a seasonal average (34 v 26%; $p < 0.001$) (Table 4.9).

Legumes

Table 4.8 shows that WC production on G plots was significantly higher ($p < 0.001$) than on C plots in winter (126% more) and spring (78% more). No significant treatment differences were recorded over the summer period ($p > 0.05$). Overall, G plots had 41% more WC accumulation than C plots ($p < 0.001$). Plots under cutting had significantly ($p < 0.05$) more SC than G plots in spring, while total SC accumulation in the season was also higher on C plots (28% more; $p < 0.01$). A significant *management* $\times$ *P* $\times$ *date* interaction ($p < 0.05$) showed that, in winter, SC production was higher on C plots, but only on the HP treatments (876 v 441 kg DM/ha, for C-HP v G-HP, respectively; $p < 0.05$). Swards under grazing management had almost three times more “other legumes” (OL) accumulation in spring (mostly suckling clover and clustered clover) ($p < 0.001$). Production of OL in winter and summer was very low, and could not be statistically analysed. Considering all legumes (TL), G plots produced 13% more TL

than C plots, but differences were only significant ($p < 0.01$) in spring (31% more TL production).

On season average, WC percentage based on total herbage accumulated, did not differ between C and G, with an average level of 23.5%. However, WC content was higher in G ν C in winter and spring, and reached similar levels on both treatments by summer, with an average of almost 30% (Table 4.9). SC dominated swards especially on C plots in winter and spring, with contents that reached 60% and 52% of total herbage accumulated, respectively, and differed significantly from those on G plots, with 44% and 28%, respectively ($p < 0.001$). C plots still had more SC content in summer ($p < 0.05$). Overall, SC content in C plots was higher than in G plots ($p < 0.001$). Other legumes were only important in G plots, where they accounted for 25% of total biomass accumulated in spring. The overall average legume content was higher ($p < 0.001$) on C plots ν G plots (70% ν 61%), and differences occurred in all periods (Table 4.9).

Weeds

Although the weed component was only minor at this site, G plots had overall 75% more weed production than C plots. This was a reflection of a significantly ($p < 0.001$) higher weed component in winter and spring on those plots (Table 4.8).

Weed content in the sward only accounted on average for 4.1% of the total biomass produced (Table 4.9). G plots had higher ($p < 0.001$) weed contents in winter and spring, but similar in summer, at an average level of 6.5%.

Table 4.8 Effect of grazing and cutting management on seasonal and total herbage mass accumulation and botanical composition of herbage accumulated (kg DM/ha). *Waipawa* (2001/2002).

Component	Treat	Season			SEM	Sign.	Total
		Winter	Spring	Summer			
Grass	C	279 (5.215)	623 (6.095)	968 (6.564)	(0.0937)	***	1871 (7.264)
	G	402 (5.551)	1391 (6.783)	1672 (7.249)			3466 (7.920)
	SEM	(0.1548)	(0.1136)	(0.1137)			(0.1016)
	Sign.	NS	***	***			***
White clover	C	161 (10.2)	732 (22.9)	919 (27.4)	(0.77)	***	1811 (37.8)
	G	364 (15.3)	1301 (31.8)	885 (28.0)			2551 (45.9)
	SEM	(0.93)	(1.27)	(1.15)			(1.60)
	Sign.	***	***	NS			**
Subt. clover	C	758 (25.8)	1789 (41.2)	659 (23.8)	(1.37)	***	3207 (55.4)
	G	539 (22.1)	1402 (35.7)	564 (21.9)			2505 (48.4)
	SEM	(1.42)	(1.83)	(1.43)			(1.99)
	Sign.	NS	*	NS			*
Other legumes	C	2.8	240 (13.3)	4.8			248 (13.5)
	G	2.4	905 (25.4)	10.5			918 (25.6)
	SEM	1.18	(1.25)	2.76			(1.27)
	Sign.		***				***
All legumes	C	921 (28.3)	2762 (51.6)	1583 (38.3)	(1.38)	***	5266 (71.2)
	G	906 (28.6)	3608 (59.0)	1460 (37.3)			5973 (76.3)
	SEM	(1.45)	(1.66)	(1.34)			(1.71)
	Sign.	NS	**	NS			*
Weeds	C	29 (4.2)	61 (6.8)	170 (10.7)	(0.73)	***	260 (14.2)
	G	90 (7.6)	165 (11.9)	201 (12.6)			455 (19.7)
	SEM	(0.64)	(0.62)	(1.24)			(1.19)
	Sign.	***	***	NS			**
Total	C	1230	3445	2721	184.8	***	7397
	G	1397	5163	3334			9894
	SEM	118.5	291.7	171.0			424.5
	Sign.	NS	***	*			***

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass (log) and total herbage accumulation (no transformation needed). Other legumes data for winter and summer were not analysed, due to very low and erratic appearance.

Table 4.9 Effect of grazing and cutting management on the seasonal proportion of sward components (%) based on herbage accumulated. *Waipawa* (2001/2002).

Component	Treat	Season			SEM	Sign.	Average
		Winter	Spring	Summer			
Grass	C	26.9	19.4	36.3	1.20	***	26.3
	G	28.9	25.8	49.3			34.3
	SEM	1.85	1.56	2.02			1.47
	Sign.	NS	**	***			***
White clover	C	10.8 (2.91)	18.9 (3.81)	32.3 (5.28)	(0.091)	***	22.1 (4.31)
	G	20.4 (3.94)	24.7 (4.46)	26.8 (4.90)			24.8 (4.59)
	SEM	(0.196)	(0.211)	(0.207)			(0.185)
	Sign.	***	*	NS			NS
Subt. clover	C	60.1	52.4	24.4	1.66	***	44.1
	G	44.3	28.0	17.3			26.3
	SEM	2.15	1.80	2.01			1.32
	Sign.	***	***	*			***
Other legumes	C	0.3	1.1 (2.36)	0.2			0.5 (1.67)
	G	0.3	25.1 (3.66)	0.3			14.3 (2.66)
	SEM	0.11	(0.168)	0.10			(0.131)
	Sign.		***				***
All legumes	C	71.2	78.9	56.9	1.32	***	70.1
	G	64.9	71.2	44.5			61.2
	SEM	1.77	1.66	2.29			1.58
	Sign.	*	**	***			***
Weeds	C	2.0 (1.17)	1.7 (1.13)	6.8 (2.11)	(0.128)	***	3.6 (1.67)
	G	6.1 (2.10)	3.0 (1.64)	6.2 (2.22)			4.5 (1.98)
	SEM	(0.159)	(0.072)	(0.222)			(0.127)
	Sign.	***	***	NS			NS

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Other legumes data for winter and summer were not analysed, due to very low and erratic appearance.

4.3.2.5. Effect of grass suppression

4.3.2.5.1. Sward height

Pre-defoliation grass height was significantly lower ($p < 0.001$) in H2 plots, compared to either H0 or H1, for most of the season. In December, all three treatments differed significantly ($p < 0.001$), H1 being the tallest sward and H2 the lowest. In March, H0 was

significantly ($p < 0.001$) higher than H1 and H2. The tallest grass heights were achieved in spring, especially in November (Table 4.10).

Legume pre-defoliation height was also generally lower on H2 plots, compared to H1 and H0. In November, when the tallest heights were recorded, treatments did not differ significantly ($p > 0.05$), while a similar situation occurred in February. In December, H2 had the lowest sward height, followed by H0 and highest in H1 ($p < 0.001$). In March however, H1 plots had the lowest height, compared to H0 plots, which were the tallest ($p < 0.01$) (Table 4.10).

Table 4.10 Effect of grass suppression on average pre-defoliation grass and legume height (cm), at different dates (2001/2002). *Waipawa*.

	Factor		Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
GRASS	PRE	H0	3.3	3.7	6.8	18.7	6.6	4.4	8.6	7.4	0.26	***
		H1	3.7	4.0	7.7	18.5	8.1	4.8	9.1	5.8		
		H2	2.0	2.3	3.3	16.5	4.8	3.5	7.1	5.6		
		SEM	0.18	0.27	0.33	0.38	0.30	0.20	0.39	0.28		
		Sign.	***	***	***	***	***	***	**	***		
LEGUME	PRE	H0	2.2	5.3	9.3	16.7	5.3	3.2	7.8	5.7	0.33	***
		H1	2.6	6.3	9.5	17.9	7.0	3.4	8.4	3.4		
		H2	1.7	3.7	7.7	17.6	3.5	2.0	6.5	4.8		
		SEM	0.15	0.32	0.46	0.56	0.39	0.25	0.54	0.26		
		Sign.	**	***	*	NS	***	**	NS	**		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean.

4.3.2.5.2. Standing herbage mass and sward composition

Total biomass

Overall, pre-harvest standing biomass was similar in H0 and H1 plots, and lower on H2 plots (2246, 2211 and 1842 kg DM/ha, for H0, H1 and H2, respectively; $p < 0.001$). Initial total biomass on H2 was very low, but recovered thereafter and, between October and December, total pre-harvest biomass was similar on all treatments ($p > 0.05$). Peak total standing biomass was recorded in November, with a general average of 3904 kg DM/ha. At the end of the season, H0 had the highest total standing biomass, which

differed significantly ($p < 0.001$) from that in H1 or H2. At that same time (March), H2 had significantly ($p < 0.05$) higher total biomass than H1 (Table 4.11).

Grass

Average grass pre-harvest biomass was significantly different between all treatments (1049, 532 and 245 kg DM/ha, for H0, H1 and H2, respectively; $p < 0.001$). These differences were maintained between July and October, and also in December ($p < 0.001$). In November, grass biomass was similar in H0 and H1, but lower in H2. In February and March, standing biomass in H1 and H2 was similar ($p > 0.05$), but significantly higher ($p < 0.001$) in H0 (Table 4.11).

Overall, grass content of the standing biomass followed the pattern $H0 > H1 > H2$ (50.3%, 24.7% and 17.5%, respectively; $p < 0.001$). H0 plots had the highest grass content at all dates, when compared to either H1 or H2 plots, except for November, when H0 and H1 plots had similar grass content in the standing biomass. Between September and December, H2 plots had significantly ($p < 0.001$) lower grass content than H0 or H1 plots. In July, February and March, H1 and H2 plots had similar ($p > 0.05$) grass content (Table 4.12).

Legumes

Overall, WC standing biomass was significantly higher on H1 plots, compared to H0 or H2, which had similar WC biomass (222, 970 and 259 kg DM/ha, for H0, H1 and H2, respectively; $p < 0.001$). At all dates, H1 plots had significantly ($p < 0.001$) higher WC standing biomass compared to both H0 and H2. H0 and H2 had generally similar WC biomass, except for September and October, where H2 had more WC biomass than H0 plots (Table 4.11).

On season average, WC content of the standing biomass followed the pattern $H1 > H2 > H0$ (44.8%, 14.8% and 10.0%, respectively; $p < 0.001$). In September and October, the same pattern previously indicated was observed. At all other dates, H0 and H2 had similar ($p > 0.05$) WC content, while in H1 it was significantly ($p < 0.001$) higher,

compared to the two other grass suppression levels. WC content in the standing biomass was especially high in H1 from November onwards, with a peak of 72% in December (Table 4.12). A *management x grass suppression x date* interaction showed that in September, in C plots H1 and H2 had similar WC contents, which were significantly higher than that on H0 (20.2, 12.8 and 2.6%, respectively; $p < 0.001$); and on G plots H1 had higher WC content than H2 or H0 (47.8, 13.1 and 10.2%, respectively, $p < 0.001$).

Average annual SC standing biomass was significantly higher in $H2 > H0 > H1$ (958, 782 and 583 kg DM/ha, respectively; $p < 0.001$). SC biomass was similar in all treatments in September ($p > 0.05$). In October, H0 and H1 had similar SC biomass, while in November SC biomass was higher in $H2 \nu H0$. Both in October and November, H1 had significantly lower SC biomass than H0 or H2 (at least $p < 0.05$). In summer, the highest SC standing biomass was recorded on H2 plots, compared to the other treatments (Table 4.11).

Overall, SC percentage of the standing biomass was highest in $H2 > H0 > H1$ (49.5%, 31.9% and 24.7%, respectively; $p < 0.001$). At all dates (except December, where SC percentage was low), H2 had significantly more SC content compared to H0 or H1 (generally $p < 0.001$). In the early (July-September) and late (February-March) parts of the year, H0 and H1 had similar SC content in the standing biomass (Table 4.12).

Both in November and December (the only period where OL standing biomass was relevant), H1 showed very low OL biomass compared to either H0 or H2 ($p < 0.001$). H2 plots had higher OL standing biomass compared to H0 plots in November ($p < 0.05$) and December ($p < 0.001$). OL biomass declined sharply to very low levels in all treatments after December (Table 4.11).

In November and December, OL content of the standing biomass in $H2 > H0 > H1$ (at least $p < 0.05$). OL content in H1 plots was extremely low, with a peak value of 2.2% in November (Table 4.12).

Overall, TL standing biomass followed the pattern $H1=H2>H0$ (1562, 1498 and 1168 kg DM/ha, respectively; $p<0.001$). In July and September H1 had the highest TL standing biomass, while in October H1 and H2 had similar TL biomass, which was significantly higher than that of H0 ($p<0.01$). In November, the highest TL standing biomass of the season was recorded for all treatments, H2 having significantly ($p<0.001$) more TL biomass than H0 and H1. TL biomass declined in December for all treatments and in February TL biomass was similar in all grass suppression treatments ($p>0.05$). In March, H2 showed significantly ($p<0.01$) more TL standing biomass than H0 and H1, which were similar (Table 4.11).

On season average, TL percentage of the standing biomass was $H2>H1>H0$ (77.0%, 69.7% and 48.3%, respectively; $p<0.001$). TL content was generally high in all treatments. Between September and November, H2 peaked at TL content values close to 90% of total standing biomass, and was significantly ($p<0.001$) higher than H1 and H0. H0 had the lowest TL content at all dates, except for November, where it was similar to H1. H1 and H2 plots had similar TL content in July and also from December onwards (Table 4.12).

Weeds

Overall, H1 and H2 plots had similar weed standing biomass, in both cases significantly higher than H0 plots (29, 113 and 99 kg DM/ha, for H0, H1 and H2, respectively; $p<0.001$). Weed standing biomass was generally very low, especially on H0 plots. H2 plots tended to increase in weed standing biomass up to November, where H2 and H1 became similar in weed biomass. In March, H2 had the highest weed standing biomass, followed by H1 and finally H0 (at least $p<0.05$) (Table 4.11).

Table 4.11 Effect of grass suppression on standing biomass and biomass components (kg DM/ha) at different dates. *Waipawa* (2001-2002).

Component	Treat.	Dates							SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Feb	Mar		
Grass	H0	648 (25.2)	774 (27.5)	874 (29.3)	1153 (33.0)	738 (26.4)	1325 (36.0)	1831 (42.2)	(1.01)	***
	H1	375 (18.8)	387 (18.6)	495 (21.3)	961 (29.6)	312 (16.8)	693 (25.0)	500 (21.5)		
	H2	116 (9.9)	75 (8.0)	94 (8.5)	235 (13.8)	134 (10.9)	585 (22.5)	474 (20.6)		
	SEM	(1.10)	(1.21)	(1.23)	(1.71)	(1.15)	(1.87)	(1.25)		
	Sign.	***	***	***	***	***	***	***		
White clover	H0	31 (4.5)	108 (8.8)	131 (11.2)	366 (17.2)	177 (11.3)	437 (19.5)	303 (16.3)	(0.98)	***
	H1	309 (16.6)	724 (26.1)	884 (28.2)	1859 (41.1)	1105 (32.3)	1250 (34.1)	662 (25.3)		
	H2	15 (3.2)	146 (11.1)	329 (16.4)	260 (15.0)	223 (12.9)	513 (21.4)	325 (16.9)		
	SEM	(0.76)	(1.11)	(1.36)	(1.45)	(1.43)	(1.31)	(1.18)		
	Sign.	***	***	***	***	***	***	***		
Subt. clover	H0	429 (20.3)	881 (28.0)	1631 (39.5)	1571 (38.9)	99 (8.3)	278 (15.5)	587 (22.9)	(1.19)	***
	H1	441 (20.5)	1161 (31.6)	1226 (33.2)	811 (26.8)	22 (3.4)	211 (12.1)	208 (13.2)		
	H2	237 (14.5)	949 (29.4)	1897 (42.6)	2091 (45.2)	97 (9.5)	541 (21.8)	893 (29.4)		
	SEM	(1.05)	(1.63)	(1.62)	(1.60)	(0.91)	(1.66)	(1.38)		
	Sign.	***	NS	***	***	***	***	***		
Other legumes	H0	0	5	32 (4.8)	738(25.6)	343(16.6)	7	16	(1.00)	***
	H1	0	1	1 (0.3)	85 (7.2)	9 (1.8)	1	0		
	H2	0	9	16 (3.4)	1207(32.7)	727(25.6)	4	6		
	SEM			(0.44)	(1.63)	(1.17)				
	Sign.			***	***	***				
All legumes	H0	460 (21.1)	994 (30.0)	1796 (41.6)	2676 (51.6)	620 (23.9)	722 (25.9)	906 (29.6)	(1.14)	***
	H1	750 (27.1)	1886 (42.9)	2111 (45.7)	2755 (52.1)	1136 (32.9)	1428 (31.6)	870 (29.3)		
	H2	252 (15.0)	1104 (32.1)	2242 (46.8)	3559 (59.4)	1047 (29.5)	1058 (31.5)	1224 (34.7)		
	SEM	(0.99)	(1.54)	(1.14)	(0.82)	(1.65)	(2.57)	(1.02)		
	Sign.	***	***	**	***	**	NS	***		
Weeds	H0	20 (2.5)	9 (2.2)	9 (1.6)	51 (3.9)	12 (2.3)	61 (5.9)	42 (4.5)	(0.95)	***
	H1	111 (9.2)	106 (9.9)	50 (5.7)	177 (12.2)	12 (2.2)	247 (10.8)	85 (7.8)		
	H2	9 (2.1)	55 (5.9)	122 (9.7)	147 (11.7)	15 (2.7)	185 (10.9)	166 (11.5)		
	SEM	(0.94)	(0.68)	(0.74)	(1.06)	(0.43)	(1.99)	(0.86)		
	Sign.	***	***	***	***	NS	NS	***		
Total	H0	1129	1777	2679	3881	1369	2108	2779	121.2	***
	H1	1236	2379	2655	3892	1462	2401	1454		
	H2	376	1234	2458	3940	1193	1828	1863		
	SEM	65.0	142.7	128.7	178.1	100.5	180.0	108.2		
	Sign.	***	***	NS	NS	NS	*	***		

*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for total herbage standing biomass (no transformation needed). Other legumes data for Jul-Sep and Feb-Mar, were not analysed, due to very low and erratic appearance.

Table 4.12 Effect of grass suppression on botanical composition of the standing biomass (%) at different dates. *Waipawa* (2001-2002).

Component	Treat.	Dates							SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Feb	Mar		
Grass	H0	57.7	47.5	34.4	28.8	54.9	64.2	65.1	1.63	***
	H1	29.7	16.1	18.1	23.6	24.3	29.2	32.0		
	H2	32.4	6.5	4.2	6.4	14.3	33.4	25.2		
	SEM	3.21	1.48	1.29	1.51	2.04	2.60	1.71		
	Sign.	***	***	***	***	***	***	***		
White clover	H0	3.0 (1.40)	6.4 (2.19)	5.1 (2.20)	9.3 (2.75)	14.9 (3.29)	19.6 (4.21)	11.6 (3.15)	(0.196)	***
	H1	25.1 (4.75)	34.0 (5.54)	34.5 (5.56)	46.7 (6.57)	72.2 (8.39)	51.9 (7.17)	48.7 (6.83)		
	H2	4.6 (1.77)	12.9 (3.30)	14.2 (3.41)	6.7 (2.39)	18.9 (3.84)	27.8 (5.06)	18.3 (3.98)		
	SEM	(0.237)	(0.277)	(0.268)	(0.275)	(0.386)	(0.251)	(0.280)		
	Sign.	***	***	***	***	***	***	***		
Subt. clover	H0	37.5	45.3	58.7	41.1	6.5	12.8	21.4	2.14	***
	H1	35.7	44.8	45.1	23.0	1.6	8.6	14.2		
	H2	59.9	74.2	75.3	53.1	8.7	27.8	47.3		
	SEM	3.73	2.25	3.10	2.49	0.73	2.67	2.46		
	Sign.	***	***	***	***	***	***	***		
Other legumes	H0	0.0	0.3	1.4 (0.94)	19.9 (4.18)	22.7 (4.46)	0.4	0.6	(0.157)	***
	H1	0.0	0.1	0.1 (0.06)	2.2 (1.14)	0.8 (0.54)	0.1	0.0		
	H2	0.0	0.8	0.8 (0.74)	30.2 (5.20)	56.7 (7.26)	0.2	0.3		
	SEM			(0.098)	(0.259)	(0.286)				
	Sign.			***	***	***				
All legumes	H0	40.5 (6.32)	52.0 (7.10)	65.1 (8.04)	70.3 (8.36)	44.1 (6.55)	32.8 (5.63)	33.5 (5.70)	(0.182)	***
	H1	60.8 (7.78)	78.8 (8.86)	79.9 (8.92)	71.9 (8.45)	74.5 (8.55)	59.1 (7.68)	62.9 (7.87)		
	H2	64.5 (7.85)	88.0 (9.37)	90.3 (9.49)	90.0 (9.49)	84.4 (8.53)	55.8 (7.40)	65.9 (8.06)		
	SEM	(0.297)	(0.105)	(0.091)	(0.127)	(0.390)	(0.213)	(0.177)		
	Sign.	**	***	***	***	***	***	***		
Weeds	H0	1.8 (0.74)	0.5 (0.52)	0.4 (0.34)	1.0 (0.56)	1.0 (0.67)	3.0 (1.30)	1.4 (0.82)	(0.226)	***
	H1	9.5 (2.69)	5.1 (2.12)	2.1 (1.16)	4.5 (1.94)	1.2 (0.65)	10.3 (2.69)	5.1 (1.99)		
	H2	3.0 (1.25)	5.5 (1.81)	5.5 (2.04)	3.6 (1.86)	1.4 (0.88)	10.7 (2.65)	8.9 (2.68)		
	SEM	(0.316)	(0.168)	(0.141)	(0.158)	(0.131)	(0.420)	(0.191)		
	Sign.	***	***	***	***	NS	*	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass and subclover (no transformation needed). Other legumes data for Jul-Sep and Feb-Mar were not analysed, due to very low and erratic appearance.

On season average, weed content of the standing biomass was similar in ($p>0.05$) H1 and H2, and significantly lower in H0 (5.4%, 5.6% and 1.3%, for H1, H2 and H0, respectively; $p<0.001$). Weed content was generally low, except for February, where it reached 10-11% in H1 and H2 treatments. Weed percentage in H0 plots was always very low, never exceeding 3% of total standing biomass (Table 4.12).

4.3.2.5.3. Population density

TPD at the start of the season (July) was significantly higher in H0 compared to H1 ($p<0.01$) and H2 ($p<0.001$) plots. Herbicide application left only about 5% of original TPD in July. TPD in H2 plots increased towards September and October, becoming closer but still significantly ($p<0.05$) lower than TPD in H1 plots. From November onwards, TPD in H1 and H2 was similar. TPD declined sharply in November in all treatments, but started to recover thereafter. H0 plots had always significantly (at least $p<0.05$) higher TPD compared to H1 and H2, and differences remained until the end of the season (Table 4.13).

White clover GPD was significantly ($p<0.001$) higher in H1 than in H0 or H2 plots for almost the whole season. H0 and H2 swards had generally similar GPD, except in October, where GPD was significantly ($p<0.05$) higher in H2 v H0. GPD in H0 and H2 tended to increase towards the end of the season, while a decrease was recorded on H1 plots. This resulted in GPD being similar in all treatments in March (Table 4.13).

Subterranean clover PD was significantly different between treatments only in November and February. In November, H1 had significantly ($p<0.05$) less SC plants per unit area than either H0 or H2. After a very low plant density in December, in February, new plants established, especially in H2 plots, which had a significantly higher SCPD than H1 or H0 plots. In March, all plots had similar SCPD (Table 4.13).

SC seedling density was similar in December and March, between treatments. In February, H0 plots had more SC seedlings per unit area than H1 or H2 (Table 4.13).

Table 4.13 Effect of grass suppression on grass tiller population density (TPD; tiller/m²), white clover growing point density (GPD; g.p./m²), subterranean clover plant density (SCPD; pl/m²) at different dates, and summer SC seedling density (SC seedl./m²). *Waipawa* (2001/2002).

Factor	Treat	Jul	Sep	Oct	Nov	Dec	Feb	Mar	SEM	Sign.
TPD	H0	10962 (103.0)	9605 (96.1)	8767 (89.6)	2131 (42.6)	4082 (61.2)	8820 (89.9)	7474 (83.9)	(6.03)	***
	H1	6276 (68.2)	5714 (63.9)	5301 (62.2)	1262 (25.0)	1824 (30.4)	2025 (35.1)	4336 (56.4)		
	H2	615 (19.7)	1548 (31.0)	1654 (30.6)	488 (15.4)	1283 (28.5)	4675 (52.0)	3976 (54.5)		
	SEM	(7.59)	(7.58)	(7.41)	(5.01)	(5.59)	(8.11)	(6.94)		
	Sign.	***	***	***	**	***	***	*		
GPD	H0	333 (13.3)	465 (16.9)	408 (15.0)	490 (15.3)	580 (17.2)	1683 (35.2)	1885 (38.3)	(4.14)	***
	H1	2395 (43.4)	2813 (49.8)	2900 (49.3)	3253 (49.3)	3065 (53.2)	3863 (60.9)	1928 (36.4)		
	H2	278 (11.6)	550 (19.2)	1203 (29.9)	443 (14.5)	473 (15.4)	1270 (28.1)	1570 (32.0)		
	SEM	(3.91)	(3.81)	(4.11)	(4.74)	(3.84)	(4.85)	(6.26)		
	Sign.	***	***	***	***	***	***	NS		
SCPD	H0	270 (5.470)	210 (5.140)	200 (4.960)	118 (4.410)	15 (0.340)	465 (5.500)	280 (4.200)	(0.3910)	***
	H1	273 (5.160)	203 (4.870)	178 (4.560)	75 (3.130)	3 (0.230)	283 (4.070)	368 (4.560)		
	H2	245 (5.030)	228 (4.740)	150 (4.870)	140 (4.750)	10 (0.740)	660 (6.190)	320 (4.930)		
	SEM	(0.3020)	(0.3440)	(0.3470)	(0.371)	(0.3440)	(0.4690)	(0.5620)		
	Sign.	NS	NS	NS	•	NS	**	NS		
SC seedl.	H0					465 (5.551)	2650 (7.490)	65 (2.537)	(0.4880)	***
	H1					230 (4.850)	1073 (5.412)	35 (1.820)		
	H2					573 (5.918)	1398 (5.786)	103 (3.036)		
	SEM					(0.3248)	(0.4168)	(0.6199)		
	Sign.					NS	**	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, either square root (TPD and GPD) or log (SCPD and SC seedl. density), with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.2.5.4. Herbage accumulation

Total herbage accumulation

Total herbage accumulation was similar in all treatments in spring and summer. In winter, H1 plots produced significantly ($p < 0.001$) more total biomass than H2 and H0. Overall, total biomass accumulated was also higher in H1, but only when compared with H2 ($p < 0.05$) (Table 4.14).

Grass

Grass biomass produced in winter and spring was similar in H1 and H0, while H2 had significantly ($p < 0.001$) lower grass production levels. In summer, H1 and H2 accumulated significantly ($p < 0.001$) lower grass than H0. Overall, H0 produced 60% more grass biomass than H1 ($p < 0.01$) and 256% more than H2 ($p < 0.001$). H1 plots also produced significantly ($p < 0.001$) more grass biomass than H2 plots (122% more) (Table 4.14).

Grass content of herbage produced was always significantly ($p < 0.001$) higher in H0, compared to H1 or H2. In winter and summer, H1 and H2 plots had similar grass percentage, while in spring H2 swards had very low grass content, significantly less ($p < 0.001$) than H1 plots. On average, grass content followed the pattern $H0 > H1 > H2$ ($p < 0.001$) (Table 4.15).

Legumes

WC production was always significantly ($p < 0.001$) higher in H1 plots compared with H0 or H2. Overall, WC produced on H1 plots was almost four times that produced on H2 plots and about five times that on H0 plots ($p < 0.001$) (Table 4.14). There was a significant *management x grass suppression x date* interaction, which showed that in winter C-H2 produced more WC than C-H0 plots (108 v 13 kg DM/ha; $p < 0.001$), while differences were not significant in G plots.

WC percentage of herbage produced was at all times higher in H1 compared to the other treatments ($p < 0.001$), WC content being highest in summer. In winter, H2 plots had significantly ($p < 0.01$) more WC content than H0 plots, but were similar thereafter. On average, WC content in H1 swards was 45%, significantly higher than on H2 and H0 plots, where it only achieved levels of 14.7% and 10.4%, respectively (Table 4.15). There was a *management x grass suppression x date* interaction, which indicated that, in winter, differences in WC content between H2 and H0 were significant ($p < 0.001$) only in C plots (11.3% v 1.5%, in C-H2 v C-H0, respectively).

In winter, H1 plots had significantly ($p < 0.05$) more SC herbage mass than H0 plots (61% more), while production was similar in H2 plots. H2 plots produced significantly more SC in spring, compared to H1 plots (110% more; $p < 0.001$) or H0 plots (40% more; $p < 0.05$). In summer, H2 had still the highest SC production, significantly different from H0 and H1 ($p < 0.001$). Overall, H2 swards produced more SC herbage mass, compared to H1 (74% more; $p < 0.001$) and H0 (42% more; $p < 0.01$). Differences between H1 and H0 were not significant ($p > 0.05$) (Table 4.14).

SC content based on herbage accumulated was always significantly ($p < 0.001$) higher on H2 plots v H0 or H1 plots. The highest SC percentages for H2 occurred in winter, but remained high throughout the season. In spring, SC content in $H2 > H0 > H1$ ($p < 0.001$), while in summer the pattern was $H2 > H0 = H1$ ($p < 0.001$). On average, H2 plots had almost 50% SC content in the sward, followed by H0 with 31.6% and finally by H1 with 24.1%, all being significantly different ($p < 0.001$) (Table 4.15).

The production of OL was only important in spring, where H2 plots produced significantly ($p < 0.001$) more than H0 and H1. H1 had also significantly ($p < 0.001$) less OL production than H0 (Table 4.14). Further, a *management x grass suppression* interaction showed that H2 plots produced significantly ($p < 0.001$) more OL than H0 plots only on G plots, but not on C plots (1832 v 822 kg DM/ha on G-H2 v G-H0; $p < 0.001$).

OL content of herbage produced was significantly higher in the sward of H2 plots, compared to H0 or H1 plots ($p < 0.001$). H1 plots had very low contents of OL. Also, a *management x grass suppression* interaction showed that H2 plots had a significantly ($p < 0.001$) higher OL content than H0 plots only on G plots (36.8% v 17.7 % on G-H2 v G-H0; $p < 0.001$), but not on C plots.

In winter, TL production was significantly ($p < 0.001$) higher on H1 plots compared to H2 or H0 plots. The main TL production was recorded in spring on all treatments, and H0 had significantly lower TL production than H1 (28% less; $p < 0.01$) and H2 (36%

less; $p < 0.001$). In summer, H1 and H2 plots had similar TL production, while H0 presented significantly ($p < 0.001$) lower values. Overall, H1 and H2 produced 64% and 49% more TL herbage mass than H0 ($p < 0.001$), respectively, while differences between H1 and H2 were not significant ($p > 0.05$) (Table 4.14).

TL percentage in herbage produced was high during most of the season. Grass suppressed treatments had significantly ($p < 0.001$) higher TL content than H0 plots at all periods. In spring, H2 plots had significantly ($p < 0.001$) higher TL content than H1 and H0, and H1 also showed more TL content than H0 ($p < 0.001$). In summer, similar TL content was present in H1 and H2. On average, TL content was almost 80% v 70% v 48% in H2 v H1 ($p < 0.01$) v H0 ($p < 0.001$) (Table 4.15).

Weeds

Weed production in winter was significantly ($p < 0.001$) higher on H1 plots, compared to H2 or H0 plots. In spring, H2 plots increased their weed herbage mass, which became similar to that in H1 plots, but significantly ($p < 0.001$) higher than weeds accumulated on H0 plots. A similar situation was observed in summer and overall in the season, where H1 and H2 plots had more than four times more weeds than H0 swards (Table 4.14).

Weed percentage in herbage produced was generally low, and overall H2 and H1 plots had similar weed content, while H0 had significantly lower percentages ($p < 0.001$). A similar pattern was observed within periods (Table 4.15).

Table 4.14 Effect of grass suppression on seasonal and total herbage mass accumulation and botanical composition of the herbage accumulated (kg DM/ha). *Waipawa* (2001/2002).

Component	Treat	Season			SEM	Sign.	
		Winter	Spring	Summer			Total
Grass	H0	512 (6.088)	1562 (7.171)	2131 (7.601)	(0.1147)	***	4205 (8.269)
	H1	410 (5.823)	1186 (6.809)	1024 (6.766)			2619 (7.691)
	H2	100 (4.237)	274 (5.335)	807 (6.353)			1180 (6.817)
	SEM	(0.1896)	(0.1391)	(0.1393)			(0.1244)
	Sign.	***	***	***			***
White clover	H0	62 (6.2)	311 (16.3)	513 (21.1)	(0.94)	***	886 (27.8)
	H1	638 (23.6)	2261 (44.8)	1593 (38.8)			4492 (64.9)
	H2	87 (8.5)	478 (20.7)	600 (23.2)			1165 (32.9)
	SEM	(1.14)	(1.55)	(1.41)			(1.96)
	Sign.	***	***	***			***
Subt. clover	H0	526 (21.1)	1563 (38.1)	556 (22.2)	(1.68)	***	2645 (49.8)
	H1	847 (27.8)	1037 (30.8)	276 (15.8)			2160 (44.9)
	H2	573 (22.8)	2187 (46.4)	1004 (30.5)			3763 (60.9)
	SEM	(1.74)	(2.23)	(1.75)			(2.20)
	Sign.	*	***	***			***
Other legumes	H0	2	537 (21.2)	14			552 (21.5)
	H1	0	50 (5.8)	1			51 (5.8)
	H2	6	1131 (31.1)	8			1145 (31.3)
	SEM	1.5	(1.53)	3.4			(1.55)
	Sign.		***				***
All legumes	H0	591 (22.5)	2410 (47.9)	1083 (31.8)	(1.69)	***	4083 (62.6)
	H1	1485 (37.9)	3348 (57.0)	1870 (42.4)			6702 (81.2)
	H2	665 (24.8)	3796 (61.1)	1612 (39.2)			6074 (77.4)
	SEM	(1.77)	(2.04)	(1.64)			(2.09)
	Sign.	***	***	***			***
Weeds	H0	10 (2.5)	38 (4.9)	67 (7.3)	(0.90)	***	115 (9.8)
	H1	131 (10.4)	134 (10.8)	230 (13.3)			496 (20.9)
	H2	37 (4.8)	166 (12.3)	259 (14.4)			462 (20.2)
	SEM	(0.78)	(0.76)	(1.52)			(1.46)
	Sign.	***	***	**			***
Total	H0	1113	4010	3281	226.4	***	8404
	H1	2026	4667	3124			9818
	H2	802	4235	2678			7715
	SEM	145.2	357.3	209.4			519.9
	Sign.	***	NS	NS			*

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass herbage accumulation (log) and total herbage accumulation (no transformation). Other legumes data for winter and summer were not analysed, due to very low and erratic appearance.

Table 4.15 Effect of grass suppression on the seasonal proportion of sward components (%) based on herbage accumulated. *Waipawa* (2001/2002).

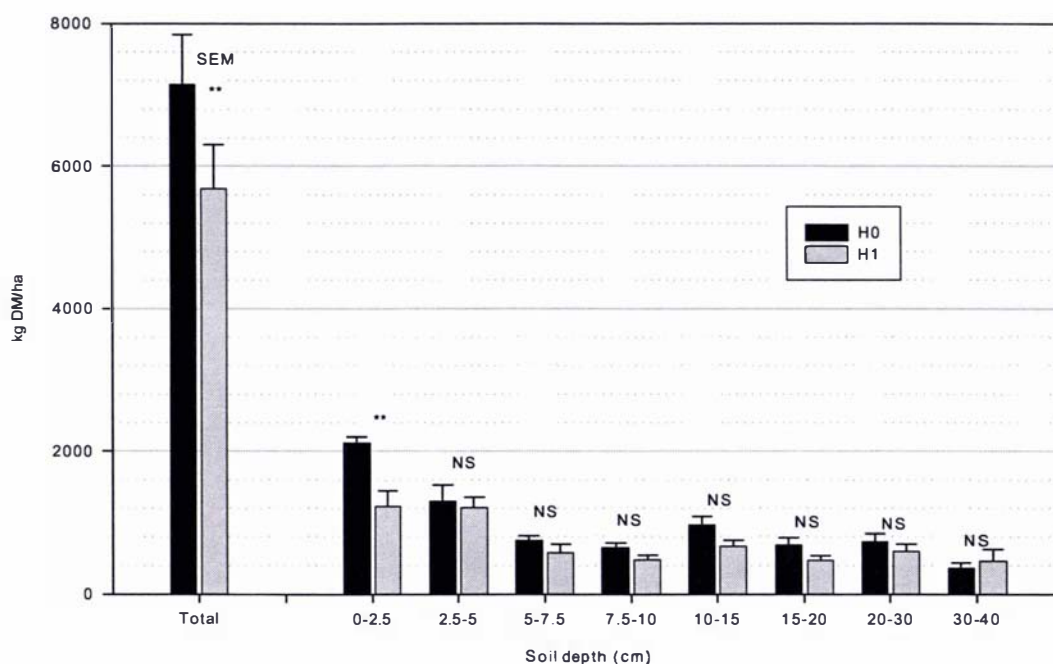
Component	Treat	Season			SEM	Sign.	Average
		Winter	Spring	Summer			
Grass	H0	51.1	37.7	66.1	1.20	***	50.4
	H1	20.0	23.4	32.0			25.2
	H2	12.6	6.7	30.4			15.3
	SEM	2.27	1.91	2.47			1.80
	Sign.	***	***	***			***
White clover	H0	5.0 (1.91)	8.0 (2.67)	14.9 (3.67)	(0.111)	***	10.4 (3.05)
	H1	30.4 (5.27)	46.6 (6.56)	51.4 (7.07)			45.3 (6.59)
	H2	11.4 (3.10)	10.9 (3.16)	22.4 (4.53)			14.7 (3.73)
	SEM	(0.240)	(0.259)	(0.254)			(0.226)
	Sign.	***	***	***			***
Subt. clover	H0	42.8	40.5	16.4	2.03	***	31.6
	H1	43.5	26.3	9.5			24.1
	H2	70.3	53.7	36.7			49.9
	SEM	2.64	2.20	2.46			1.62
	Sign.	***	***	***			***
Other legumes	H0	0.2	13.0 (3.44)	0.6			6.4 (2.38)
	H1	0.1	1.1 (0.85)	0.1			0.5 (0.56)
	H2	0.6	25.1 (4.74)	0.3			14.3 (3.55)
	SEM	0.14	(0.206)	0.13			(0.161)
	Sign.		***				***
All legumes	H0	47.9	61.6	31.9	1.62	***	48.4
	H1	73.9	73.9	60.9			69.8
	H2	82.3	89.7	59.3			78.8
	SEM	2.17	2.03	2.80			1.93
	Sign.	***	***	***			***
Weeds	H0	1.0 (0.80)	0.7 (0.70)	2.0 (1.26)	(0.157)	***	1.3 (1.05)
	H1	6.1 (2.31)	2.7 (1.57)	7.2 (2.35)			5.0 (2.12)
	H2	5.0 (1.79)	3.7 (1.87)	10.3 (2.90)			5.8 (2.31)
	SEM	(0.194)	(0.088)	(0.272)			(0.155)
	Sign.	***	***	***			***

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass, subterranean clover and All legumes, which did not require transformation. Other legumes data for winter and summer were not analysed, due to very low and erratic appearance.

4.3.2.5.5. Root mass

Vertical distribution of the total root mass within the 0-40 cm layer of the soil (expressed as kg DM/ha), is presented in Figure 4.3, for two contrasting treatments.

Root mass was greater in H0 swards (grass dominated) v H1 swards (legume dominated) only in the surface layer (0-25 mm). In deeper strata, root mass distribution was similar for both treatments. The total root mass in the 0-40 cm layer was 26% higher in H0 swards compared to H1 plots (7150 v 5687 kg DM/ha, respectively). H0 and H1 plots had 29 and 21% of total root mass in the first 2.5 cm of the soil. The cumulative root mass to the 5cm, 10cm, 15 cm, 20 cm and 30 cm levels was, 46%, 64%, 77%, 86% and 95% for H0 plots; and 43%, 61%, 73%, 81% and 92% for H1 plots.

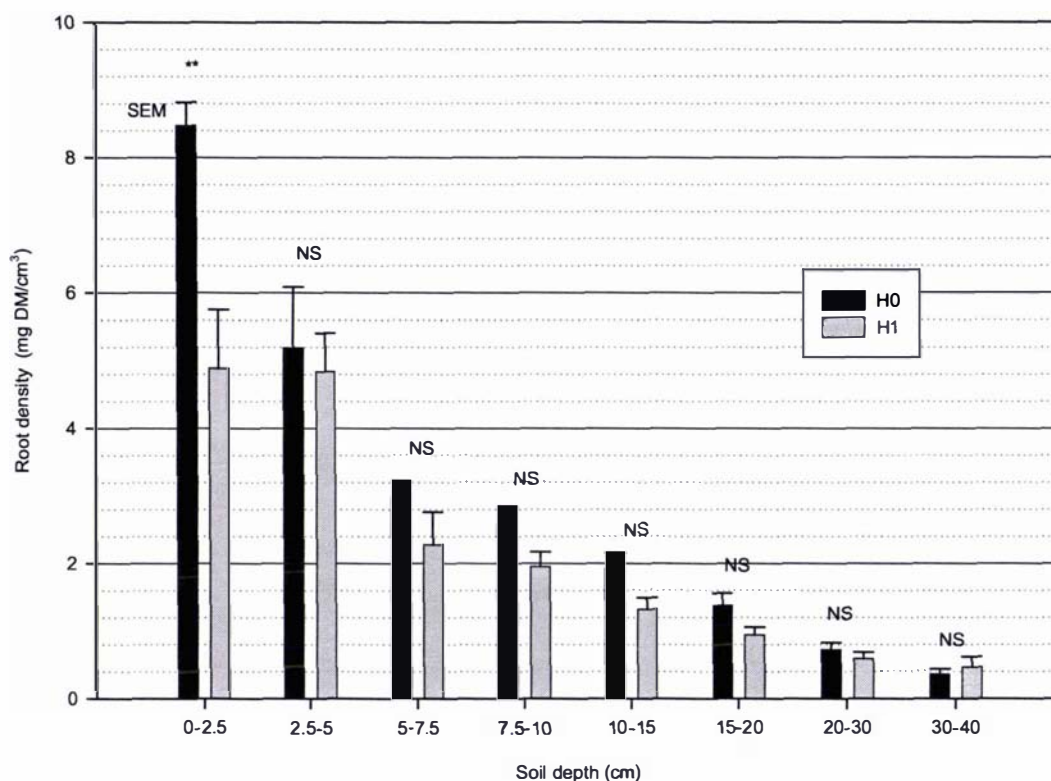


***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$); SEM, standard error of the mean.

Figure 4.3 Vertical distribution of the root mass at different layers for grass dominated (H0) and legume dominated (H1) swards, during the active legume-growing period in *Waipawa*.

Root density declined sharply from the top layers to the bottom layers within the measured soil profile, especially in the H0 plots. H0 plots had significantly ($p < 0.01$) higher root density in the top layer, compared to H1 plots. H1 plots had similar root

density in the two surface layers, as opposed to H0, where root density declined. Thereafter, the decline in root density followed a similar pattern between swards (Figure 4.4).



***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$); SEM, standard error of the mean.

Figure 4.4 Vertical distribution of the root density at different layers for grass dominated (H0) and legume dominated (H1) swards, during the active legume-growing period in Waipawa.

4.3.2.6. Effect of soil phosphorus status

4.3.2.6.1. Sward height

Pre-defoliation grass height was significantly higher on HP plots between October and February, except for December, where HP and LP grass heights were similar. Main differences occurred in November, where grass on HP swards was 3.5 cm taller than on LP swards ($p < 0.001$). In March, swards had similar grass pre-defoliation heights.

Legume pre-defoliation height was higher on HP v LP plots from September onwards, with the exception of January, where heights were similar. Differences were especially contrasting in spring (2.9 cm and 4.8 cm more legume height on HP plots compared to LP plots in October and November, respectively; $p<0.001$) (Table 4.16). Post-defoliation heights were not affected by soil-P status (not shown).

Table 4.16 Effect of soil-P status on average pre-defoliation grass and legume height (cm), at different dates (2001/2002). *Waipawa*.

			Factor	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
GRASS	PRE	HP		3.0	3.5	6.3	19.7	6.8	4.5	8.8	6.4	0.21	***
		LP		3.0	3.2	5.4	16.2	6.2	4.0	7.7	6.1		
		SEM		0.15	0.22	0.27	0.31	0.25	0.16	0.32	0.23		
		Sign.		NS	NS	*	***	NS	*	*	NS		
LEGUME	PRE	HP		2.3	5.8	10.3	19.8	5.8	3.1	8.8	5.0	0.27	***
		LP		2.1	4.4	7.4	15.0	4.7	2.6	6.3	4.3		
		SEM		0.12	0.26	0.37	0.46	0.32	0.21	0.44	0.21		
		Sign.		NS	***	***	***	*	NS	***	*		

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SEM, standard error of the mean.

4.3.2.6.2. Standing herbage mass and sward composition

Total biomass

Average total standing biomass was significantly higher on HP v LP plots (2261 v 1939 kg DM/ha; $p<0.001$). However, when individual dates are considered, HP plots had significantly higher per-harvest standing biomass only in November (+30%; $p<0.001$) and December (+32%; $p<0.01$) (Table 4.17). A *management x P x date* interaction indicated that in February total standing biomass was HP>LP only on C plots (2722 v 1778 kg DM/ha, for C-HP v C-LP, respectively; $p<0.001$).

Grass

Overall, grass standing biomass was 10% higher on LP v HP plots (638 v 578 kg DM/ha; $p<0.001$). On a date basis, significant ($p<0.05$) differences were only achieved in December (Table 4.17), but a *grass suppression x P x date* interaction further showed

that at that date, LP>HP only in H1 plots (459 v 165 kg DM/ha, for H1-LP v H1-HP, respectively; $p<0.01$), while no differences occurred at the other levels.

On season average, HP plots had significantly lower grass content in the standing biomass than LP plots (26.2% v 35.5%, in HP and LP, respectively; $p<0.001$). This pattern was observed from September onwards, with the exception of November, where HP and LP plots had similar grass content ($p>0.05$) (Table 4.18). A *management x P x date* interaction described that in September, November and December, differences in grass percentage between HP and LP occurred only in C plots (15.1 v 30.5%, 13.2 v 22.7%, and 24.3 v 51.0%, for C-HP v C-LP, in September ($p<0.001$), November ($p<0.05$) and December ($p<0.001$)). Further, a *grass suppression x soil-P x date* interaction showed that in September only H0 plots had less grass content on HP v LP plots (34.4 v 61.5%, for H0-HP v H0-LP; $p<0.001$), and in December this occurred only in H1 and H2 plots (10.5 v 38.1%, for H1-HP v H1-LP; $p<0.001$; and 6.1 v 22.5%, for H2-HP v H2-LP; $p<0.05$).

Legumes

WC standing biomass was on average 95% higher on HP v LP plots (640 v 328 kg DM/ha; $p<0.001$). At individual dates, HP plots had between 71-87% more WC pre-harvest biomass compared to LP plots (at least $p<0.05$), except for November, where peak WC standing biomass was recorded, and HP had 162% more WC biomass than LP plots (Table 4.17). A *management x soil-P x date* interaction indicated that WC standing biomass in September was HP>LP only on G plots (548 v 217 kg DM/ha, for G-HP v G-LP, respectively; $p<0.001$), and only on C plots in February (1229 v 405 kg DM/ha, for C-HP v C-LP, respectively, $p<0.001$).

A higher annual average WC percentage was recorded for HP v LP plots (29.5% v 16.9%; $p<0.001$). This pattern was observed throughout the season, with the exception of December, where WC content was similar for both treatments. HP plots had more than 40% WC in the standing biomass in December to February, while at that same time

LP plots peaked at 25-28% (Table 4.18). However, In November and December WC content was significantly higher in HP ν LP only in C plots (31.1 ν 9.5%, and 48.9 ν 24.6%, for C-HP ν C-LP, in November ($p < 0.01$) and December respectively ($p < 0.01$)), as shown by a *management $\times$ P $\times$ date* interaction.

No significant ($p > 0.05$) differences were observed for SC standing biomass between HP and LP treatments (Table 4.17). However, a *grass suppression $\times$ P $\times$ date* interaction showed that from July-December, a positive response in SC standing biomass to P was recorded on H0 plots only (544 ν 315, 1294 ν 469, 1941 ν 1323, 1889 ν 1253, and 166 ν 32 kg DM/ha, for H0-HP ν H0-LP, in July ($p < 0.05$), September ($p < 0.01$), October ($p < 0.05$), November ($p < 0.05$) and December ($p < 0.01$), respectively), while no differences occurred on H1 or H2 plots.

No significant ($p > 0.05$) differences were observed for OL standing biomass between HP and LP treatments (Table 4.17). However, a *grass suppression $\times$ P $\times$ date* interaction showed that in November a significant response in OL biomass to soil-P was observed in H0 plots (473 ν 1003 kg DM/ha, for H0-HP ν H0-LP, $p < 0.05$), and in December the same occurred in H2 plots (875 ν 579, for H2-HP ν H2-LP, $p < 0.05$).

SC percentage of the standing biomass was higher on LP ν HP plots (36.9% ν 33.8%; $p < 0.01$). However, on all individual dates differences did not achieve significant levels ($p > 0.05$). In September and November, a *grass suppression $\times$ P $\times$ date* interaction indicated that on H1 plots there was a negative response in SC percentage to soil-P level (34.7 ν 54.9%, and 10.4 ν 35.7%, for H1-HP ν H1-LP, for both dates, respectively, $p < 0.001$).

OL content in the sward was significantly ($p < 0.01$) higher in LP ν HP only in November (Table 4.18).

Overall, TL standing biomass was 30% higher on HP ν LP plots (1593 ν 1225 kg DM/ha; $p < 0.001$). Apart from July, at all other dates TL biomass was higher on HP ν LP plots, differences ranging from 15% in October to 57% in December. The peak TL

standing biomass was observed in November, and HP>LP by 31% (Table 4.17). A *management x P x date* interaction described that P effects in September and February were mostly due to differences in C plots (1964 v 1315, and 1745 v 738 kg DM/ha, for C-HP v C-LP, in September ($p<0.01$) and February ($p<0.05$), respectively). Also, H0 plots showed differences in TL biomass due to soil-P status in September and October, while similar values were recorded for H1 and H2, as indicated by a *grass suppression x P x date* interaction (1448 v 541, and 2148 v 1444 kg DM/ha, for H0-HP v H0-LP, in September ($p<0.001$) and October ($p<0.01$), respectively).

On season average, HP plots had a higher TL content in the sward than LP plots (69.5% v 60.5%; $p<0.001$). This was the situation during most of the season, except for July and November, where no significant ($p>0.05$) differences were found (Table 4.18). A *grass suppression x P x date* interaction for September, October and February indicated that differences in TL content due to soil-P status were mostly due to differences at the H0 level (65.4 v 38.6%, 70.5 v 59.8%, and 42.1 v 23.6%, for H0-HP v H0-LP, in September ($p<0.001$), October ($p<0.01$) and February ($p<0.01$), respectively).

Weeds

On average, no significant differences in weed standing biomass or weed content were recorded between HP and LP plots ($p>0.05$). Weed biomass levels were generally low, and some differences were achieved at particular months. Weed content tended to be higher in February with levels around 8% on both treatments (Table 4.17 and Table 4.18).

Table 4.17 Effect of soil-P status on standing biomass and biomass components (kg DM/ha) at different dates. *Waipawa* (2001-2002).

Component	Treat.	Dates							SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Feb	Mar		
Grass	HP	392 (17.7)	370 (16.9)	449 (18.8)	865 (25.5)	373 (16.5)	811 (26.4)	785 (24.7)	(0.83)	***
	LP	367 (18.2)	454 (19.2)	526 (20.7)	701 (25.4)	415 (19.6)	924 (29.3)	1084 (31.4)		
	SEM	(0.90)	(0.99)	(1.00)	(1.40)	(0.94)	(1.52)	(1.02)		
	Sign.	NS	NS	NS	NS	*	NS	***		
White clover	HP	149 (9.2)	422 (17.4)	573 (22.0)	1199 (30.5)	635 (21.2)	956 (29.5)	544 (22.5)	(0.80)	***
	LP	87 (7.0)	230 (11.8)	324 (15.2)	458 (18.3)	369 (16.5)	511 (20.5)	316 (16.5)		
	SEM	(0.62)	(0.90)	(1.11)	(1.19)	(1.17)	(1.07)	(0.96)		
	Sign.	*	**	***	***	**	***	***		
Subt. clover	HP	376 (18.3)	1082 (30.4)	1601 (33.7)	1580 (36.9)	96 (8.0)	346 (15.3)	535 (20.9)	(0.97)	***
	LP	362 (18.5)	912 (28.9)	1568 (38.2)	1402 (37.0)	49 (6.1)	341 (17.6)	591 (22.8)		
	SEM	(0.86)	(1.33)	(1.32)	(1.30)	(0.74)	(1.35)	(1.13)		
	Sign.	NS	NS	NS	NS	NS	NS	NS		
Other legumes	HP	0	4	21 (3.1)	616 (20.2)	411 (15.3)	3	4	(0.81)	
	LP	0	6	12 (2.6)	738 (23.5)	308 (13.9)	5	10		
	SEM			(0.36)	(1.33)	(0.95)				
	Sign.			NS	NS	NS				
All legumes	HP	525 (21.7)	1508 (37.6)	2196 (46.5)	3395 (58.1)	1142 (33.2)	1304 (32.8)	1083 (32.5)	(0.93)	***
	LP	449 (20.4)	1148 (32.4)	1903 (42.9)	2598 (50.7)	726 (24.3)	834 (26.5)	917 (29.9)		
	SEM	(0.81)	(1.25)	(0.93)	(0.67)	(1.35)	(2.10)	(0.83)		
	Sign.	NS	**	*	***	***	*	*		
Weeds	HP	43 (4.4)	75 (7.1)	69 (6.2)	147 (10.9)	10 (1.6)	166 (8.9)	117 (8.6)	(0.78)	***
	LP	50 (4.8)	38 (4.9)	52 (5.1)	103 (7.6)	16 (3.2)	163 (9.5)	78 (7.3)		
	SEM	(0.77)	(0.55)	(0.60)	(0.87)	(0.35)	(1.62)	(0.70)		
	Sign.	NS	**	NS	**	**	NS	NS		
Total	HP	961	1953	2714	4408	1525	2281	1984	98.9	***
	LP	866	1641	2481	3401	1158	1944	2079		
	SEM	53.1	116.4	105.1	145.4	82.1	146.9	88.4		
	Sign.	NS	NS	NS	***	**	NS	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for total herbage standing biomass (no transformation needed). Other legumes data for Jul-Sep and Feb-Mar, were not analysed, due to very low and erratic appearance.

Table 4.18 Effect of soil-P status on botanical composition of the standing biomass (%) at different dates. *Waipawa* (2001–2002).

Component	Treat.	Dates							SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Feb	Mar		
Grass	HP	38.2	18.3	15.9	18.3	23.1	36.5	32.9	1.63	***
	LP	41.6	28.4	21.9	20.8	39.1	48.1	48.6		
	SEM	3.21	1.48	1.29	1.51	2.04	2.6	1.71		
	Sign.	NS	***	**	NS	***	**	***		
White clover	HP	14.2 (3.11)	23.0 (4.15)	22.8 (4.35)	28.3 (4.65)	42.4 (5.61)	41.0 (6.27)	34.7 (5.51)	(0.160)	***
	LP	7.6 (2.17)	12.5 (3.20)	13.2 (3.10)	13.5 (3.16)	28.3 (4.74)	25.3 (4.69)	17.7 (3.80)		
	SEM	(0.193)	(0.226)	(0.219)	(0.224)	(0.315)	(0.205)	(0.229)		
	Sign.	**	**	***	***	NS	***	***		
Subt. clover	HP	43.3	53.2	57.4	36.3	5.9	14.6	25.9	1.75	***
	LP	45.4	56.3	62.0	41.9	5.2	18.1	29.4		
	SEM	3.05	1.84	2.53	2.03	0.59	2.18	2.01		
	Sign.	NS	NS	NS	NS	NS	NS	NS		
Other legumes	HP	0.0	0.3	0.9 (0.62)	14.0 (3.04)	27.9 (4.03)	0.1	0.2	(0.157)	***
	LP	0.0	0.4	0.6 (0.54)	20.9 (3.97)	25.6 (4.14)	0.3	0.4		
	SEM			(0.080)	(0.211)	(0.233)				
	Sign.			NS	**	NS				
All legumes	HP	57.5 (7.43)	76.5 (8.72)	81.0 (8.98)	78.5 (8.82)	76.2 (8.62)	55.8 (7.37)	60.7 (7.67)	(0.149)	***
	LP	53.0 (7.20)	69.3 (8.17)	75.8 (8.65)	76.3 (8.71)	59.1 (7.13)	42.8 (6.43)	47.5 (6.75)		
	SEM	(0.242)	(0.085)	(0.074)	(0.104)	(0.318)	(0.174)	(0.145)		
	Sign.	NS	***	**	NS	**	***	***		
Weeds	HP	4.3 (1.45)	5.2 (1.78)	3.1 (1.28)	3.2 (1.63)	0.7 (0.42)	7.8 (2.09)	6.4 (2.03)	(0.185)	***
	LP	5.3 (1.67)	2.3 (1.19)	2.3 (1.07)	2.9 (1.28)	1.7 (1.05)	8.2 (2.34)	3.9 (1.64)		
	SEM	(0.258)	(0.137)	(0.115)	(0.129)	(0.106)	(0.343)	(0.156)		
	Sign.	NS	**	NS	NS	***	NS	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass and subclover (no transformation needed). Other legumes data for Jul-Sep and Feb-Mar were not analysed, due to very low and erratic appearance.

4.3.2.6.3. Population density

Both treatments started with similar grass TPD, but from October onwards (except for November), LP plots had higher TPD than HP plots. Differences were highest in February, but TPD in March was still 63% higher on LP v HP plots (Table 4.19).

White clover GPD in October was almost doubled, and trebled in November, when comparing HP v LP plots. After similar GPD in December, in February HP still had 63% more GPD than LP plots, but differences disappeared by March (Table 4.19).

SCPD was similar on HP and LP plots for most of the season. Only by the end of summer, LP plots had higher SC plant density than LP plots (69% more), as shown in Table 4.19.

SC seedling density was higher on LP v HP plots in February, while no differences were recorded in December or March (Table 4.19).

Table 4.19 Effect of soil-P status on grass tiller population density (TPD; tiller/m²), white clover growing point density (GPD; g.p./m²), subterranean clover plant density (SCPD; pl/m²) at different dates, and summer SC seedling density (SC seedl./m²). *Waipawa* (2001/2002).

Factor	Treat	Jul	Sep	Oct	Nov	Dec	Feb	Mar	SEM	Sign.
TPD	HP	5937 (62.5)	4834 (61.1)	4396 (52.2)	1088 (23.6)	1760 (32.8)	3096 (40.8)	4000 (53.4)	(4.92)	***
	LP	5965 (64.8)	6410 (66.3)	6085 (69.4)	1498 (31.8)	3032 (47.3)	7251 (77.2)	6523 (76.5)		
	SEM	(6.19)	(6.19)	(6.05)	(4.09)	(4.57)	(6.62)	(5.66)		
	Sign.	NS	NS	*	NS	*	***	***		
GPD	HP	1207 (26.5)	1567 (31.6)	1969 (37.7)	2094 (35.1)	1655 (32.3)	2840 (48.2)	1825 (36.2)	(3.38)	***
	LP	797 (19.1)	985 (25.6)	1038 (25.2)	697 (17.6)	1090 (24.9)	1703 (34.6)	1763 (35.0)		
	SEM	(3.19)	(3.11)	(3.35)	(3.87)	(3.14)	(3.96)	(5.11)		
	Sign.	NS	NS	*	**	NS	*	NS		
SCPD	HP	252 (5.000)	203 (4.559)	152 (4.562)	105 (3.876)	3 (0.309)	393 (4.809)	240 (3.805)	(0.3190)	***
	LP	273 (5.445)	223 (5.274)	200 (5.033)	117 (4.314)	15 (0.566)	545 (5.699)	405 (5.317)		
	SEM	(0.2470)	(0.2810)	(0.2830)	(0.3030)	(0.2807)	(0.3830)	(0.4585)		
	Sign.	NS	NS	NS	NS	NS	NS	*		
SC seedl.	HP					373 (5.165)	1297 (5.707)	50 (2.184)	(0.3980)	***
	LP					472 (5.713)	2117 (6.752)	85 (2.745)		
	SEM					(0.2652)	(0.3403)	(0.5061)		
	Sign.					NS	*	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, either square root (TPD and GPD) or log (SCPD and SC seedl. density), with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.2.6.4. Herbage accumulation

Total herbage accumulation

HP plots had on average 31% more total herbage mass accumulation than LP plots over the season. Winter production was similar on both treatments, while in spring and summer, HP plots produced 38% and 26% more than LP plots, respectively (Table 4.20). However, a *management x soil-P x date* interaction indicated that, in summer, HP plots had higher total production only in plots under cutting (3404 v 2039 kg DM/ha, in C-HP v C-LP, respectively; $p < 0.01$), while under grazing no differences were found.

Grass

Grass accumulation did not differ significantly ($p > 0.05$) between HP and LP plots in any of the periods considered. The interaction of *grass suppression x P x date* indicated that grass accumulation differences between HP and LP could be observed only in H2 swards in spring, summer, and also on a seasonal basis (211 v 336 kg grass DM/ha in spring; 565 v 1049 kg grass DM/ha in summer; and 860 v 1500 kg grass DM/ha season total, for C-HP v C-LP plots, respectively; $p < 0.05$) (Table 4.20).

Grass content based on total herbage accumulated, was always higher on LP v HP plots; on average LP plots had 34% grass, while HP swards had 26% ($p < 0.001$) (Table 4.21). The interaction *grass suppression x P x date* indicated that main differences for grass percentage occurred in winter at the H0 plots, where HO-HP had much lower grass content than HO-LP (41.9% v 60.2%, respectively, $p < 0.05$), and in summer, where H0 and H2 plots had more grass content on LP v HP plots, while percentages were similar on H1 plots (20.2 v 40.6%, for H2-HP v H2-LP; and 58.9 v 73.4%, for H)-HP v HO-LP, respectively; $p < 0.05$).

Legumes

Higher WC production was recorded on HP plots in every period measured, compared to LP plots. On HP swards, there was 90% more WC production in winter ($p < 0.01$), 117% more in spring, and 96% more in summer ($p < 0.001$). Overall, HP plots produced

more than double the amount of WC than LP plots ($p < 0.001$) (Table 4.20). A *management x P x date* interaction showed that differences between HP and LP in spring and summer WC production are mostly a reflection of the differences observed on plots under cutting management (1203 v 261 kg WC DM/ha in spring, and 1389 v 448, kg WC DM/ha in summer, for C-HP v C-LP, respectively; $p < 0.01$). In those periods, differences on G plots were not significant ($p > 0.05$). Further, a *grass suppression x P x date* interaction indicated that in the spring period, H1-HP plots had significantly higher WC production than H1-LP plots (3122 v 1400 kg DM/ha, respectively; $p < 0.01$), while no significant ($p > 0.05$) differences occurred on H2 or H0 plots.

WC percentage in herbage produced was higher on HP v LP at all periods, and differences for the seasonal averages were also significant ($p < 0.001$), at values of 29.9% in HP v 17% in LP plots (Table 4.21). A *management x P x date* interaction showed that differences between HP and LP in spring were significant only on C plots (28.4 v 9.4%, for C-HP v C-LP, respectively, $p < 0.01$).

No significant ($p > 0.05$) differences were observed on HP v LP plots for SC accumulation (Table 4.20). However, a *grass suppression x P x date* interaction described that, in winter, on H0-HP plots SC accumulation was higher than on H0-LP plots (806 v 246 kg DM/ha, respectively; $p < 0.001$), while no differences occurred at other levels. Likewise, total SC production for the year was higher on H0-HP v H0-LP (3537 v 1752 kg DM/ha, respectively; $p < 0.01$).

SC content based on total herbage produced was significantly lower ($p < 0.05$) on HP v LP plots in spring, while no differences were observed at a main factor level for the other periods. On average, SC content was also higher on LP plots compared to HP plots (Table 4.21). The negative P response of SC content was mainly observed on H1 plots in winter and spring, as well as on a seasonal average, as indicated by a *grass suppression x P x date* interaction. H1-HP v H1-LP plots had 34.6 v 52.4% in winter, 17.3 v 35.3% in spring, and 16.3 v 31.9% SC, respectively ($p < 0.001$). There were no

differences at the H0 and H2 level. A lower SC content was observed on HP plots in winter, but only on G plots, as indicated by a *management x P x date* interaction (36.4 v 52.3%, for G-HP v G-LP, respectively; $p < 0.01$).

No differences in OL production or OL content in the sward were observed due to phosphorus level in the soil.

TL accumulation was 46% higher in spring and 55% in summer, on HP v LP plots, respectively ($p < 0.001$), while no differences were recorded in the winter period, due to soil-P status. The total seasonal TL accumulation was also higher on HP plots by 44%, compared to LP plots ($p < 0.001$) (Table 4.20). The interaction *management x soil-P x date* showed that, in summer, differences between HP and LP were only significant under the cutting regime (2207 v 958 kg DM/ha, for C-HP v C-LP, respectively; $p < 0.001$).

TL content of herbage produced was always higher on HP v LP plots. Legume content in the sward was high on both treatments but, on average, HP plots had also higher TL content than LP plots (69.2 v 62%) (Table 4.21). In summer, a *management x soil-P x date* interaction showed higher TL content on HP v LP only on C plots, while similar TL percentage on G swards (65.5 v 48.3%, for C-HP v C-LP, respectively; $p < 0.01$). Also, a *grass suppression x soil-P x date* interaction showed that, in winter and only on H0 plots, TL content was higher on HP v LP plots (57.6 v 38.3%, on H0-HP v H0-LP, respectively; $p < 0.01$).

Weeds

Weed production was affected by soil-P status only in spring, and was higher on HP plots v LP plots ($p < 0.05$). Weed accumulation on HP plots was also higher ($p < 0.05$) than LP swards on an overall basis, but actual amounts produced were comparatively low (Table 4.21).

Weed percentage based on total herbage accumulated, was not significantly different ($p>0.05$) between treatments, except for a *grass suppression* $\times$ *soil-P* $\times$ *date* interaction, which indicated that in winter and only on H2 swards, weed content on HP > LP (8.0 v 2.0%, for H2-HP v H2-LP, respectively; $p<0.05$).

Table 4.20 Effect of soil-P status on seasonal and total herbage mass accumulation and botanical composition of herbage accumulated (kg DM/ha). *Waipawa* (2001/2002).

Component	Treat	Season			SEM	Sign.	
		Winter	Spring	Summer			Total
Grass	HP	354 (5.278)	1082 (6.340)	1313 (6.820)	(0.0937)	***	2749 (7.497)
	LP	327 (5.488)	932 (6.537)	1328 (6.993)			2587 (7.688)
	SEM	(0.1548)	(0.1136)	(0.1137)			(0.1016)
	Sign.	NS	NS	NS			NS
White clover	HP	344 (14.6)	1395 (33.2)	1195 (33.2)	(0.77)	***	2934 (50.3)
	LP	181 (10.9)	638 (21.5)	609 (22.1)			1428 (33.4)
	SEM	(0.93)	(1.27)	(1.15)			(1.60)
	Sign.	**	***	***			***
Subt. clover	HP	658 (24.0)	1752 (39.9)	650 (23.3)	(1.37)	***	3060 (53.1)
	LP	639 (23.8)	1439 (36.9)	574 (22.5)			2652 (50.6)
	SEM	(1.42)	(1.82)	(1.43)			(1.99)
	Sign.	NS	NS	NS			NS
Other legumes	HP	2	630 (19.9)	6			638 (20.0)
	LP	3	515 (18.8)	10			527 (19.1)
	SEM	1.2	(1.25)	2.8			(1.26)
	Sign.		NS				NS
All legumes	HP	1005 (30.1)	3778 (60.6)	1850 (42.3)	(1.38)	***	6632 (80.8)
	LP	823 (26.7)	2592 (50.0)	1193 (33.2)			4607 (66.7)
	SEM	(1.45)	(1.66)	(1.34)			(1.71)
	Sign.	NS	***	***			***
Weeds	HP	69 (6.6)	137 (10.6)	217 (12.8)	(0.73)	***	423 (18.8)
	LP	50 (5.2)	88 (8.1)	154 (10.5)			292 (15.1)
	SEM	(0.64)	(0.62)	(1.24)			(1.19)
	Sign.	NS	*	NS			*
Total	HP	1428	4997	3380	184.8	***	9805
	LP	1199	3612	2676			7487
	SEM	118.5	291.7	171.0			424.5
	Sign.	NS	**	**			***

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass (log) and total herbage accumulation (untransformed). Other legumes data for winter and summer were not analysed, due to very low and erratic appearance.

Table 4.21 Effect of soil-P status on the seasonal proportion of sward components (%) based on herbage accumulated. *Waipawa* (2001/2002).

Component	Treat	Season			SEM	Sign.	Average
		Winter	Spring	Summer			
Grass	HP	24.0	20.1	36.9	1.20	***	26.2
	LP	31.8	25.2	48.7			34.4
	SEM	1.85	1.56	2.02			1.47
	Sign.	**	*	***			***
White clover	HP	20.0 (3.87)	28.0 (4.77)	36.4 (5.82)	(0.091)	***	29.9 (5.13)
	LP	11.1 (2.98)	15.7 (3.50)	22.7 (4.36)			17.0 (3.78)
	SEM	(0.196)	(0.211)	(0.207)			(0.185)
	Sign.	**	***	***			***
Subt. clover	HP	50.6	37.2	19.4	1.658	***	32.6
	LP	53.8	43.1	22.3			37.6
	SEM	2.15	1.80	2.01			1.32
	Sign.	NS	*	NS			**
Other legumes	HP	0.3	12.2 (2.84)	0.2			6.8 (2.07)
	LP	0.3	13.9 (3.18)	0.4			7.3 (2.25)
	SEM	0.11	(0.168)	0.10			(0.131)
	Sign.		NS				NS
All legumes	HP	70.9	77.4	56.0	1.32	***	69.3
	LP	65.2	72.7	45.4			62.0
	SEM	1.77	1.66	2.29			1.58
	Sign.	*	*	**			**
Weeds	HP	5.1 (1.84)	2.6 (1.48)	7.1 (2.28)	(0.128)	***	4.5 (1.93)
	LP	3.0 (1.43)	2.1 (1.29)	5.9 (2.06)			3.6 (1.72)
	SEM	(0.159)	(0.072)	(0.222)			(0.127)
	Sign.	NS	NS	NS			NS

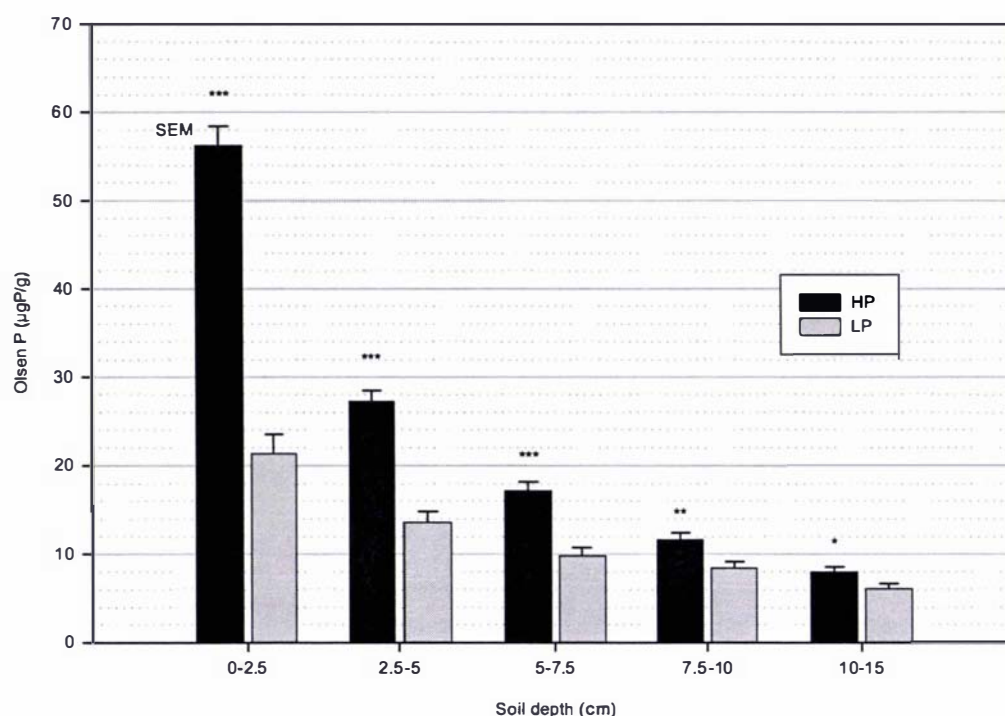
*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except for grass, subterranean clover and All legumes, which did not require transformation. Other legumes data for winter and summer were not analysed, due to very low and erratic appearance.

4.3.2.6.5. Vertical distribution of soil phosphorus

The concentration of available phosphorus in the soil was different at all levels measured. However, differences were greatest in the first layer (0-25mm), where soil-P on HP plots was 56.2 $\mu\text{g/g}$ v 21.4 $\mu\text{g/g}$ on LP plots ($p < 0.001$), a relative difference of 163%. In the second layer (25-50 mm) in HP plots, the soil-P concentration was double

that of LP plots ($27.2 \text{ v } 13.6 \text{ } \mu\text{gP/g}$; $p<0.001$), while on subsequent layers relative differences became smaller (50-75mm; 75%, $p<0.001$; 75-100mm; 39%, $p<0.01$; 100-150mm; 30%, $p<0.05$) (Figure 4.5).

No significant effects nor interactions were recorded for grass suppression or management regime ($p>0.05$).



***, $p<0.001$; **, $p<0.01$; *, $p<0.05$; NS, not significant ($p>0.05$); SEM, standard error of the mean.

Figure 4.5 Vertical distribution of soil-P at different layers under high (HP) and low (LP) soil-P status. *Waipawa*.

4.3.2.6.6. Earthworm population

Earthworm abundance and biomass were not significantly ($p>0.05$) affected by either management regime or soil-P status. The site had an average earthworm abundance of 181 worms/m². Fresh earthworm biomass was 37.1 g/m², while average individual fresh weight was 186 mg.

4.3.3. Ballantrae

At this site, swards were sampled on eight occasions, on 11 July, 6 September, 11 October, 22 November, 12 December 2001, and 3 January, 7 February and 13 March 2002. As for the Waipawa data, standing biomass, botanical composition of the standing biomass and other measurements are presented on a monthly basis, and for the ease of reading, dates in these cases will be hereafter referred to as July, September, October, November, December, January, February and March, in the text and tables. As in the Waipawa site, pre- and post-harvest herbage mass measurements were available, and data for herbage mass accumulation and botanical composition of the accumulated herbage could be generated and these were organised into the same three periods within the season and presented as: *Winter* (July to September; 97 days), *Spring* (September to December; 97 days), and *Summer* (December to March, 91 days). Cumulative herbage mass for a particular period was defined as $\{\Sigma (\text{pre harvest herbage mass}_{(n+1)}) - (\text{post harvest herbage mass}_{(n)})\}$.

4.3.3.1. Temperature and rainfall

The year between May 2001 and April 2002 had a rainfall very close to the average reading registered for the location. However, distribution was different from the average year. The autumn months of May and June had average rainfall, but a relatively dry winter followed, with 30% below average precipitation between July and September. Although August had 22% more rain than average, July had 31% less, and September 77% less than average. On the other hand, spring was a wet season, with a 45% above average rainfall figure. The wettest month by far was December, when the average rainfall for that month almost doubled. The summer rainfall was 11% above average, a result from February being 84% above normal, while January and March were slightly below average (Table 4.22).

Temperature data were again taken from the Pahiatua station for season comparisons, as explained in Chapter 3. The season considered was only 0.3 °C above the yearly average

10-cm soil temperature. In winter, July was on average 1°C colder and August and September 0.9° and 0.7°C warmer than the average temperature registered for those months. The spring months were on average between 0.7° and 2.3°C warmer than normal. Summer was closer to average temperatures, except from February, that was 1.3°C colder than the normal soil temperature recorded. Soil temperatures obtained for the Ballantrae location were always higher than the Pahiatua data, and were on average 2.7°C higher on a seasonal basis (Table 4.22). Soil temperatures recorded at Ballantrae during the 2001/2002 season were higher than those obtained for the previous season, with the exceptions of July (where it was 1°C lower) and March/April, where they were similar. On average, the 2001/02 season was 2.3°C warmer than the season 2000/01 (see also Table 3.23).

Table 4.22 Rainfall and soil temperature (10 cm) for the experimental period and average year at Ballantrae and Pahiatua.

Month	Rainfall (mm)		Soil temp. 10 cm (°C)		
	<i>Ballantrae</i>		<i>Ballantrae</i>	<i>Pahiatua</i> **	
	2001/02 #	Average*	2001/02 #	2001/02	Average***
May	126	130	13.5	11.0	10.2
June	109	108	9.3	7.1	7.7
July	93	135	8.0	6.0	7.0
August	141	116	10.0	8.2	7.3
September	28	123	13.0	10.1	9.4
October	143	120	15.7	13.3	11.8
November	125	101	17.0	14.4	13.7
December	204	105	20.2	18.6	16.3
January	80	89	21.2	17.9	17.4
February	112	61	20.1	16.0	17.3
March	92	105	18.7	15.4	15.1
April	49	98	15.1	12.3	12.6
Annual	1302	1291	15.2	12.5	12.2

* Average 1970-80 from (NZMS, 1983); ** Data supplied by NIWA; *** Average 1992-2002; # Supplied by Agresearch and Hortresearch.

4.3.3.2. *Soil moisture*

After a rewetting from early autumn, the top 50 mm layer of the soil remained slightly above FC at the dates measured, until the end of August. There was a decline in soil moisture by late September, but a recovery thereafter brought the top soil layer again to saturation levels until the end of December. In January, soil moisture fell sharply but remained at intermediate soil moisture levels of 40-50% available water capacity until early March, where it again recovered, but still not reaching FC. The 50-100 mm layer followed a similar pattern of response, but tended to show a more stable soil moisture content over the season (Figure 4.6). Soil moisture content at the surface layers of the soil never approached limiting levels at this site during the 2001/2002 season.

The volumetric soil moisture patterns at four layers between 0-40 cm are described in Figure 4.7 for the spring-summer period, as measured by time domain reflectometry (TDR). During the wettest part of the season (spring), the top layer (0-10cm) showed the highest soil moisture values, reaching saturation levels between mid November to the end of December. The drop in soil moisture after December was very sharp in the top layer, and during the rest of the season the soil had similar moisture levels within the first 30 cm. The moisture in the deeper layer (30-40cm) fell, especially in mid February, but recovered thereafter. The soil moisture levels in the top layers showed a much higher variation, while moisture in deeper layers tended to show a much more stable pattern.

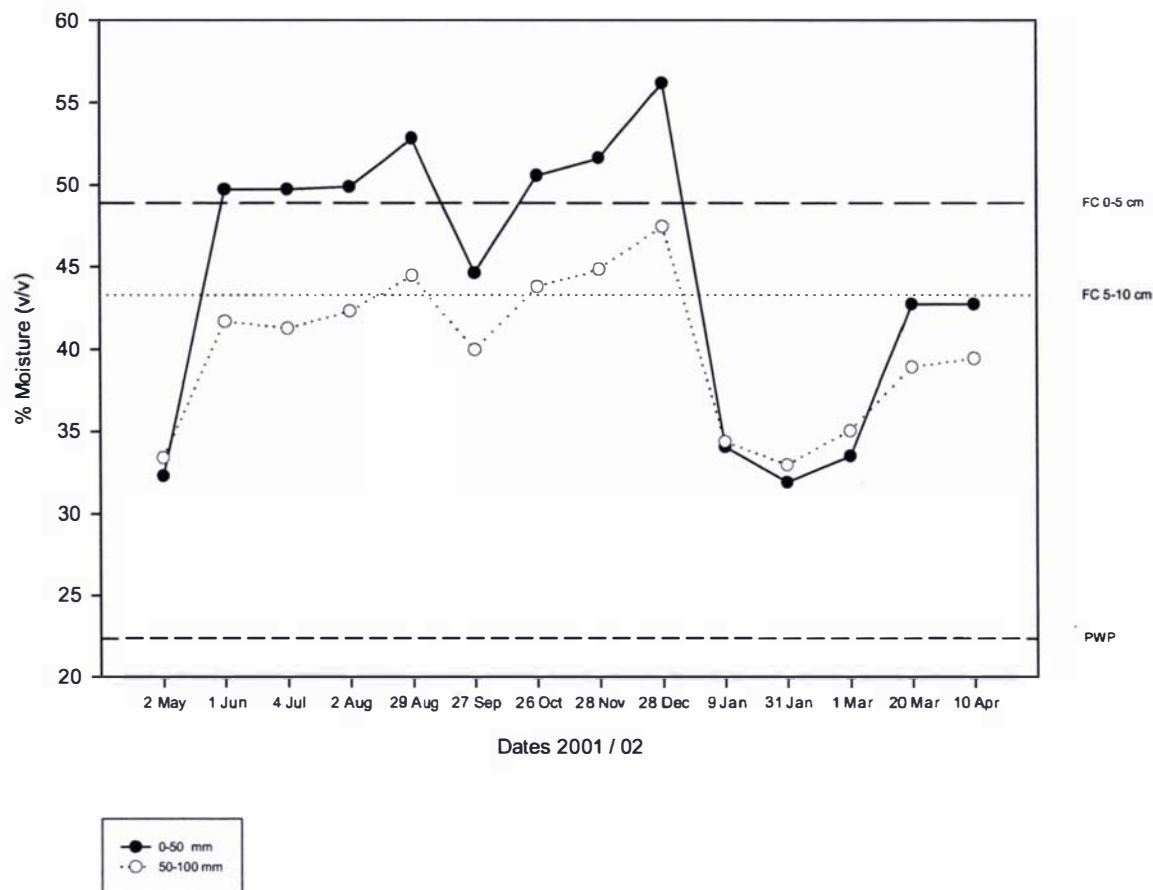


Figure 4.6 Seasonal variation of soil volumetric moisture at the 0-50 mm and 50-100 mm layers of the soil in Ballantrae (2001/02).

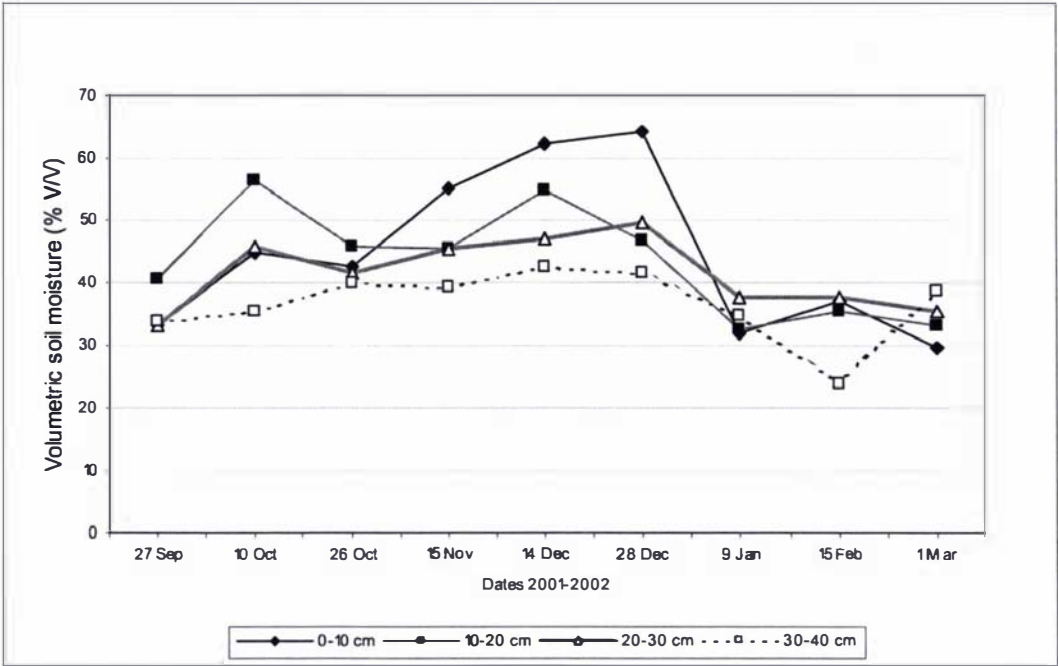


Figure 4.7 Seasonal variation of the volumetric soil moisture (%) at different depths within the 0-40 cm layer during spring and summer. *Ballantrae*.

4.3.3.3. Significance of main effects and interactions

The statistical significance of main effects and some interactions of the different variables analysed at the Ballantrae site are presented in Table 4.23.

Table 4.23 Summary of main effects (management (*manag*), grass suppression (*supp*) and soil-P status (*phos*)), and interactions. Statistical significance. *Ballantrae*.

Main effect or Interaction	----- Standing biomass Total .	Grass	(kg DM/ha) White clover	----- Weeds	Grass %	White Clover %	Weeds %
manag	NS	***	***	***	***	***	***
supp	***	***	***	***	***	***	***
phos	***	NS	***	***	***	***	NS
date	***	***	***	***	***	***	***
manag x date	***	***	***	***	***	***	***
supp x date	***	***	***	***	***	***	***
phos x date	**	*	***	**	***	***	*
manag x supp x date	*	NS	NS	NS	NS	***	NS
manag x phos x date	NS	NS	**	**	NS	***	**
supp x phos x date	NS	NS	NS	NS	NS	**	*

Main effect or Interaction	--- Season herbage accumulation (kg DM/ha) --- Total	Grass.	White clover	Weeds	Sward height cm	Tiller density till/m ²	Grow.pt. density gp/m ²
manag	NS	**	*	NS	NS	NS	NS
supp	***	***	***	***	**	***	**
phos	NS	NS	***	NS	*	*	*
date	***	***	***	***	***	***	***
manag x date	NS	***	*	NS	***	NS	***
supp x date	***	***	***	***	***	***	***
phos x date	***	***	***	NS	***	***	***
manag x supp x date	NS	***	NS	NS	***	***	NS
manag x phos x date	**	NS	***	*	NS	NS	NS
supp x phos x date	NS	NS	NS	NS	NS	NS	*

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; date refers to either "season" (winter, spring, summer) for herbage accumulation data or "month" (Jul – Mar) for standing biomass, botanical composition and plant density data. Botanical composition by percent is based on standing biomass data. NOTE: Interactions are listed if significant ($p < 0.05$) at least for one variable.

4.3.3.4. Effect of grazing

4.3.3.4.1. Sward height

Grazing and cutting management interacted with grass suppression treatments for the variable pre-defoliation grass height (Table 4.24.). Pre-defoliation grass height was significantly lower (at least $p < 0.05$) from July to November on H2 plots, especially when compared to H0 plots. From December onwards, this continued to be the case only on plots under grazing, while cutting plots did not differ significantly ($p > 0.05$). H0 plots under grazing had taller grass heights than H0 plots under cutting between December and March ($p < 0.01$), while in October and November, the opposite was the case. H1 plots did not differ significantly ($p > 0.05$) in grass pre-defoliation height during the season, with the exception of March.

Table 4.24 Effect of grazing/cutting management, and grass suppression on average pre-defoliation grass height (cm), at different dates (2001/2002). *Ballantrae*.

Management	Grass suppression	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
cutting	H0	3.5	3.4	5.6	9.9	5.7	5.9	8.1	6.9		
	H1	2.5	2.3	3.5	6.7	5.2	5.6	7.2	4.9		
	H2	1.9	2.0	1.7	2.8	4.5	5.3	8.0	5.0		
grazing	H0	3.4	2.7	3.3	7.3	8.7	7.7	9.7	9.8		
	H1	2.4	2.0	2.7	5.7	6.9	6.5	8.4	7.7	0.32	***
	H2	2.0	1.1	1.2	2.4	4.1	4.1	5.6	5.4		
SEM		0.21	0.17	0.33	0.76	0.60	0.43	0.58	0.52		
Sign.		***	***	***	***	***	***	***	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean.

Pre-grazing legume height was significantly lower than pre-cutting legume height, between September ($p < 0.001$) and November ($p < 0.01$). However, in December G plots had higher legume pre-defoliation height than C plots ($p < 0.001$). In January and February heights were similar, and in March G plots had again taller legume heights

than C plots ($p < 0.001$) (Table 4.25). However, a *management x grass suppression x date* interaction showed that on G plots only, and for January, February and March, H2 plots had significantly lower legume pre-defoliation heights than H0 plots (2.5 v 5.6 cm, 3.9 v 8.1 cm, and 3.4 v 8.14 cm, for G-H2 v G-H0 on those three months, respectively; $p < 0.001$) and H1 plots (2.5 v 4.4 cm, 3.9 v 6.4 cm, and 3.4 v 5.7 cm, for G-H2 v G-H0 in the same three months, respectively; $p < 0.05$).

Table 4.25 Effect of grazing and cutting management on average pre-defoliation legume height (cm), at different dates (2001/2002). *Ballantrae*.

Factor	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
cutting	1.5	1.5	2.5	5.2	3.6	4.4	6.7	4.2		
grazing	1.4	1.1	1.7	3.8	5.2	4.1	6.1	5.7	0.18	***
SEM	0.07	0.06	0.11	0.34	0.31	0.23	0.36	0.30		
Sign	NS	***	***	**	***	NS	NS	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean.

No significant ($p > 0.05$) effects were recorded for general post-cutting grass heights for any of the grass suppression treatments (Table 4.26). On G plots, grass post-defoliation height was significantly lower on H2 compared to either H0 or H1 from October onwards, differences becoming greater in the summer period ($p < 0.001$), especially in relation to H0 plots. A similar situation occurred when legume post-grazing heights are considered, but in this case differences were significant from the start of the season. Legume post-grazing heights were always lower on H2 plots, compared to H0 and H1 plots, where heights were similar (Table 4.26).

Table 4.26 Management regime and grass suppression on average post-grazing grass and legume height (cm), and general sward height post-cutting at different dates (2001/2002). *Ballantrae*.

Factor		Treat	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
GENERAL	cutting	H0	1.8	1.7	1.6	2.2	2.3	2.3	2.5	2.6	0.18	***
	cutting	H1	1.6	1.4	1.3	2.1	2.1	2.3	2.4	2.4		
	cutting	H2	1.9	1.1	0.8	1.8	1.9	2.3	2.3	2.3		
		SEM	0.14	0.10	0.08	0.26	0.24	0.18	0.36	0.40		
		Sign.	NS	NS	NS	NS	NS	NS	NS	NS		
GRASS	grazing	H0	1.7	1.2	1.5	3.4	4.3	4.5	6.0	6.9	0.18	***
	grazing	H1	1.0	1.0	1.3	3.0	4.0	3.9	4.9	6.0		
	grazing	H2	1.6	1.0	0.9	1.7	2.1	2.0	2.7	3.3		
		SEM	0.14	0.10	0.08	0.26	0.24	0.18	0.36	0.40		
		Sign.	NS	NS	•	**	***	***	***	***		
LEGUMES	grazing	H0	1.0	0.7	1.2	2.7	3.1	3.2	5.1	5.0	0.22	***
	grazing	H1	0.4	0.7	0.9	2.3	3.0	2.7	4.2	4.3		
	grazing	H2	0.9	0.5	0.8	1.5	1.7	1.3	1.8	2.0		
		SEM	0.12	0.04	0.08	0.25	0.31	0.22	0.42	0.50		
		Sign.	**	*	**	**	**	***	***	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean.

4.3.3.4.2. Standing herbage mass and sward composition

Total biomass

On season average, total standing biomass was similar in C and G plots (1658 v 1634 kg DM/ha; $p > 0.05$). However, in September (+45%), October (+39%) and November (+30%), C plots had higher total standing biomass than G plots. The reverse occurred in December and March, where G plots had more standing biomass than C plots (Table 4.27). Also, a *management x grass suppression x date* interaction showed that, only in December, G plots had higher standing biomass than C plots and only at the H0 and H1 levels (1359 v 2155, for C-H0 v G-H0, and 1774 v 2431, for C-H1 v G-H1, respectively; $p < 0.01$).

Grass

Overall, G plots had 12% more grass standing biomass than C plots (1121 v 998 kg DM/ha; $p < 0.001$). This was the result of 49% and 30% more grass biomass on C v G plots in September and October, respectively, and 52% and 73% more grass biomass on G v C plots in December and March (Table 4.27).

Grass content in the standing biomass was on average lower on C v G plots (55.2 v 61.5%; $p < 0.001$). The same pattern of response was observed during the season, except for September-October and December, where grass content in the sward were similar between treatments (Table 4.28).

Legumes

C plots had on season average 16% more WC standing biomass compared to G plots (284 v 245 kg DM/ha; $p < 0.001$). From similar WC biomass levels in July and September, C swards increased their WC pre-harvest biomass to differences of 43% in October, 32% in November, 50% in February and 34% in March, when compared to G plots. In December G plots had significantly ($p < 0.05$) more WC biomass than C plots and was similar in January. The peak values for WC standing biomass were obtained in February (Table 4.27).

WC content in the standing biomass was on average slightly but significantly higher in C v G plots (20.5 v 18.7%; $p < 0.001$). Significant ($p < 0.001$) differences occurred mainly in July and February-March (Table 4.28). A *management x grass suppression x date* interaction showed that, in July, WC percentage differences between C and G plots were significant only at the H2 level (55.3 v 31.9%, for C-H2 v G-H2; $p < 0.001$).

Weeds

On average, C plots had 40% more weed standing biomass than G plots (377 v 269 kg DM/ha; $p < 0.001$). Main differences occurred between September and November, with

contrasts of 66-77% between C and G plots. Thereafter weed standing biomass was similar between treatments (Table 4.27).

Weed content in the standing biomass was significantly higher on C v G plots (24.3 v 19.8%; $p < 0.001$) on annual average basis. However, at individual dates, differences were not significant ($p > 0.05$).

Table 4.27 Effect of cutting and grazing management on standing biomass and biomass composition (kg DM/ha) at different dates. *Ballantrae* (2001-2002).

Component	Treat.	Dates								SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar		
Grass	C	634 (21.8)	555 (19.1)	686 (22.0)	1627 (35.6)	831 (27.0)	1057 (30.5)	1474 (37.5)	1118 (32.5)	(0.85)	***
	G	676 (23.9)	372 (16.0)	529 (19.2)	1388 (33.6)	1265 (33.3)	1167 (33.0)	1639 (39.7)	1929 (42.7)		
	SEM	(0.74)	(0.93)	(0.67)	(1.10)	(1.07)	(1.06)	(1.00)	(1.33)		
	Sign.	NS	*	**	NS	***	NS	NS	***		
White clover	C	83 (8.6)	151 (11.6)	211 (14.2)	385 (19.2)	279 (16.0)	236 (14.9)	499 (21.8)	422 (20.1)	(0.53)	***
	G	88 (8.5)	133 (10.9)	148 (11.4)	292 (16.1)	380 (18.3)	271 (15.6)	333 (17.6)	314 (17.0)		
	SEM	(0.44)	(0.51)	(0.59)	(0.65)	(0.70)	(0.71)	(0.56)	(0.64)		
	Sign.	NS	NS	**	**	*	NS	***	**		
Weeds	C	143 (9.3)	126 (9.3)	260 (14.2)	737 (23.3)	497 (18.5)	586 (19.7)	441 (18.8)	222 (13.4)	(0.74)	***
	G	118 (9.3)	71 (7.4)	157 (11.3)	439 (18.1)	437 (18.3)	381 (17.9)	364 (17.7)	187 (13.0)		
	SEM	(0.44)	(0.56)	(0.49)	(1.10)	(1.13)	(0.94)	(0.94)	(0.56)		
	Sign.	NS	*	***	**	NS	NS	NS	NS		
Total	C	860	833	1158	2749	1608	1879	2413	1763	74.8	***
	G	881	576	834	2119	2082	1819	2336	2428		
	SEM	44.3	55.3	49.9	119.6	88.3	75.3	91.3	133.7		
	Sign.	NS	**	***	***	***	NS	NS	**		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except total biomass (no transformation needed).

Table 4.28 Effect of cutting and grazing management on botanical composition of the standing biomass (%) at different dates. *Ballantrae* (2001-2002).

Component	Treat.	Jul	Sep	Oct	Dates Nov	Dec	Jan	Feb	Mar	SEM	Sign.
Grass	C	58.5 (7.31)	46.6 (5.86)	48.2 (6.05)	53.9 (6.58)	54.0 (6.86)	57.9 (7.12)	61.1 (7.68)	61.1 (7.69)	(0.150)	***
	G	70.1 (8.21)	48.1 (6.15)	47.5 (6.09)	60.2 (7.26)	58.2 (7.31)	62.8 (7.73)	68.8 (8.21)	76.6 (8.71)		
	SEM	(0.150)	(0.198)	(0.120)	(0.210)	(0.179)	(0.195)	(0.113)	(0.088)		
	Sign.	***	NS	NS	*	NS	*	**	***		
White clover	C	23.4 (4.21)	30.4 (5.14)	19.7 (4.35)	15.0 (3.76)	17.0 (3.98)	12.5 (3.44)	20.9 (4.48)	25.3 (4.87)	(0.141)	***
	G	16.3 (3.44)	31.3 (5.31)	24.0 (4.58)	14.4 (3.62)	19.4 (4.14)	15.2 (3.70)	14.6 (3.68)	14.4 (3.61)		
	SEM	(0.126)	(0.178)	(0.178)	(0.119)	(0.146)	(0.160)	(0.081)	(0.145)		
	Sign.	***	NS	NS	NS	NS	NS	***	***		
Weeds	C	18.1 (3.74)	23.0 (4.15)	32.1 (4.78)	31.1 (4.69)	29.0 (4.50)	29.7 (4.51)	18.0 (3.84)	13.7 (3.30)	(0.162)	***
	G	13.7 (3.38)	20.6 (3.91)	28.5 (4.76)	25.4 (4.27)	22.5 (4.17)	22.0 (4.28)	16.6 (3.75)	8.9 (2.77)		
	SEM	(0.179)	(0.182)	(0.134)	(0.157)	(0.225)	(0.184)	(0.202)	(0.092)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.4.3. Population density

TPD was generally similar on both management regimes during the year, except for November, where G plots had a significantly ($p < 0.01$) higher TPD than C plots. However, differences disappeared the following month (Table 4.29). A *management x grass suppression x date* interaction showed that on H2 plots, the tillering pattern under G or C management differed from that observed at main effects level, from December to March. G-H2 had higher TPD than C-H2 plots (5068 v 1781, 5810 v 2650, 9859 v 3180, and 10749 v 5046 tiller/m²; for G-H2 v C-H2, on December, January, February and March, respectively; $p < 0.001$).

White clover GPD was also similar under C and G management, but at the end of the season C plots showed a significantly higher GPD than G plots by 40% (Table 4.29).

Table 4.29 Effect of grazing and cutting management on grass tiller population density (TPD; tiller/m²), and white clover growing point density (GPD; g.p./m²), at different dates. *Ballantrae* (2001/2002).

Factor	Treat	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
TPD	C	9584 (78.1)	11676 (89.2)	10672 (87.7)	6304 (74.5)	7909 (77.9)	8474 (84.4)	7986 (80.8)	10679 (98.6)	(4.44)	***
	G	8467 (73.2)	11520 (87.5)	12029 (93.1)	10375 (96.8)	6771 (76.0)	7386 (82.3)	9647 (94.0)	9167 (91.2)		
	SEM	(4.24)	(6.00)	(5.27)	(4.97)	(5.92)	(3.99)	(5.34)	(4.84)		
	Sign.	NS	NS	NS	**	NS	NS	NS	NS		
GPD	C	1547 (35.9)	1523 (37.0)	2012 (39.8)	2049 (41.3)	1038 (30.2)	938 (29.5)	1713 (39.3)	4189 (63.0)	(2.06)	***
	G	1315 (31.9)	2039 (40.4)	1953 (40.0)	1953 (41.2)	897 (26.3)	932 (28.9)	1418 (35.6)	2984 (52.3)		
	SEM	(2.31)	(2.48)	(3.85)	(3.28)	(1.82)	(1.70)	(1.99)	(2.08)		
	Sign.	NS	NS	NS	NS	NS	NS	NS	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.4.4. Herbage accumulation

Total herbage accumulation

Management regime did not significantly ($p > 0.05$) affect total herbage accumulation in any of the periods considered. Total seasonal herbage production was also similar between grazing and cutting treatments (Table 4.30).

Grass

Grass accumulation was always greater on G plots compared to C plots. The highest herbage accumulation occurred during the summer period. Total seasonal grass accumulated was also significantly ($p < 0.01$) higher on G, with 20% more herbage mass produced than C plots (Table 4.30). A *management x grass suppression x date* interaction showed that grass herbage mass accumulated on G plots in spring and summer was significantly higher only on H2 plots (114 v 15 kg DM/ha and 270 v 88 kg DM/ha, for G-H2 v C-H2 on each period, respectively; $p < 0.001$), while being similar on H1 and H0.

Grass content based on herbage accumulated was higher on G v C plots in every period considered, and also as a season average. Two thirds of herbage accumulated was grass on G plots, while C plots had almost 59% ($p < 0.001$). Grass percentage in the sward was highest in summer on both treatments (Table 4.31). However, a *management x grass suppression x date* interaction indicated that grass content was higher only on H2 plots on G v C plots in winter and spring (44.2 v 10.2% and 24.1 v 6.8%, for G-H2 v C-H2 plots, in winter and spring, respectively; $p < 0.001$). Overall, this was also the case, because differences in grass content between C and G were highest ($p < 0.001$) on G-H2 (37.9%) v C-H2 (22.7%), while less significant ($p < 0.05$) for G-H1 (76.1%) v C-H1 (68.9%), and not significant ($p > 0.05$) at the G-H0 v C-H0 level.

Legumes

During this season, in Ballantrae white clover was the dominant (and almost only) legume species, with very rare occurrences of both suckling clover and subterranean clover. Legume production and composition results are stated in tables as white clover, but they contain in some isolated cases traces of other legumes, which do not have any practical implication on the outcome.

White clover production was 29% higher on C plots compared to G plots, but only in summer, where also the main proportion of WC was produced. Both treatments had similar WC production in winter and spring. Overall, WC herbage accumulation was almost 15% higher on C v G plots (Table 4.30).

WC content based on herbage produced was higher on C plots, but only in winter and summer ($p < 0.001$). However, on an average seasonal basis WC percentage was similar under both management regimes, with a general average of 16.3% (Table 4.31). Only in winter, WC content on C-H2 plots (57.8%) was higher than that on G-H2 plots (34.8%; $p < 0.001$), while similar at H1 or H0 levels, as indicated by a *management x grass suppression x date* interaction.

Weeds

No significant differences were achieved for weed accumulation either on individual periods or on total weed herbage accumulation (Table 4.30).

Although no significant ($p>0.05$) differences were recorded for weed content in the sward at individual periods, the overall seasonal average was significantly ($p<0.05$) higher on C plots compared to G plots (Table 4.31).

Table 4.30 Effect of grazing and cutting management on seasonal and total herbage mass accumulation and botanical composition of herbage accumulated (kg DM/ha). *Ballantrae* (2001/2002).

Component	Treat	Season			SEM	Sign.	Total
		Winter	Spring	Summer			
Grass	C	508 (5.108)	1226 (6.406)	1602 (7.245)	(0.0902)	***	3337 (7.858)
	G	570 (5.792)	1265 (6.729)	2171 (7.536)			4006 (8.132)
	SEM	(0.1016)	(0.0907)	(0.0826)			(0.0618)
	Sign.	***	*	*			**
White clover	C	97 (4.404)	293 (5.617)	518 (6.088)	(0.0831)	***	908 (6.747)
	G	96 (4.324)	294 (5.459)	403 (5.799)			792 (6.544)
	SEM	(0.0704)	(0.0773)	(0.1027)			(0.066)
	Sign.	NS	NS	*			*
Weeds	C	92 (3.535)	487 (5.360)	586 (5.637)	(0.1508)	***	1164 (6.431)
	G	88 (4.125)	386 (5.407)	455 (5.714)			929 (6.515)
	SEM	(0.2125)	(0.1035)	(0.1183)			(0.0689)
	Sign.	NS	NS	NS			NS
Total	C	697 (6.108)	2006 (7.521)	2706 (7.850)	(0.0708)	***	5409 (8.560)
	G	753 (6.334)	1945 (7.473)	3029 (7.933)			5727 (8.609)
	SEM	(0.0803)	(0.0685)	(0.0744)			(0.0473)
	Sign.	NS	NS	NS			NS

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are natural logarithm (log) transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

Table 4.31 Effect of grazing and cutting management on the seasonal proportion of sward components (%) based on herbage accumulated. *Ballantrae* (2001/2002).

Component	Treat	Season			SEM	Sign.	Average
		Winter	Spring	Summer			
Grass	C	52.3	53.7	60.8	1.65	***	58.5
	G	65.1	60.2	70.2			66.7
	SEM	1.35	1.92	1.40			1.13
	Sign.	***	*	***			***
White clover	C	27.2	16.3	18.9	1.03	***	17.7
	G	19.5	16.3	14.2			14.9
	SEM	1.27	0.69	0.92			0.66
	Sign.	***	NS	***			NS
Weeds	C	20.5 (3.98)	30.1 (4.63)	20.3 (3.96)	(0.154)	*	23.8 (4.26)
	G	15.4 (3.65)	23.5 (4.26)	15.6 (3.63)			18.4 (3.92)
	SEM	(0.158)	(0.157)	(0.154)			(0.105)
	Sign.	NS	NS	NS			*

*, p<0.05; **, p<0.01; *** p<0.001; NS, not significant; SEM, standard error of the mean. For weed data, values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.5. *Effect of grass suppression*

4.3.3.5.1. **Sward height**

Legume pre-grazing height was lower on H2 v H0 plots from September onwards, to the end of the season (p<0.001, except in December and February where p<0.01). H0 plots had generally also higher legume pre-grazing height than H1 plots, except in December, where they were similar (p>0.05). From December onwards (with the exception of February) H1 and H2 swards had similar legume pre-grazing heights, but both were lower than that on H0 plots (Table 4.32). Pre-grazing grass height and post-grazing grass and legume height results were presented previously, as grass suppression interacted with management regime.

Table 4.32 Effect of grass suppression on average pre-grazing legume height (cm), at different dates (2001/2002). *Ballantrae*.

Factor	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
H0	1.8	1.7	3.1	6.5	5.3	5.1	7.6	6.6		
H1	1.1	1.3	2.1	4.6	4.4	4.1	6.1	4.6		
H2	1.4	0.8	1.1	2.5	3.4	3.2	5.6	3.7	0.22	***
SEM	0.09	0.07	0.13	0.42	0.38	0.28	0.44	0.36		
Sign	***	***	***	***	**	***	**	***		

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SEM, standard error of the mean.

4.3.3.5.2. Standing herbage mass and sward composition

Total biomass

On annual average, total standing biomass followed the pattern $H1 > H0$ ($p < 0.05$) $> H2$ ($p < 0.001$) (1915, 1784 and 1239 kg DM/ha). From July to November, H0 and H1 had similar total standing biomass, and both had significantly ($p < 0.001$) higher biomass than H2. Between December and February, standing biomass was closer on all three treatments, being not significantly ($p > 0.05$) different in January. By March, H2 had significantly ($p < 0.01$) lower standing biomass, but only when compared to H1 (Table 4.33).

Grass

Grass standing biomass was on average $H0 > H1 > H2$ (1513, 1332 and 333 kg DM/ha; $p < 0.001$). From July to October, the same pattern was maintained, however thereafter H0 and H1 treatments became similar ($p > 0.05$), while H2 had always significantly ($p < 0.001$) lower grass standing biomass compared to H0 or H1. H2 plots had a steady increase in grass standing biomass from November onwards (Table 4.33).

Grass content in the standing biomass was on season average highest in H0, followed by H1 and least in H2 (85.1, 66.2 and 23.7%; $p < 0.001$). This pattern was only changed from January onwards, when H0 and H1 had similar grass content in the sward, which

was always significantly ($p < 0.001$) higher than H2. H2 plots increased the proportion of grass in the standing biomass from 3-5% in spring, to almost 48% in March (Table 4.33).

Legumes

H2 plots had the highest annual average WC standing biomass, followed by H1 and H0 (327, 250 and 215 kg DM/ha; $p < 0.001$). Until October, H1 plots had significantly higher ($p < 0.001$) WC standing biomass, compared to H0 and H2, which were similar. In November, WC biomass increased especially in H2 plots, becoming similar to that on H1 and higher than H0. From December to February, H2 had significantly ($p < 0.001$) more WC biomass than H1 or H0. By March, H2 had similar WC biomass than H0, but significantly ($p < 0.001$) more than H1 (Table 4.33).

Overall, WC content in the standing biomass followed the pattern $H2 > H1 > H0$ (32.3, 14.8 and 11.8%; $p < 0.001$). H2 plots had always significantly ($p < 0.001$) higher WC content in the sward, compared to H0 or H1 plots. H1 plots had significantly ($p < 0.001$) higher WC percentage in the sward than H0 until October, similar ($p > 0.05$) in November to January, and lower in February ($p < 0.001$) and March ($p < 0.01$) (Table 4.34).

Weeds

The season average for weed standing biomass was $H2 > H1 > H0$ (579, 334 and 56 kg DM/ha; $p < 0.001$). Weed biomass was low on H0 plots, the highest being recorded in February, with 137 kg DM/ha. Except for July, where $H0 = H2$, H0 plots had always significantly ($p < 0.001$) lower weed standing biomass compared to H1 and H2. From July to September, weed biomass in $H1 > H2$, similar in October, and the reverse was the case from November onwards, H2 plots having significantly ($p < 0.001$) more weed biomass than H1 plots (Table 4.33).

On season average, weed content in the standing biomass was $H2 > H1 > H0$ (44.0, 19.0 and 3.1%; $p < 0.001$). This pattern was maintained throughout the season.

Table 4.33 Effect of grass suppression on standing biomass and biomass composition (kg DM/ha) at different dates. *Ballantrae* (2001-2002).

Component	Treat.	Dates								SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar		
Grass	H0	1078 (32.7)	922 (29.7)	1168 (33.8)	2382 (48.3)	1537 (38.4)	1537 (39.1)	1726 (41.3)	1753 (41.3)	(1.04)	***
	H1	784 (27.9)	461 (20.9)	645 (25.1)	1992 (44.4)	1331 (36.1)	1381 (36.8)	2043 (44.9)	2016 (43.9)		
	H2	102 (8.0)	8 (2.0)	12 (3.0)	148 (11.2)	277 (16.0)	419 (19.2)	899 (29.6)	801 (27.5)		
	SEM	(0.90)	(1.13)	(0.83)	(1.34)	(1.31)	(1.29)	(1.23)	(1.62)		
	Sign.	***	***	***	***	***	***	***	***		
White clover	H0	43 (6.3)	101 (9.8)	146 (11.5)	262 (15.7)	173 (12.8)	222 (14.4)	395 (19.4)	380 (19.1)	(0.65)	***
	H1	158 (12.2)	247 (15.5)	260 (15.9)	332 (17.6)	296 (16.5)	177 (13.1)	276 (16.3)	255 (15.6)		
	H2	56 (7.1)	78 (8.5)	133 (10.9)	421 (19.6)	519 (22.2)	360 (18.3)	577 (23.4)	470 (21.0)		
	SEM	(0.53)	(0.62)	(0.72)	(0.80)	(0.86)	(0.87)	(0.69)	(0.78)		
	Sign.	***	***	***	***	***	***	***	***		
Weeds	H0	33 (5.1)	21 (3.9)	29 (5.2)	57 (6.8)	47 (5.1)	70 (7.1)	137 (10.7)	56 (7.3)	(0.91)	***
	H1	331 (17.9)	206 (13.5)	297 (17.0)	528 (22.1)	476 (21.2)	343 (18.1)	302 (17.1)	187 (13.4)		
	H2	27 (4.9)	69 (7.7)	300 (16.0)	1180 (33.1)	878 (28.8)	1036 (31.3)	769 (26.9)	371 (18.9)		
	SEM	(0.53)	(0.69)	(0.59)	(1.34)	(1.39)	(1.15)	(1.16)	(0.68)		
	Sign.	***	***	***	***	***	***	***	***		
Total	H0	1155	1043	1342	2701	1757	1830	2258	2188	91.6	***
	H1	1273	915	1202	2852	2102	1901	2621	2458		
	H2	184	155	445	1749	1675	1816	2245	1642		
	SEM	54.2	67.7	61.2	146.4	108.2	92.2	111.8	163.8		
	Sign.	***	***	***	***	*	NS	*	**		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except total biomass (no transformation needed).

Table 4.34 Effect of grass suppression on botanical composition of the standing biomass (%) at different dates. *Ballantrae* (2001-2002).

Component	Treat.	Dates								SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar		
Grass	H0	93.4 (9.66)	87.0 (9.32)	87.0 (9.32)	88.3 (9.39)	86.9 (9.32)	84.2 (9.17)	76.0 (8.70)	78.3 (8.83)	(0.183)	***
	H1	62.0 (7.87)	50.5 (7.01)	53.1 (7.26)	70.4 (8.38)	62.8 (7.90)	72.4 (8.50)	77.9 (8.82)	80.7 (8.97)		
	H2	37.4 (5.75)	4.6 (1.68)	3.4 (1.61)	12.5 (3.00)	18.5 (4.04)	24.4 (4.62)	40.9 (6.32)	47.5 (6.80)		
	SEM	(0.183)	(0.242)	(0.147)	(0.257)	(0.219)	(0.239)	(0.138)	(0.108)		
	Sign.	***	***	***	***	***	***	***	***		
White clover	H0	3.8 (1.86)	10.9 (3.18)	10.7 (3.15)	9.6 (3.04)	10.2 (3.14)	12.0 (3.36)	17.7 (4.11)	19.2 (4.23)	(0.173)	***
	H1	12.1 (3.43)	28.0 (5.23)	21.5 (4.61)	11.7 (3.33)	13.8 (3.61)	9.3 (3.02)	10.4 (3.20)	11.3 (3.25)		
	H2	43.6 (6.17)	53.7 (7.25)	33.4 (5.64)	22.9 (4.70)	30.5 (5.44)	20.2 (4.33)	25.2 (4.93)	29.1 (5.26)		
	SEM	(0.155)	(0.218)	(0.218)	(0.146)	(0.178)	(0.196)	(0.099)	(0.178)		
	Sign.	***	***	***	***	***	***	***	***		
Weeds	H0	2.8 (1.52)	2.1 (1.27)	2.3 (1.46)	2.1 (1.32)	2.9 (1.30)	3.8 (1.67)	6.3 (2.31)	2.5 (1.56)	(0.199)	***
	H1	25.9 (5.04)	21.6 (4.49)	25.4 (4.96)	17.9 (4.19)	23.3 (4.70)	18.3 (4.19)	11.7 (3.38)	8.1 (2.78)		
	H2	19.0 (4.12)	41.7 (6.34)	63.2 (7.88)	64.6 (7.99)	51.0 (7.02)	55.4 (7.33)	33.9 (5.69)	23.3 (4.76)		
	SEM	(0.220)	(0.223)	(0.164)	(0.193)	(0.276)	(0.226)	(0.247)	(0.113)		
	Sign.	***	***	***	***	***	***	***	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.5.3. Population density

TPD on H2 plots was very low at the start, but increased steadily throughout the season. In July, H1 plots had significantly ($p < 0.001$) lower TPD than H0, and differences remained significant ($p < 0.05$) until January, except in November ($p > 0.05$). By late summer, TPD in H1 and H0 became similar. TPD in H2 v H1 plots in February and March was similar, while still significantly ($p < 0.05$) lower than H0 (Table 4.35).

Until September, white clover GPD on H1 plots was significantly ($p < 0.001$) higher than on H0 or H2. GPD on H2 swards increased and was similar to H1 plots in October and November, and both H1 and H2 had higher GPD than H0 on those dates. In December and January, there was a sharper decline in GPD on H1 and H0, compared to H2, and H2 had therefore significantly (at least $p < 0.05$) more GPD than the other treatments. GPD on H2 plots continued to recover towards the end of the season, at a faster rate than

on H1 or H0, and so was significantly higher in February ($p<0.01$) and March ($p<0.001$).

Table 4.35 Effect of grass suppression on grass tiller population density (TPD; tiller/m²), and white clover growing point density (GPD; g.p./m²), at different dates. *Ballantrae* (2001/2002).

Factor	Treat	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
TPD	H0	16930 (129.1)	20609 (142.3)	20471 (141.2)	11863 (107.4)	11672 (106.0)	11767 (107.2)	11343 (104.3)	10707 (102.4)	(5.44)	***
	H1	10114 (96.0)	13739 (110.4)	12594 (108.3)	8566 (88.5)	6923 (77.6)	7792 (85.8)	8587 (87.1)	11163 (99.9)		
	H2	32 (2.0)	445 (12.3)	986 (21.8)	4590 (61.1)	3424 (47.2)	4230 (57.2)	6520 (70.8)	7898 (82.5)		
	SEM	(5.19)	(7.34)	(6.45)	(6.09)	(7.25)	(4.88)	(6.55)	(5.93)		
	Sign.	***	***	***	***	***	***	**	*		
GPD	H0	690 (23.4)	758 (26.4)	735 (26.1)	1033 (30.1)	398 (18.4)	678 (25.1)	1183 (32.7)	3073 (53.8)	(2.53)	***
	H1	2755 (51.6)	3045 (53.5)	2393 (48.2)	2118 (44.5)	753 (26.4)	795 (27.2)	1208 (33.7)	2710 (50.1)		
	H2	848 (26.6)	1540 (36.2)	2820 (45.3)	2853 (49.1)	1753 (39.9)	1333 (35.2)	2308 (46.0)	4976 (69.0)		
	SEM	(2.83)	(3.04)	(4.71)	(4.01)	(2.23)	(2.08)	(2.43)	(2.55)		
	Sign.	***	***	**	**	***	**	***	***		

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.5.4. Herbage accumulation

Total herbage accumulation

Total herbage accumulated in winter was very low in H2 plots, compared to either H0 or H1 ($p<0.001$). H0 had also significantly ($p<0.05$) higher total herbage accumulation than H1 by that time, but both became similar in spring, and H1 produced significantly more than H0 and H2 in the summer period ($p<0.01$). H2 produced still lower total biomass than H1 and H0 in spring, but produced similar herbage mass to H0 and H1 in summer ($p>0.05$). The seasonal total biomass accumulated on H0 and H1 was similar, but H2 swards produced 33% less than H1 and 23% less than H0 plots (Table 4.36).

Grass

In all individual periods, grass accumulated on H2 plots was significantly ($p<0.001$) lower than H0 or H1. Overall, H2 plots produced only 27% and 26% of herbage mass accumulated on H1 and H0 plots, respectively. In winter, H0 plots had significantly

more grass accumulation than H1 plots ($p < 0.001$). Grass production in H0 and H1 plots was similar in spring. However, in summer, H1 plots accumulated more grass than H0 plots ($p < 0.05$). The total seasonal herbage accumulation on H1 and H0 was similar (Table 4.36).

Grass content based on total herbage produced, was significantly ($p < 0.001$) higher on H0 plots, compared to H2 or H1, except in summer, where H0 was similar to H1. H1 plots increased in grass content over the season, and H2 had always the lowest values ($p < 0.001$), compared to either H0 or H1. As a season average, grass content was highest in H0, followed by H1 and lowest in H2 ($p < 0.001$) (Table 4.37).

Legumes

Although WC production was low, H1 produced significantly ($p < 0.001$) more WC in winter, compared to either H0 or H2. H2 plots increased WC production in spring and had similar levels than H1, both having significantly more WC herbage mass accumulation than H0. By summer, H2 plots had 115% and 83% more WC production than H1 ($p < 0.001$) and H0 ($p < 0.01$), respectively. Overall, H0 and H1 had similar WC accumulation, but H2 produced 50% more WC herbage mass than H1 ($p < 0.05$) and 76% more than H0 ($p < 0.001$) (Table 4.36).

WC content in herbage accumulated on H2 plots was always higher than on H1 or H0 plots ($p < 0.001$). H1 had higher white clover content than H0 in winter and spring, but the opposite was the case in summer. On season average, H1 and H0 plots had similar WC content (nearly 12%), while H2 plots had a significantly ($p < 0.001$) higher average value (25.6%) (Table 4.37).

Weeds

Weed levels on H0 and H2 plots in winter were very low, and both treatments had significantly lower weed herbage accumulation than H1 ($p < 0.001$). In spring, summer and also overall, H0 had significantly ($p < 0.001$) less weed accumulation than H2 and H1. H2 had higher weed accumulation than H1 in spring ($p < 0.05$) and differences were

greatest in summer ($p < 0.001$). Overall, H2 plots had 87% more weed production than H1 plots, and more than ten times more than H0 plots ($p < 0.001$) (Table 4.36).

In winter, in H1 and H2, weed levels accounted for about a quarter of total biomass accumulated, while H0 had significantly ($p < 0.001$) lower content. In spring and summer, the weed contents based on herbage produced, were $H2 > H1 > H0$ ($p < 0.001$), the same as on season average. On H2 plots, weeds accounted for 44% of total biomass accumulated in the season, while H1 (16%) and H0 (3%) had lower figures.

Table 4.36 Effect of grass suppression on seasonal and total herbage mass accumulation and botanical composition of herbage accumulated (kg DM/ha). *Ballantrae* (2001/2002).

Component	Treat	Season			SEM	Sign.	
		Winter	Spring	Summer			Total
Grass	H0	1052 (6.918)	2000 (7.495)	1865 (7.447)	(0.1105)	***	4918 (8.462)
	H1	500 (6.050)	1558 (7.315)	2732 (7.846)			4791 (8.447)
	H2	65 (3.381)	179 (4.892)	1062 (6.880)			1306 (7.077)
	SEM	(0.1244)	(0.1110)	(0.1011)			(0.0757)
	Sign.	***	***	***			***
White clover	H0	75 (4.251)	200 (5.193)	375 (5.775)	(0.1018)	***	650 (6.423)
	H1	139 (4.789)	302 (5.634)	319 (5.663)			759 (6.590)
	H2	75 (4.052)	379 (5.787)	687 (6.393)			1141 (6.924)
	SEM	(0.0862)	(0.0947)	(0.1258)			(0.0811)
	Sign.	***	***	***			***
Weeds	H0	32 (2.712)	41 (3.530)	98 (4.284)	(0.1847)	***	171 (5.005)
	H1	194 (5.151)	469 (6.066)	373 (5.849)			1036 (6.903)
	H2	44 (3.627)	799 (6.554)	1091 (6.894)			1933 (7.512)
	SEM	(0.2602)	(0.1268)	(0.1449)			(0.0843)
	Sign.	***	***	***			***
Total	H0	1158 (7.018)	2241 (7.616)	2339 (7.679)	(0.0867)	***	5738 (8.625)
	H1	834 (6.603)	2329 (7.726)	3424 (8.082)			6587 (8.771)
	H2	183 (5.041)	1357 (7.149)	2840 (7.913)			4378 (8.358)
	SEM	(0.0984)	(0.0839)	(0.0910)			(0.0579)
	Sign.	***	***	**			***

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are natural logarithm (log) transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

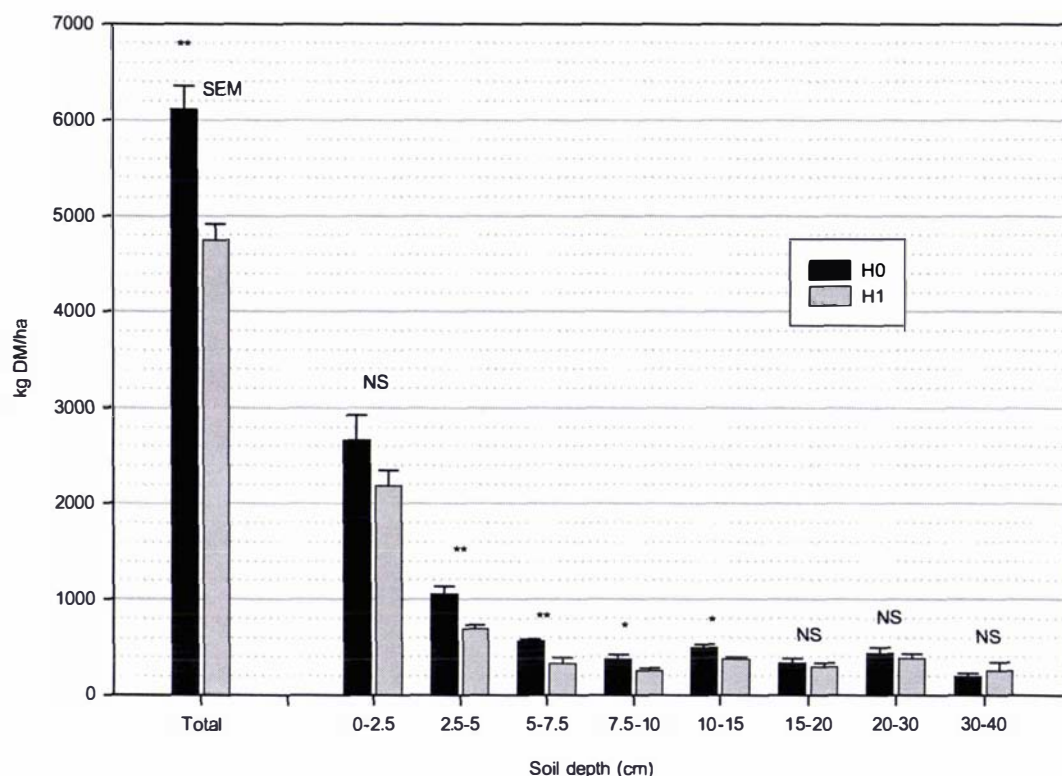
Table 4.37 Effect of grass suppression on the seasonal proportion of sward components (%) based on herbage accumulated. *Ballantrae* (2001/2002).

Component	Treat	Season			SEM	Sign.	Average
		Winter	Spring	Summer			
Grass	H0	90.5	88.6	79.6	2.03	***	85.1
	H1	58.3	66.7	79.2			72.5
	H2	27.2	15.4	37.8			30.3
	SEM	1.66	2.35	1.72			1.38
	Sign.	***	***	***			***
White clover	H0	6.8	9.3	16.3	1.26	***	11.8
	H1	17.0	13.0	9.4			11.5
	H2	46.3	26.6	23.9			25.6
	SEM	1.56	0.84	1.13			0.81
	Sign.	***	***	***			***
Weeds	H0	2.7 (1.50)	2.1 (1.38)	4.2 (1.94)	(0.189)	***	3.2 (1.71)
	H1	24.7 (4.91)	20.2 (4.44)	11.5 (3.33)			16.0 (3.96)
	H2	26.5 (5.04)	58.0 (7.53)	38.3 (6.10)			44.1 (6.60)
	SEM	(0.194)	(0.192)	(0.188)			(0.128)
	Sign.	***	***	***			***

*, $p<0.05$; **, $p<0.01$; *** $p<0.001$; NS, not significant; SEM, standard error of the mean. For weed data, values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.5.5. Root mass

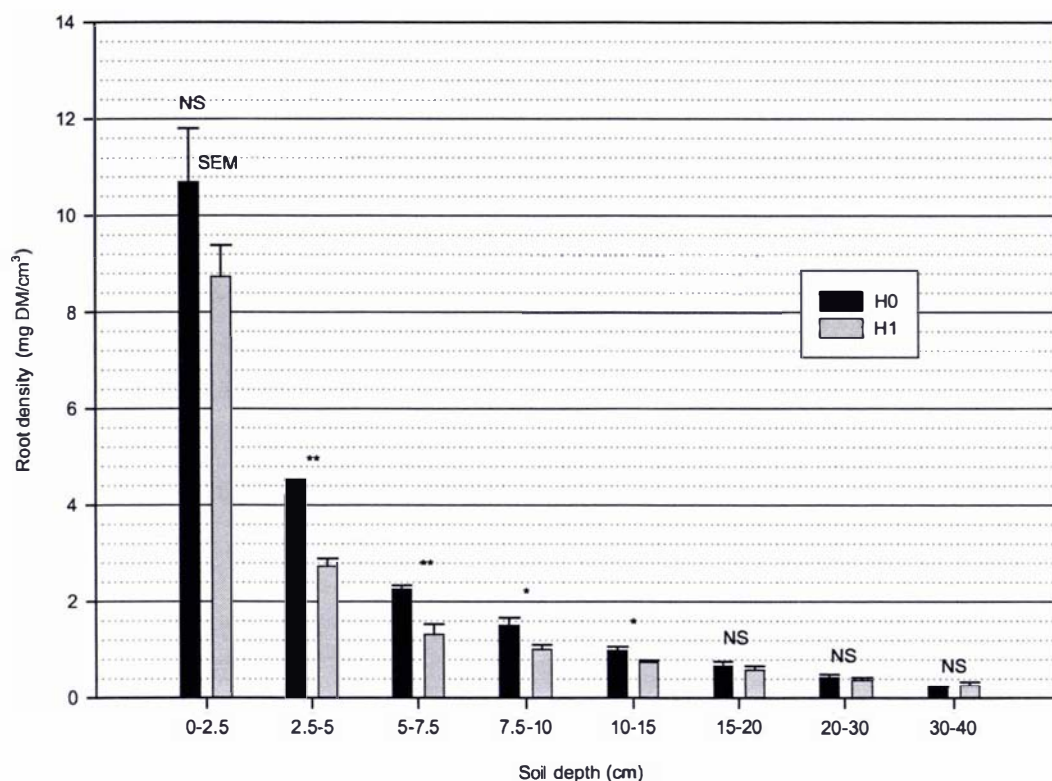
Vertical distribution of the root mass within the 0-40 cm layer of the soil (expressed as kg DM/ha), is presented in Figure 4.8, for two contrasting treatments. Root mass at the surface 0-25 mm layer was similar on the H0 swards (grass dominated) v H1 swards (grass suppressed, more legume). In subsequent layers, down to the 100-150 mm level, root mass of H0 plots was significantly higher ($p<0.01$ in 25-50 and 50-75 mm layers; $p<0.05$ in 75-100 and 100-150 mm layers). In the lower levels of the soil profile considered, root mass distribution was similar for both treatments. The total root mass in the 0-40 cm layer was 29% higher in H0 swards compared to H1 plots (6118 v 4752 kg DM/ha, respectively). H0 and H1 plots had 43 and 46% of total root mass in the first 2.5 cm of the soil. The cumulative total root DM at the 5cm, 10cm, 15 cm, 20 cm and 30 cm levels was, 61%, 76%, 84%, 90% and 97% for H0 plots; and 61%, 73%, 81%, 87% and 95% for H1 plots.



***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$); SEM, standard error of the mean.

Figure 4.8 Vertical distribution of the root mass at different layers for grass dominated (H0) and legume dominated (H1) swards, during the active legume-growing period in *Ballantrae*.

As at Waipawa, root density declined sharply from the top soil layers to the deeper layers within the measured soil profile. Root density in the top layer was similar on H0 v H1 plots. In the 2.5-5 cm, 5-7.5 cm, 7.5-10 cm and 10-15 cm, root density was significantly higher (at least $p < 0.05$) in H0 than H1 plots. There was a considerable drop in root density from the top layer to the layer immediately underneath (60% in H0 and 68% in H1). The decline thereafter was much less pronounced. Root density was similar for H0 and H1 plots under 150 mm depth (Figure 4.9).



***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$); SEM, standard error of the mean.

Figure 4.9 Vertical distribution of the root density at different layers for grass dominated (H0) and legume dominated (H1) swards, during the active legume-growing period in *Ballantrae*.

4.3.3.6. Effect of soil phosphorus status

4.3.3.6.1. Sward height

Grass pre-defoliation height was significantly ($p < 0.05$) higher on HP plots compared to LP swards from November onwards, to the end of the season. A similar response was recorded for legume pre-defoliation height, which was also higher on HP v LP plots between November and March. The pattern of response followed the one observed for grass (Table 4.38). Post-defoliation heights did not differ significantly ($p > 0.05$) between HP and LP plots (not shown).

Table 4.38 Effect of soil-P status on average pre-defoliation grass and legume height (cm), at different dates (2001/2002). *Ballantrae*.

	Factor	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
GRASS	HP	2.6	2.3	3.2	6.6	6.5	6.2	8.7	7.1	0.32	***
	LP	2.7	2.2	2.8	5.0	5.3	5.5	7.0	6.2		
	SEM	0.12	0.10	0.19	0.44	0.35	0.25	0.33	0.30		
	Sign.	NS	NS	NS	*	*	*	**	*		
LEGUME	HP	1.4	1.3	2.2	5.2	5.1	4.7	7.5	5.4	0.18	***
	LP	1.4	1.2	2.0	3.8	3.6	3.6	5.3	4.5		
	SEM	0.07	0.06	0.11	0.34	0.31	0.23	0.36	0.30		
	Sign.	NS	NS	NS	**	**	**	***	*		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean.

4.3.3.6.2. Standing herbage mass and sward composition

Total biomass

On average, HP plots had 13% more total standing biomass than LP plots (1749 v 1543 kg DM/ha; $p < 0.001$). Differences for HP and LP were significant (at least $p < 0.05$) between October and February, ranging between 13% to 24% more total biomass on HP v LP plots.

Grass

No significant ($p > 0.05$) differences were recorded for P effects on grass standing biomass on an annual average or monthly basis, except for a slight difference ($p < 0.05$) in July (Table 4.39). The annual average for grass standing biomass was 1060 kg DM/ha.

On annual average, grass content in the standing biomass was lower in HP v LP (55.0 v 61.7%; $p < 0.001$). The same pattern was observed on a date basis, except between October and December, where HP and LP had similar ($p > 0.05$) grass content (Table 4.40).

Legumes

HP plots had significantly more WC standing biomass than LP plots (325 v 203 kg DM/ha; $p < 0.001$). This was the case for all dates considered, differences being highest between November and February, where HP plots had between 68-87% more WC biomass than LP plots (Table 4.39). A *management x P x date* interaction showed that in November and December, differences in WC biomass due to soil-P level were significant only on G plots (406 v 177, and 523 v 237 kg DM/ha, for G-HP v G-LP plots, for November and December, respectively; $p < 0.001$).

On average, WC content in the standing biomass was higher on HP v LP plots (22.7 v 16.6%; $p < 0.001$). The main differences occurred from November onwards (Table 4.40). A *management x P x date* interaction showed that in July and November, WC content in the sward was higher on HP v LP only in G plots (26.1 v 6.5%, and 18.3 v 10.6%, for G-HP v G-LP, in July and November, respectively; $p < 0.001$), while it was similar on C plots. Further, a *grass suppression x P x date* interaction indicated that in January and February, differences in WC content due to soil-P levels were observed only on H0 plots (17.4 v 6.7%, and 23.1 v 12.4%, for H0-HP v H0-LP, in January ($p < 0.01$) and February ($p < 0.001$), respectively), and not in the grass suppressed plots.

Weeds

Overall, HP plots had a higher weed content in the sward than LP plots (360 v 286 kg DM/ha; $p < 0.001$). Differences between treatments were only significant ($p < 0.01$) in September and November (Table 4.39). In September and January, differences between HP and LP plots in weed percentage were only significant in C plots, but not in G-plots (183 v 70 and 878 v 597 kg DM/ha, for C-HP v C-LP, in September ($p < 0.001$) and January ($p < 0.05$)), as shown by a *management x P x date* interaction.

Average weed content in the standing biomass was not significantly ($p > 0.05$) different between HP and LP treatments, with a general average of 22.1%. Only in September, HP plots showed significantly ($p < 0.05$) higher weed content than LP plots (Table 4.40).

A grass suppression $\times$ P $\times$ date interaction further showed that, for that date the differences occurred mostly at the H1 level (30.4 v 12.8%, for H1-HP v H1-LP; $p < 0.01$). Also, in September and January, HP plots had higher weed percentage than LP plots, but

Table 4.39 Effect of soil-P status on standing biomass and biomass composition (kg DM/ha) at different dates. *Ballantrae* (2001-2002).

Component	Treat.	Dates								SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar		
Grass	HP	607 (21.6)	433 (16.8)	639 (21.2)	1554 (35.4)	1160 (31.2)	1095 (31.3)	1560 (38.6)	1468 (36.7)	(0.85)	***
	LP	703 (24.1)	494 (18.2)	577 (20.1)	1460 (33.8)	936 (29.1)	1129 (32.2)	1553 (38.6)	1578 (38.4)		
	SEM	(0.74)	(0.93)	(0.67)	(1.10)	(1.07)	(1.06)	(1.00)	(1.33)		
	Sign.	*	NS	NS	NS	NS	NS	NS	NS		
White clover	HP	101 (9.5)	159 (12.0)	208 (13.6)	425 (20.1)	426 (19.6)	317 (17.3)	533 (22.6)	429 (20.3)	(0.53)	***
	LP	70 (7.6)	125 (10.5)	151 (12.0)	252 (15.2)	233 (14.7)	189 (13.2)	300 (16.8)	308 (16.8)		
	SEM	(0.44)	(0.51)	(0.59)	(0.65)	(0.70)	(0.71)	(0.56)	(0.64)		
	Sign.	**	*	NS	***	***	***	***	***		
Weeds	HP	143 (9.5)	132 (9.7)	227 (13.0)	715 (23.0)	444 (17.7)	544 (20.2)	455 (19.3)	218 (13.6)	(0.74)	***
	LP	117 (9.1)	65 (7.0)	190 (12.4)	462 (18.4)	490 (19.0)	423 (17.5)	350 (17.2)	191 (12.7)		
	SEM	(0.44)	(0.56)	(0.49)	(1.10)	(1.13)	(0.94)	(0.94)	(0.56)		
	Sign.	NS	**	NS	**	NS	NS	NS	NS		
Total	HP	852	725	1074	2694	2030	1957	2548	2115	74.8	***
	LP	889	685	918	2175	1660	1740	2202	2076		
	SEM	44.3	55.3	49.9	119.6	88.3	75.3	91.3	133.7		
	Sign.	NS	NS	*	**	**	*	*	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means. Data were square root transformed, except total biomass (no transformation needed).

Table 4.40 Effect of soil-P status on botanical composition of the standing biomass (%) at different dates. *Ballantrae* (2001-2002).

Component	Treat.	Dates								SEM	Sign.
		Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar		
Grass	HP	58.3 (7.29)	42.7 (5.61)	48.9 (6.02)	53.5 (6.72)	54.7 (6.94)	56.2 (7.11)	60.8 (7.68)	64.8 (7.95)	(0.150)	***
	LP	70.3 (8.23)	52.0 (6.39)	46.8 (6.11)	60.6 (7.12)	57.4 (7.23)	64.5 (7.74)	69.0 (8.22)	72.8 (8.45)		
	SEM	(0.150)	(0.198)	(0.120)	(0.210)	(0.179)	(0.195)	(0.113)	(0.088)		
	Sign.	***	**	NS	NS	NS	*	**	***		
White clover	HP	26.4 (4.47)	33.3 (5.44)	21.2 (4.38)	17.1 (4.00)	21.9 (4.45)	16.5 (3.94)	21.7 (4.54)	23.4 (4.65)	(0.141)	***
	LP	13.3 (3.18)	28.4 (5.00)	22.5 (4.55)	12.4 (3.37)	14.5 (3.68)	11.2 (3.19)	13.8 (3.62)	16.4 (3.83)		
	SEM	(0.126)	(0.178)	(0.178)	(0.119)	(0.146)	(0.160)	(0.081)	(0.145)		
	Sign.	***	NS	NS	***	***	**	***	***		
Weeds	HP	15.3 (3.49)	24.1 (4.32)	29.9 (4.61)	29.4 (4.62)	23.4 (4.06)	27.4 (4.56)	17.4 (3.82)	11.8 (3.11)	(0.162)	***
	LP	16.5 (3.63)	19.5 (3.75)	30.7 (4.92)	27.0 (4.34)	28.1 (4.62)	24.3 (4.23)	17.2 (3.77)	10.8 (2.96)		
	SEM	(0.179)	(0.182)	(0.134)	(0.157)	(0.225)	(0.184)	(0.202)	(0.092)		
	Sign.	NS	*	NS	NS	NS	NS	NS	NS		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

only under cutting (28.3 v 17.6%, and 34.4 v 24.9%, for C-HP v C-LP, in September ($p < 0.01$) and January ($p < 0.05$), respectively), as indicated by a *management x P x date* interaction.

4.3.3.6.3. Population density

TPD of HP and LP plots was similar from July to December. From January onwards, LP plots had higher TPD than HP swards (Table 4.41).

White clover GPD was significantly ($p < 0.05$) higher on HP v LP plots at the start of the season (by 56%). Although there seemed to be a trend of HP plots maintaining a higher GPD than LP swards over spring and early summer, differences were not significant ($p > 0.05$). In February and March, HP had again significantly ($p < 0.001$) higher WC GPD than LP plots (Table 4.41). A *grass suppression x P x date* interaction showed that HP plots in March had higher white clover GPD compared to LP plots in H1 (3890 v 1530

g.p./m², respectively; $p < 0.001$) and H2 (5776 v 4176 g.p./m², respectively; $p < 0.05$), but not on H0 plots (3350 v 2795 g.p./m², respectively; $p > 0.05$).

Table 4.41 Effect of soil-P status on grass tiller population density (TPD; tiller/m²), and white clover growing point density (GPD; g.p./m²), at different dates. *Ballantrae* (2001/2002).

Factor	Treat	Jul	Sep	Oct	Nov	Dec	Jan	Feb	Mar	SEM	Sign.
TPD	HP	8234 (70.8)	12955 (90.9)	12573 (96.0)	7527 (79.2)	7273 (74.8)	6672 (75.3)	6629 (73.8)	8389 (86.3)	(4.44)	*
	LP	9817 (80.6)	10241 (85.8)	10128 (84.9)	9152 (92.1)	7407 (79.1)	9188 (91.4)	11004 (101.0)	11456 (103.6)		
	SEM	(4.24)	(6.00)	(5.27)	(4.97)	(5.92)	(3.99)	(5.34)	(4.84)		
	Sign.	NS	NS	NS	NS	NS	**	***	*		
GPD	HP	1742 (37.8)	2050 (41.1)	2365 (43.2)	2372 (45.6)	1145 (30.7)	1048 (31.4)	2032 (43.6)	4339 (64.3)	(2.06)	***
	LP	1120 (30.0)	1512 (36.4)	1600 (36.6)	1630 (36.8)	790 (25.8)	822 (26.9)	1100 (31.3)	2834 (51.0)		
	SEM	(2.31)	(2.48)	(3.85)	(3.28)	(1.82)	(1.70)	(1.99)	(2.08)		
	Sign.	*	NS	NS	NS	NS	NS	***	***		

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.6.4. Herbage accumulation

Total herbage accumulation

Total herbage accumulated in winter was significantly ($p < 0.001$) higher on LP plots than HP plots (Table 4.42). As shown by the interaction *management* $\times$ *P* $\times$ *date*, this was mostly because C-LP plots produced more total biomass than C-HP plots (897 v 497 kg DM/ha; $p < 0.001$), while differences in G plots in winter were not significant ($p > 0.05$).

Grass

Grass accumulation was significantly ($p < 0.001$) higher on LP v HP plots only in winter. During the rest of the season, and also overall, grass produced was similar under both soil-P levels (Table 4.42).

Grass content based on herbage accumulated, was significantly ($p < 0.001$) higher on LP v HP plots, except in spring, where it was similar (Table 4.43). Overall, LP plots

averaged 66% grass, compared to 59% on LP plots ($p < 0.001$). An interaction for the combination of *management* $\times$ *P* $\times$ *date* indicated that, in winter only, LP plots had higher grass content compared to HP plots under grazing (75.0 v 55.2%, for G-LP v G-HP, respectively; $p < 0.001$), while it was similar on C plots. Also, a *grass suppression* $\times$ *P* $\times$ *date* interaction showed that, also in winter only, LP plots had higher grass content than HP plots only in the H1 and H2 treatments (65.4 v 51.2%, for H1-LP v H1-HP, respectively; $p < 0.01$; and 39.2 v 15.3%, for H2-LP v H2-HP, respectively; $p < 0.001$), while on H0 plots differences were not significant (91.4 v 89.7%, for H0-LP v H0-HP, respectively; $p > 0.05$).

Legumes

WC accumulation for HP v LP was similar in winter, but 65% and 62% higher in spring ($p < 0.001$) and summer ($p < 0.01$) respectively. Overall, HP plots produced 53% ($p < 0.001$) more WC than LP swards (Table 4.42). A *management* $\times$ *P* $\times$ *date* interaction showed, particularly in spring, that WC produced on C plots was similar for HP and LP ($p > 0.05$), while it was significantly higher on G-HP v G-LP (403 v 184 kg DM/ha, respectively; $p < 0.001$).

WC content in herbage produced was significantly ($p < 0.001$) higher on HP v LP plots, for all periods considered. On average, HP plots contained 19.3% of WC, while only 13.3% on LP plots (Table 4.43). However, the interaction of *management* $\times$ *P* $\times$ *date* showed, that differences in WC content were higher on HP v LP plots under grazing conditions (28.6 v 10.4%, and 20.8% v 11.8%, for G-HP v G-LP, in winter and spring, respectively; $p < 0.001$), compared to the cutting regime (28.7 v 25.7%; $p > 0.05$, and 17.8 v 14.7%; $p < 0.05$, for C-HP v C-LP, in winter and spring, respectively). On a season average, differences in WC content were also higher for G plots (19.3 v 10.6%, for G-HP v G-LP, respectively; $p < 0.001$) than for C plots (19.4 v 16.1%, for C-HP v C-LP; $p < 0.05$). Moreover, a *grass suppression* $\times$ *P* $\times$ *date* interaction indicated that differences in WC content between HP and LP were highest on H2 plots, especially in winter (59.6

v 33.1%; $p < 0.001$) and spring (32.4 v 20.7%; $p < 0.001$), but also on season average (30.8 v 20.4%; $p < 0.001$).

Weeds

Weed biomass produced on HP and LP plots was similar for the periods considered and also for the season as a whole (Table 4.42). However, the interaction *management x soil-P x date* indicated that in summer, on C plots only, weed biomass produced was higher on HP v LP (736 v 436 kg DM/ha; $p < 0.05$). This was also the case for the overall weed biomass accumulation (1357 v 971 kg DM/ha, for C-HP v C-LP; $p < 0.05$).

No significant differences ($p > 0.05$) were recorded for weed content in the sward, between HP and LP plots, with a season average of 21% (Table 4.43).

Table 4.42 Effect of soil-P status on seasonal and total herbage mass accumulation and botanical composition of herbage accumulated (kg DM/ha). *Ballantrae* (2001/2002).

Component	Treat	Season			SEM	Sign.	
		Winter	Spring	Summer			Total
Grass	HP	421 (5.068)	1279 (6.540)	1801 (7.350)	(0.0902)	***	3501 (7.941)
	LP	657 (5.832)	1212 (6.594)	1972 (7.431)			3841 (8.049)
	SEM	(0.1016)	(0.0907)	(0.0826)			(0.0618)
	Sign.	***	NS	NS			NS
White clover	HP	92 (4.359)	365 (5.771)	570 (6.173)	(0.0831)	***	1027 (6.848)
	LP	100 (4.369)	221 (5.304)	351 (5.713)			672 (6.443)
	SEM	(0.0704)	(0.0773)	(0.1027)			(0.0663)
	Sign.	NS	***	**			***
Weeds	HP	84 (3.898)	478 (5.390)	582 (5.804)	(0.1508)	***	1143 (6.552)
	LP	96 (3.762)	395 (5.377)	459 (5.548)			951 (6.395)
	SEM	(0.2125)	(0.1035)	(0.1183)			(0.0689)
	Sign.	NS	NS	NS			NS
Total	HP	597 (6.002)	2122 (7.566)	2952 (7.916)	(0.0708)	***	5672 (8.604)
	LP	853 (6.440)	1829 (7.428)	2783 (7.867)			5464 (8.566)
	SEM	(0.0803)	(0.0685)	(0.0744)			(0.0473)
	Sign.	***	NS	NS			NS

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. Values in brackets are natural logarithm (log) transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

Table 4.43 Effect of soil-P status on the seasonal proportion of sward components (%) based on herbage accumulated. *Ballantrae* (2001/2002).

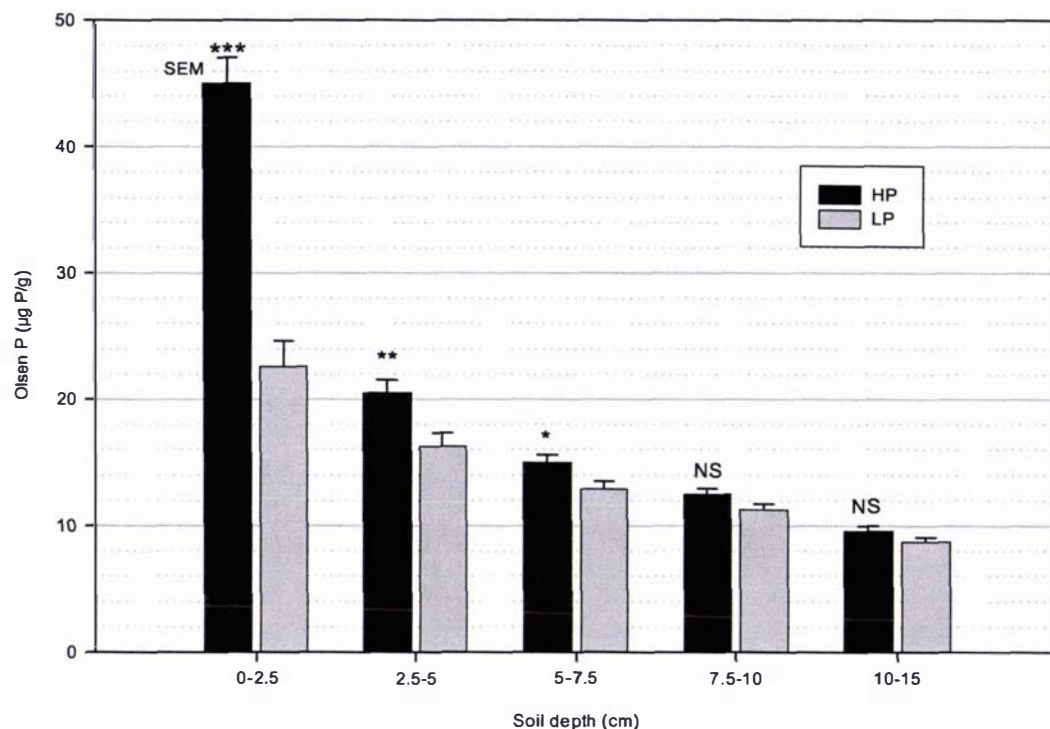
Component	Treat	Season			SEM	Sign.	Average
		Winter	Spring	Summer			
Grass	HP	52.0	54.3	61.6	1.65	***	59.2
	LP	65.3	59.6	69.4			66.1
	SEM	1.35	1.92	1.40			1.13
	Sign.	***	NS	***			***
White clover	HP	28.7	19.3	19.8	1.03	***	19.3
	LP	18.1	13.3	13.3			13.3
	SEM	1.27	0.69	0.92			0.66
	Sign.	***	***	***			***
Weeds	HP	19.3 (4.00)	26.4 (4.39)	18.6 (3.91)	(0.154)	**	21.5 (4.15)
	LP	16.6 (3.63)	27.2 (4.51)	17.4 (3.67)			20.6 (4.03)
	SEM	(0.158)	(0.157)	(0.154)			(0.105)
	Sign.	NS	NS	NS			NS

*, $p < 0.05$; **, $p < 0.01$; *** $p < 0.001$; NS, not significant; SEM, standard error of the mean. For weed data, values in brackets are square root transformations, with corresponding SEM values also in brackets. Values without brackets are original (untransformed) means.

4.3.3.6.5. Vertical distribution of soil phosphorus

A very uneven vertical distribution of available phosphorus was observed between layers of the soil. Differences were greatest in the first layer (0-25mm), where soil-P on HP plots was double that on LP plots (45.0 $\mu\text{g/g}$ v 22.6 $\mu\text{g/g}$, respectively; $p < 0.001$). In the second layer (25-50 mm) HP plots had 26% higher soil-P concentration than LP plots (20.5 v 16.3 $\mu\text{gP/g}$, respectively; $p < 0.01$), while on the 50-75 mm soil layer differences between HP and LP plots were 16% (15.0 v 12.9 $\mu\text{gP/g}$, respectively; $p < 0.05$). On subsequent layers differences between HP and LP plots were not significant ($p > 0.05$) (Figure 4.10).

No significant effects nor interactions were recorded for grass suppression or management regime ($p > 0.05$).



***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$); SEM, standard error of the mean.

Figure 4.10 Vertical distribution of soil-P at different layers under high and low soil-P status. *Ballantrae*.

4.3.3.6.6. Earthworm population

Earthworm abundance and biomass were not significantly ($p > 0.05$) affected by either management regime or soil-P status. The site had an average earthworm abundance of 48 worms/m². Fresh earthworm biomass was 39.0 g/m², while average individual fresh weight was 955 mg, much heavier than at Waipawa.

4.4 DISCUSSION

4.4.1. Year effects on summer-dry hill country pastures

The experimental period between autumn 2000 and autumn 2002 was marked by two very contrasting seasons in Waipawa, where rainfall was 8% and 30% lower in spring and summer 2000/01, respectively, while it was 69% and 31% higher, for the same periods in 2001/02, respectively, compared to the 35-year average. This contrast is a reflection of the high variability of moisture patterns that is a characteristic of summer-dry areas in New Zealand (Radcliffe, 1975), and in these experiments was seen to dramatically affect the abundance and production of legumes. During the first year, low summer soil moisture levels caused pasture growth to practically cease by December, while in the second year swards showed active growth between December and March. Based on a similar annual average total standing biomass in Year 1 and Year 2 (1988 v 2171 kg DM/ha), comparable H0 swards (under short cutting conditions) had on average in Year 2 v Year 1: 8.3% v 3.1% white clover, 37.9% v 11.6% subterranean clover, and 4.5% v 6.7% of other legumes. This meant a 2.4 fold increase in legume abundance in the sward (from 21.4% in Year 1 to 50.6% in Year 2) mostly due to better moisture availability and distribution in the season. In the usually summer-dry Waipawa site, on average 43% of total WC, 22% of total SC, 27% of total legumes and 36% of total herbage accumulation occurred during the exceptionally wet summer in Year 2. The suitability of subterranean clover to these conditions is highlighted by the fact that in contrast to white clover most of its production occurred before the onset of summer (Rickard and Radcliffe, 1976, Frame *et al.*, 1998). This gives an insight into the magnitude of moisture constraints on inter-annual production and composition variability of hill pastures in summer-dry areas.

Results from cages in the grazed area around the experiment (M.H.Gray, personal communication) showed also contrasting legume performance in the two seasons

(Table 4.44). This stresses the importance of soil moisture distribution patterns and how they can affect the composition of swards in contrasting seasons, being a key factor in the definition of legume abundance in summer-dry hill country pastures. Other factors which are discussed later will interact, but are likely to be subordinate to soil moisture conditions.

Table 4.44 Total and summer herbage accumulation and legume performance on contrasting seasons in Waipawa.

Variable		2000/01	2001/02
Total herbage accumulation	kg DM/ha	6956	9445
Legume herbage mass	kg DM/ha	661	3021
Average legume content	%	9.5	32.0
Average summer herbage accumulation	kg DM/ha/d	6.0	32.6
Average summer legume accumulation	kg DM/ha/d	0.2	4.2

Adapted from data supplied by M. Gray, Agresearch. Data were derived from serial harvests of cages within the grazed area around the experimental site in Waipawa (north aspect). Summer data=Jan-Mar.

4.4.2. Magnitude of treatment effects

The treatments imposed produced different, and sometimes contrasting effects on the various legume-related variables considered in this study. A summary of the main effects observed on legume abundance in the sward is presented in Table 4.45. The results are discussed and, when applicable, comparisons are drawn with results from the previous season.

Table 4.45 Summary of the magnitude of treatment effects on the sward legume content white clover growing point density and subterranean clover plant density, during the main legume growing period, at the Waipawa (Sep-Feb) and Ballantrae sites (Nov-Mar).

Factor	White clover	Subterranean clover	Other legumes	All legumes	WC GPD	SC PD	White clover	WC GPD
Site →	Waipawa						Ballantrae	
Effect								
grazing	+	---	++	-	+++++	---	-	---
H1 v H0	+++++	--	---	+++	+++++	---	-	+++++
H2 v H0	+	+++	+++	++++	++	+++	+++	+++++
H2 v H1	---	++++	++++	++	---	+++++	+++	+++++
P application	+++	-	-	++	+++++	---	++	+++++

Magnitude of responses based on average legume abundance and WC-GPD and SCPD percentage points change by effect of treatments, during the main legume growing period at each site. (+ or -, <5%; ++ or --, 5-10%; +++ or ---, 10-20%; ++++ or ----, 20-30%; +++++ or -----, >30%)

4.4.3. Management regime

In Waipawa, swards under grazing had on average more grass, more white clover, more “other legumes” component, and less subterranean clover than those under cutting conditions. The overall effect of grazing on the total legume abundance was slightly negative on a standing biomass basis. The stronger negative effect of grazing on subterranean clover (Table 4.5) may be partly related to the close-to-ground legume post-grazing heights, especially observed on grass suppressed plots in winter and early spring, when the main accumulation of SC occurs, but also thereafter. Post-grazing observations on individual SC plants that showed complete removal of leaf area seem to confirm this. Sheath and Broom (1985b) observed higher SC levels and regeneration potential on more laxly grazed hill pastures compared to hard grazed swards, while Cayley *et al* (1998) in Australia report an average 10% decline in annual net production of ryegrass-SC pastures subjected to hard grazing. Higher residual grass height on grazed plots occurred after the onset of grass flowering (early November) (Table 4.4),

which may partly explain the higher total and grass herbage accumulation observed in G v C (Table 4.8), especially in spring and summer, as shown by Brougham (1960). Intermittent rotational sheep grazing as used in this trial was not capable of adequately controlling the surplus grass growth during late spring, which is sometimes done by introducing cattle (McCall *et al.*, , Gillingham *et al.*, 1998). Although differences observed in grass and total standing biomass between C and G did not result in significant differences in tiller population density at any time of the year, grazed plots showed higher WC growing point density, and lower SC plant density in Spring. Up to late Spring, there was evidence of negative effects of SC plant density on WC growing point density and WC standing biomass:

$$\text{GPD} = 2160 - 4.55 (\text{SCPD}) \quad (r = -0.72; n=8; p<0.001)$$

$$\text{WC} = 1057 - 3.29 (\text{SCPD}) \quad (r = -0.87; n=8; p<0.001)$$

A higher competitive ability of SC compared to WC, especially during the establishing phase and peak SC growth period in spring is reported by Hill and Gleeson (1988, 1990). Higher white clover production on grazed than on cut plots (Table 4.8) therefore was due to slower SC levels in G than in C (Table 4.9), coupled with the favourable soil moisture conditions that prevailed during the present season. Higher “other legumes” component (mostly suckling and clustered clover) on grazed plots is also likely to be related to lower SC density on those plots (Table 4.8, Table 4.9). Dear (2002) showed a better competitive ability of SC when grown alongside other annual legumes.

It seems that on these pastures, characterized by low tiller population density, when soil moisture constraints are lifted, faster establishing species like subterranean clover have competitive advantages and can affect abundance and production of other legumes, like white clover or suckling clover, more than the effect of grasses, as has been reported by Hill and Gleeson (1988). The timing and intensity of grazing may alter these negative effects and balance abundance towards other legume species. However, if late spring and summer conditions are dry, most of the growth will have occurred by December (as

in the previous year), and white clover will not have the opportunity to express its potential.

In the summer-moist site at Ballantrae, there was an overall 14% decline in annual WC production and 22% in summer WC production due to grazing. In standing biomass terms, the WC production decline in summer was sharper, being 43% in February and 25% in March. The 36% higher grass accumulation in grazed v cut swards in summer can offer some explanation for the legume decline (Table 4.30), as it may be affected by shading. Sheep tended to show preference to graze on H2 plots, where WC standing biomass and production was higher in summer. Post-grazing heights, and especially legume heights were always lower on H2 than on H0 or H1 (Table 4.26), indicative of the higher grazing pressure on H2. The behaviour of sheep showing preference to graze white clover compared to grasses has been widely reported (Parsons *et al.*, 1994, Chapman *et al.*, 1996, 1999, Cosgrove *et al.*, 2002, Rook *et al.*, 2002), and seems to be especially strong in summer (Cosgrove *et al.*, 1996). Post-grazing observations showed hard grazing on WC stolons located on H2 plots, with low residual leaf area, which can markedly affect regrowth, and lower starch (Lawson *et al.*, 1998) and soluble carbohydrate reserves (Grant *et al.*, 1991), while plant size will adjust to a smaller size (Hay and Newton, 1996). Also, on these recently grass suppressed plots (G-H2), tiller population density was stimulated and recovered faster than on swards under cutting (doubled from 5068 tiller/m² in December to 10750 tiller/m² in March; see Section 4.3.3.4.3) which affected WC growing point density at the end of the season (-28% in March on grazed plots). Grasses that form a denser sward such as browntop, tend to adversely affect white clover persistence more than grasses that form less dense swards (Woodfield and Caradus, 1996). On plots under cutting, WC was not differentially defoliated, since cutting level was defined by rotary blade height. Although TPD was on average similar in C and G swards, grass accumulation and grass pre- and post-defoliation heights during summer were lower on plots under cutting, which may have contributed to a better light environment, which in turn would favour WC presence in the sward (Thompson, 1993, Patterson *et al.*, 1995). GPD was lower on G v C plots only

at the end of the season, and may be related also to stolon removal through grazing, as has been reported by Evans *et al* (1992).

Evans and Williams (1987) report a reduction in white clover yield of 42% and 65%, when rotational and continuous grazing are respectively compared with cutting treatments, and differences were mainly due to selective grazing and stolon material removal under grazing conditions. Although differences in clover content in the sward can be achieved by management, changes may be only transient, as was observed by Yarrow and Penning (Yarrow and Penning, 1994) when previously contrasting treatments were evaluated. Grazing effects at the experiments in Waipawa and Ballantrae may have shown greater differences if set stocking by sheep, rather than a rotational grazing system had been used. However, rotational grazing is a common management tool, and of general use under commercial practice.

4.4.4. Grass suppression

The relationship between grass related variables and legume variables was explored using multivariate canonical correlation analysis, as indicated in Chapter 3. Canonical regression values were relatively high on both sites, indicating a high relationship between the two sets of variables (Table 4.46). The canonical redundancy coefficient indicated also that the canonical “grass” variables predicted a higher proportion of the variation of individual WC biomass variables (66% in Waipawa, 59% in Ballantrae), than that of SC or OL biomass variables (e.g. less than 17% for SC biomass variables). The prediction of the variation in total legume biomass accounted for by “grass” variables at Waipawa was only 18%, which is probably a reflection of the influence of subterranean clover on the total legume biomass production at this site. The generally lower canonical correlations in Year 2 compared to Year 1 (Chapter 3) suggest that also other variables different to the grass component are likely to influence legume abundance. In Waipawa, the large difference between seasons suggest that soil moisture

patterns in spring and summer are likely to have played a major role in defining legume abundance during that season.

Table 4.46 Relationship between an *independent canonical variable** composed by grass related individual variables, and *dependent canonical (CAN) variables*** defined by legume related variables, for each of the experimental sites, as obtained from canonical correlation analysis.

Dependent Canonical variable**	Waipawa		Ballantrae	
	Canonical r ² #	Canonical redundancy coefficient ##	Canonical r ² #	Canonical redundancy coefficient ##
CAN-WC	0.928 (p<0.001)	0.657	0.798 (p<0.001)	0.587
CAN-SC	0.887 (p<0.001)	0.165	n/a	n/a
CAN-OL	0.714 (p<0.01)	0.516	n/a	n/a
CAN-TL	0.857 (p<0.001)	0.183	0.798 (p<0.001)	0.587
CAN-GPD	0.843 (p<0.01)	0.455	0.828 (p<0.001)	0.524
CAN-SCPD	0.712 (NS)	0.148	n/a	n/a

* Independent canonical variable defined by the following individual original variables: Grass biomass, tiller population density, weed biomass (only Ballantrae) and sward height at different dates.
** Canonical variable defined by legume related original individual variables within the main legume growing season at each site: WC, white clover biomass; SC, subterranean clover biomass; OL, other legumes biomass; TL, total (all) legumes biomass; GPD, white clover growing point density; SCPD, subterranean clover plant density.
Proportion of variance in the dependent canonical variable explained by the independent canonical variable.
Proportion of variance of the individual dependent variables explained by the independent canonical variable.
n/a, not analysed due to low presence of species at a particular site.

In both sites, immediate effects of grass suppression (H2 v H0) were similar to those observed in Year 1, characterized by a significant increase in legume abundance (Table 4.12, Table 4.34). As for the previous year, increase in white clover abundance was stronger at Ballantrae than at Waipawa, while subterranean clover and other annuals were of major importance at Waipawa.

At Waipawa, SC was the dominant legume in H0 and H2 swards, and its short-term abundance was boosted by grass suppression (Table 4.12). SC standing biomass and SC

content in grass-suppressed plots was higher in Year 2 than in Year 1, probably due to better soil moisture levels and distribution. After finishing its cycle in December, the wet summer conditions in Year 2 favoured a new start for SC seedlings (Table 4.13), which developed into a significant SC contribution to summer biomass production (Table 4.14), especially on recently grass suppressed plots where 37% of total summer herbage accumulation was SC (1.0 t DM/ha). If soil moisture levels declined thereafter, SC could have a “false strike” (Frame *et al.*, 1998), where previously germinated seedlings will die off due to drought, which is a common occurrence on summer-dry hill country pastures. The fact that SC plant density was only occasionally affected by grass suppression (H_2 v H_0 ; Table 4.13), suggests that productive SC response was mostly through increased individual plant weight rather than increasing plant density. In SC swards, intraspecific competition seems to be of importance (Cocks, 1973, Hill and Gleeson, 1988), and new germinating seedlings or smaller plants may be suppressed by older plants of the same species. Grass suppression effects (H_2 v H_0) on WC (Table 4.12) were less pronounced than those observed in Year 1. During the drier Year 1, it is likely that the SC boost on grass-suppressed plots also induced a better soil moisture environment by providing a better soil coverage, which in turn helped WC development in spring. Dear and Cocks (1997) reported a decline of soil moisture in the surface 5 cm of the soil when perennial grasses were present in the sward, which affected the establishment of clover seedlings. In Year 2, soil moisture was generally not a constraint, and therefore WC colonized spaces both on grass-suppressed plots as well as on unsuppressed swards, allowed by their relatively low tiller density. The favourable summer moisture conditions also allowed WC to produce significant amounts of herbage during that season (600 kg DM/ha on H_2 ; Table 4.14), and to end the season with much higher growing point densities than in Year 1. Hill and Gleeson (1990) indicate that in established pastures the co-existence of SC and WC is generally allowed by soil diversity and spatial separation, but under moist summer conditions WC can proliferate and may result in severe competition for SC.

At Ballantrae, in Year 2, when grass was suppressed by herbicide application in H2 plots, tiller density was almost reduced to zero, WC growing point density increased and by September GPD was double and in October 3.8 times greater in H2 v H0, respectively (Table 4.35). From November onwards grass suppression produced an increase in WC standing biomass (H2 v H0), which was sustained to almost the end of the season (Table 4.33). The patterns observed resemble those occurring during Year 1, but the timing and magnitude were different. In Year 2, WC had a more stable distribution during the season than in Year 1 (Table 3.28; Table 4.34), WC abundance in Year 2 was lower in summer compared to Year 1 and differences between H0 and H2 plots, although present and highly significant ($p < 0.001$), were less dramatic, because WC on H0 plots was higher in year 2. Several factors may have contributed to the differences observed between seasons, like a higher than average soil temperature in Year 2 v Year 1 (4.2°C higher in spring and 2.3°C in summer) and a lower early spring tiller population density in Year 2 v Year 1, both of which will have encouraged early WC growth, and lower grass standing biomass during most of the season in Year 2, which may also have reduced competition effects, especially on H0 plots. In Year 1, plots were managed under cutting conditions, resembling rotational grazing, which may explain the reduced early tiller population density in Year 2, compared to the much higher initial TPD values in Year 1 from a previous set-stocked situation (Hunt, 1989).

One of the objectives of the trials was to evaluate the residual effect of grass suppression on legume abundance in a second year (H1 v H0). In Ballantrae, plots that were treated with herbicide in the previous season (H1) regressed during the following season to a situation comparable to swards that did not have grass suppression (H0) (Table 4.33 to Table 4.35). H1 plots had more WC standing biomass than H0 only until October in Year 2, while grass standing biomass converged to that of H0 from December onwards. TPD and GPD also became similar in H1 and H0 in the summer of Year 2. A significant recovery of the grass population occurred in the autumn period, since tiller population density in H1 swards was low in March 2001 (2768 tiller/m²) and by July 2001 had increased to 10114 tiller/m². It seems that the dominant grasses (especially browntop

and sweet vernal) were capable of colonising these plots in a period during which they had competitive advantages over white clover and weed species. A successional study of a sown hill country pasture reported by Harris (1973) showed that re-invasion by browntop was based on the considerable buried seed population and areas were occupied by an increasing tiller density. The competitive advantage of browntop may be higher under lower fertility conditions, but also under higher fertility conditions if no high fertility grasses are present.

Residual effects on H1 plots at Waipawa differed from those observed at Ballantrae. During Year 2, WC standing biomass was always much higher on H1 v H0, while SC, OL, and especially grass standing biomass were lower during the whole season (Table 4.11). Average tiller population density in December 2000 was 2946 tiller/m² in H1 plots and increased to 6276 tiller/m² in July 2001 and remained always lower than on H0 for all the season. In H1 plots, WC growing point density had a surprisingly high increase from December 2000 (592 g.p./m²) to July 2001 (2395 g.p./m²). It seems that stolons were capable of resisting the relative dry summer conditions and GPD increased in autumn in an environment with low grass density. However, the possibility of new recruitment from the seed bank cannot be discounted. After drought periods on oversown or direct drilled paddocks, white clover recovery is also a reflection of the contribution of buried seed and regeneration of resident stolons (Smith *et al.*, 1993). Further, Hollowell (1966) proposed that white clover be rather classified as an annual that may behave as a perennial through asexual propagation. Brock and Kim (1994) observed that shelter from grasses was important during severe droughts to have higher white clover survival. A higher GPD early in the season may confer WC a competitive advantage over SC seedlings, as WC is a more aggressive competitor if it is a major component in the sward (Hill and Gleeson, 1988). This was also reflected on the higher WC standing biomass measured on H1 v H0 plots in July 2001 (Table 4.11). H1 plots maintained a high GPD throughout the season, although it declined in March 2002 and became similar to H2 and H0 (Table 4.13). From these results, it is likely that immediately after grass suppression, SC will have advantages over WC as a fast

establishing legume, and will tend to dominate the sward during the first season, especially prior to flowering and seed production, as stated by Smith (1979). White clover will establish a network of growing points during the same season and, while still being vegetative during the SC flowering period will successfully compete with SC (Smith and Crespo, 1979), especially if spring and early summer conditions are relatively moist. H1 swards had 18% less SC than H0 swards in Year 2, but five times more WC herbage accumulation, and 64% more total legume herbage accumulation than unsuppressed swards (Table 4.14). Adequate soil moisture conditions (as was the case in Year 2) will boost white clover spread and production, especially if summer soil moisture is high, which will encourage WC growth even on unsuppressed swards (H0). Grass suppression may have a higher effect on legume abundance if moisture constraints are present, as grasses will compete with legumes for water and also for nutrients. A much greater root competitive ability of browntop v clover is reported by Snaydon and Baines (1981), especially when soil fertility is low. In the present experiment, there was indication that root mass and density was significantly higher in H0 v H1, especially in the top soil layer in Waipawa, where moisture is most scarce. Hill and Hoveland (1993), under glasshouse conditions, found that legumes were usually more competitive than grass (fescue) when moisture was not restrictive, while grass developed a massive fibrous root system and was able to maintain during drought periods a higher leaf water potential than legumes. Root density in top soil layers was higher at Ballantrae than at Waipawa, the latter having a more uniform root distribution within the profile than the former, which may imply a better response of Waipawa pastures against moisture constraints. Stevenson and Laidlaw (1985) stated that surface soil drying will reduce root initiation and old, well developed roots will supply water for stolon development. If drought continues, even these old roots will become moisture stressed and the stolon may die.

4.4.5. Soil-P status

As in the previous Year, effect of soil-P status were mostly observed on white clover responses, compared to other legumes. At Waipawa in Year 2, WC standing biomass was higher than in Year 1 from the start of the season (Table 4.17), and less limiting overall soil moisture conditions boosted positive effects of higher soil-P levels in this legume. Moreover, phosphorus distribution in the soil profile was characterized by high concentrations of available P in the top 25 mm of the soil, the layer that also had a higher proportion of the root mass (Figure 4.5 and Figure 4.3). Lower tiller population density and higher WC growing point density on HP plots v LP during most of the spring and summer months (Table 4.19), are also factors that may have had a positive impact on final WC outcomes (95% more average WC standing biomass and 105% more WC annual accumulation in HP v LP swards). Browntop can reduce phosphorus availability to white clover both by direct competition at root level and also indirectly by drying out the top soil layer, (Jackman and Mouat, 1973). The highest WC abundance and production in Year 2 was recorded on plots that had grass suppression in Year 1 (H1), and although P effects on annual WC accumulation were significantly different (5875 v 3108 kg DM/ha; in H1-HP v H1-LP; $p < 0.001$) it is interesting to highlight the high WC production achieved on these LP plots. Even on unsuppressed swards, WC in Year 2 became a more important component of the swards, e.g. being responsible for 20% and 10% of total summer production on HP v LP plots, respectively. It seems that on LP plots, with adequate soil moisture in spring-summer, WC was able to utilise enough P from the top soil layers, where available P concentration was higher (Figure 4.5), to increase WC productivity.

Both in Waipawa and in Ballantrae the largest contrasts in vertical distribution of P were observed in the top 25 mm (Figure 4.5 and Figure 4.10), where also the largest proportion of roots are encountered. The very high levels on HP plots reflect the recent heavy P fertiliser application to raise soil P. However, on LP plots medium levels of P are present, that can be utilised adequately by legumes if soil moisture is not limiting.

At Ballantrae, as stated before, WC was more evenly distributed in Year 2 v Year 1, and P effects on WC abundance were present during most of the season (Table 4.39). On average, 54% of WC production occurred in summer, and a lower tiller population density and higher WC growing point density, along with higher available P on top layers of the soil on HP v LP swards by that time, may explain the responses observed. Higher temperatures throughout Year 2 compared to Year 1 may also have improved P uptake from the soil, as the white clover growing season was extended.

4.5 CONCLUSIONS

The results obtained from two very contrasting seasons highlight the dominant effects of soil moisture patterns on legume abundance and production, especially in summer-dry hill country pastures. At Waipawa, adequate soil moisture in spring and especially in summer during Year 2 produced significant increases in legume abundance compared with that in Year 1, and can be seen as the primary factor that interacts with the other factors considered in this study.

Grazing decreased subterranean clover abundance and production at Waipawa, while increasing that of white clover, probably by removing at least partly the negative effects of SC on WC observed in spring, and the overall effect was a net increase in annual legume production. In the summer-moist site at Ballantrae, grazing negatively affected white clover abundance and production, which was likely to be related to more severe defoliation intensity, as well as suppression due to the higher grass accumulation and grass height in the grazed swards.

Short-term effects of grass suppression in both seasons were similar, producing an explosive increase in subterranean clover in Waipawa and also increasing white clover abundance in Ballantrae. Residual effects from grass suppression (H1) in the previous year were different between sites. While Waipawa H1 plots were dominated by white clover throughout the second year, at Ballantrae H1 swards tended to regress to their

original status so that, by the end of Year 2, H1 plots were close to H0 swards. However, the moisture conditions that prevailed at Waipawa in Year 2 were exceptionally favourable to white clover.

On both sites, increased soil-P differentially stimulated white clover and increased white clover abundance and production. At Waipawa, adequate spring and summer moisture facilitated the uptake of P, especially from the top layers of the soil, which translated into high WC production. LP swards with medium levels of available soil-P in the top layers also enabled reasonable WC production when soil moisture was adequate.

Soil moisture is recognised as a key factor influencing legume abundance and production, especially in summer-dry hill country pastures. However of the controlled factors in the experiments, in both years and at both sites, grass suppression was seen to have dramatic effects in increasing legume abundance. The presence of grasses represents a competitive challenge for legumes, and the following glasshouse experiment (Chapter 5) was intended to examine some aspects related to effects of companion grasses on legume responses, both in white clover and subterranean clover, under two defoliation regimes.

CHAPTER 5

EFFECTS OF COMPANION GRASS STRUCTURE ON INDIVIDUAL WHITE CLOVER AND SUBTERRANEAN CLOVER PLANTS WITH TWO DEFOLIATION REGIMES UNDER GLASSHOUSE CONDITIONS

5.1 INTRODUCTION

Low legume content of hill country pastures is likely to be the result of a series of different interacting factors, like moisture constraints, soil fertility, pasture management, grass competition, as well as grazing effects (Orr and Wedderburn, 1996, Woodfield and Caradus, 1996). Results from the previous experiments (Chapters 3 and 4) in which some of these factors were tested, suggested that grass competition is likely to be a major determinant of the legume content of the swards. The suppression of grass growth had strong positive effects on legume abundance and production, especially under favourable soil moisture conditions. This factor was seen to be of relatively more importance than others such as nitrogen application, soil phosphorus status, pasture utilization and rotational sheep grazing. The competition effects exerted by the grass component of pastures may be due to the influence of the surrounding light environment, competition for space, below-ground competition for nutrients and water, or some combination of those factors (Harris, 1973, Turkington *et al.*, 1979, Brereton *et al.*, 1985, Harris, 1987). Selective and repeated defoliation is also likely to put the legume plant at a disadvantage relative to grass and to affect persistence and production (Grant *et al.*, 1991, Hay and Newton, 1996, Lawson *et al.*, 1998).

The following glasshouse experiment was intended to evaluate the responses of individual legume plants to different grass environments, using intact cores with resident hill pasture from the Waipawa field site. The objectives were to test the effects of

different companion grass structures on subterranean clover and white clover plants grown with and without control of root competition, under two defoliation regimes.

5.2 MATERIALS AND METHODS

5.2.1. General

This glasshouse experiment was located at the Plant Growth Unit, Massey University, Palmerston North. The experiment was conducted between 4 February and 3 April 2002 (a period of 58 days) (for general view see Plate 5.1).

5.2.2. Design and treatments

Three hundred 10.3 cm diameter cores were collected from a site (Olsen P=28) at Waipawa (dominated by browntop (*Agrostis capillaris* L.) and sweet vernal (*Anthoxanthum odoratum* L.) with minor components of crested dogtail (*Cynosurus cristatus* L.) and perennial ryegrass (*Lolium perenne* L.)), and put into PVC drain-tube segments (10.4 cm inner diameter, 15 cm deep) to contain them and serve as pots. Cores from the field were preferred to using prepared media, in order to have an original hill country soil and grass composition and test the performance of clover seedlings under those conditions, without moisture constraints. The cores were standardized to a depth of 10 cm, the remaining basal 5 cm being filled with sand. Pots were taken to a glasshouse, put on 90 cm high benches, watered daily and temperature controlled to a maximum of 25°C. After a period of recovery of 10 days, 10% of the pots was discarded due to factors like uneven botanical composition, uneven soil surface, excess of legumes, etc. From the remaining pots, to develop contrasting sward types, 80 pots were treated with glyphosate (50 ml/10 l, applied with a knapsack sprayer) to eliminate all vegetation. On herbicide treated pots, all dead material was removed and new grass, legume or weed seedlings germinating were manually removed if necessary. On the 160 untreated pots, any legumes present were manually removed (including stolons) and only grass species were allowed to grow. These were subjected to two contrasting

cutting regimes: half were cut to 2 cm height using hand shears, and half were cut to 8 cm height. The 2 cm pots were cut frequently (when regrowth reached 4-5 cm) to stimulate tillering and generate a short dense sward, whereas 8 cm pots were subjected to a lax cutting regime and were cut back to 8 cm when they exceeded 12 cm height, to form a tall open sward. Pots were checked for legume repopulation and new appearing seedlings were removed.

Along with the large cores, 300 smaller 2.54 cm diameter cores were also collected at the same site, put on trays to avoid disturbance, and taken to the laboratory for processing. Cores were cut to a length of 10 cm, wrapped in a 15 cm long plastic sheet (forming a tube around the core) and sealed around with black tape. The remaining bottom 5 cm was filled with sand. They were placed into deep containers in rows and spaces between tubes were filled with sand to support them. Containers were placed in the same glasshouse. Tubes were treated with glyphosate at the rate indicated previously to kill all existing vegetation, which was removed once herbicide had acted.

On 20 December, half of the tubes were sown with white clover (*cv. Tahora*) and the remaining half with subterranean clover (*cv. Karridale*). Seeds were previously tested for germination and were pelleted and inoculated. Two seeds were placed in each tube and allowed to germinate. At an early stage (first trifoliate leaflet fully expanded) only the strongest seedling was kept. Prior to the start of the experiment, seedlings were ranked for size and allocated to five different blocks, in order to control within-block variation. Sample tubes were also kept for initial destructive measurements on individual plants. Before the start of the experiment, in the centre of each pot a hole was made with a corer (matching the outer diameter of the corer to legume tube diameter), and legume tubes were inserted (see Plate 5.2). Depending on treatment, the plastic tube was either removed, or left intact to prevent inter-mingling of legume and grass roots (root exclusion).



Plate 5.1 General view of the glasshouse experiment (March 2002).



Plate 5.2 Insertion of clover seedlings into grass swards in pots: central hole with corer (A), insertion of seedling in exclusion tube (B); clover seedling inserted in sward (C).

The legume plants were allocated to the different grass pots to create the following treatments:

1. Legume species: White clover (**WC**) or subterranean clover (**SC**).
2. Companion grass structure: Short and dense grass sward (**S2**), Tall and sparse sward (**T8**), or control without grass (**Co**).
3. Root exclusion: Legume growing in tube (**R0**), or legume without root barrier (**R1**).
4. Selective legume defoliation: Legume defoliated at regular intervals (**D1**), or no legume defoliation (**D0**).

After preparation, pots were randomly assigned to five different benches (i.e. blocks), to conform to a randomised block design with a 2 x 3 x 2 x 2 factorial structure with five replicates. Each pot had a duplicate to allow destructive measurements to be made on 5 March and at the end of the experiment on 3 April. Pots were re-randomized weekly within blocks.

The glasshouse was fitted with automatic overhead irrigation, that activated twice daily to restore as near as possible field capacity conditions. This was monitored by two Time Domain Reflectometry (TDR) probes per replicate set in special pots. Temperature was controlled by fans, but initial tests indicated that temperature was excessive even with continuous fan activity. Therefore, up to the 5 March harvest, a protective clear cover was installed over the glasshouse to reduce incident radiation. Extra air circulation was allowed by removing some side glass sheets. At the start of the second phase of the experiment (5 March), as temperatures declined, the cover was removed.

At the start of the experiment, to avoid nitrogen deficit for grass species, 82.2 mg of calcium nitrate were applied in a solution with water (equivalent to 15 kg N/ha) to all pots.

White clover stolons tended to grow out of the tubes and pots. A decision was taken to impede rooting nodes outside the confining tube on treatments with root exclusion (R0) by cutting roots when they started to grow into the soil. Also, stolons that left the boundaries of the pot were redirected back to the pot, by means of wire pins if necessary. This was especially important in the second half of the experimental period.

5.2.3. Measurements

5.2.3.1. *Repeated measurements*

Soil moisture content was recorded daily at 9 am and 6 pm using TDR equipment, which allowed direct estimation of volumetric soil moisture (%v/v). Maximum, minimum and ambient air temperature and soil temperature were monitored daily.

Average grass canopy height and height of the tallest legume lamina were measured with a ruler at regular intervals throughout the experiment. Readings were recorded on tape recorder.

To maintain grass structure differences between treatments it was necessary to cut grass on S2 back to the target 2 cm, by means of scissors. This was done at the start of the experiment and repeated on 19 February, 5 March and 19 March. On the same dates, in treatments with legume defoliation (D1), all fully expanded leaves and corresponding petioles were removed using scissors. Herbage removed on each date was dried and weighed, to be added to final plant mass.

Light conditions were checked periodically inside and outside the glasshouse, using a Li-Cor data logger connected to Skye sensors to determine photosynthetically active radiation (PAR) and red:far-red ratio. Measurements were also done on pots before

harvest dates to evaluate light quality at the base of the sward. For each pot, light conditions (red:far-red ratio) were measured with Skye sensors at the base of the sward. For light measurements, days with close to clear sky were chosen, and measurements were between 11 am and 1 pm. Once during the second phase of the experiment, the instrument was installed inside the glasshouse to record light conditions during a five day period, in order to have an average daily light profile.

5.2.3.2. *Initial measurements*

To confirm differences attained in pots with different companion grass structure, 12 S2 pots and 12 T8 pots were evaluated. Tiller density was estimated by cutting to ground level and counting all tillers within a 5 cm diameter ring sited centrally. Live and dead tissue was also separated, dried at 65°C for 48 h and weighed. Tiller mass and live and dead percentage could therefore be determined. The rest of the grass in the pot was also cut to ground level, dried and weighed, to determine total grass mass per pot (by adding also tiller mass obtained previously).

From seedlings grown in spare tubes, a sample of 100 white clover and 100 subterranean clover leaves of a range of mid-rib lengths (MRL) of the central leaflet (3-23 mm for SC and 3-35 mm for WC) was collected and run individually through a Li-Cor LI-3100 leaf area meter (0.1 mm² resolution). For all leaves MRL of the central leaflet was measured following the procedure used by Bircham (1981), and regressions were made of actual leaf area on MRL for both legumes:

Subterranean clover: $AREA = 2.8079 (MRL)^2 - 0.5192 (MRL)$ ($r^2=0.955$ $n=100$; $p<0.001$)

White clover; $AREA = 2.0047 (MRL)^2 - 0.4503 (MRL)$ ($r^2=0.978$ $n=100$; $p<0.001$)

Twelve subterranean clover seedlings and 12 white clover seedlings growing in tubes were also evaluated. Plants were dissected into leaf lamina, petiole, and stem or stolon. MRL for each leaf, and white clover stolon length were measured, and plant components dried and weighed. Leaf area per plant was calculated using regression

equations. Roots from the tubes were washed using the procedure based on the hydropneumatic elutriation system developed by Smucker (1982). Remaining soil particles and non-root material were manually removed. Root samples were floated in water and dead root material (mostly remaining grass roots which could easily be distinguished by colour) were separated. Roots were dried and weighed.

5.2.3.3. 5 March and 3 April harvests

Half of the pots were evaluated on 5 March (one from each set of duplicated pots), while the rest were evaluated on 3 April 2002. From each pot, legume plants were cut at ground level, and separated into leaf, petiole and stem. White clover growing points and subterranean clover branches were counted, white clover stolon length was measured, and all components were dried and weighed. In one replicate (R3), MRL of the central leaflet was measured on a random sample of 30 leaves which were afterwards dried and weighed. Relative leaf area (mg/cm^2) was determined by estimating leaf area with the regression equations described in Section 5.2.3.2. These parameters were applied to legume leaf weight on all pots to have an estimation of leaf area per plant.

Tiller density was measured on grass swards by counting tillers from a 3 x 3 cm quadrat sited beside the legume on each pot, live and dead material separated, dried and weighed. All remaining grass was cut to ground level, dried and weighed, to determine total grass DM per pot.

Legume root mass in tubes was determined following the procedure described in Section 5.2.3.2, and only for the samples evaluated on 5 March. Evaluation of legume root mass in the treatments without root exclusion was not attempted, since separation of legume and grass roots on test pots proved to be not possible.

5.2.4. Statistical analysis

Data were analysed by analysis of variance (ANOVA) using the general linear model (GLM) procedure (SAS, 1990, 1997). Height variables generated from sequential

sampling over time were analysed using also the ‘repeated measures’ option of SAS. Data were checked for normality and homogeneity of variance, and where assumptions were not met, adequate adjustment of data was made by square-root or natural logarithm transformation.

5.3 RESULTS

5.3.1. General results layout

Results have been organized in tables and figures, usually containing responses to main effects, which were in general very significant. In some cases particular interactions were also significant (but with much lower F values than those occurring for main effects), and thus are described in the text. Most of the interactions occurred in relation to the root exclusion factor, and they are presented for clarity in separate tables.

Results related to legume variables will be hereafter expressed on a “per plant” basis, since they are the response of individual plants of either subterranean clover or white clover. However, when variables related to the grass component are considered, they will be expressed on a “per pot” basis.

The interpretation of the root exclusion treatment, generated by the growth of legume seedlings in tubes, was influenced by the differences in soil volume between excluded and non-excluded seedlings. Legumes grown in tubes had a more limited development compared to the treatment with no root exclusion. As the experiment was planned for a relatively short period (less than two months), it was expected that soil volume constraints would not significantly limit seedling growth, but the opposite was the case, especially in the second phase of the experiment. The interpretation of root exclusion results was based on relative responses of legume plants standardized respective to the control treatments (see Section 5.3.6).

5.3.2. Glasshouse environment

5.3.2.1. Temperature

The overall mean air temperature in the glasshouse was 21.2 °C, with a mean maximum of 29.3 °C and a mean minimum temperature of 13 °C. The daily variation during the experimental period can be observed in Figure 5.1.

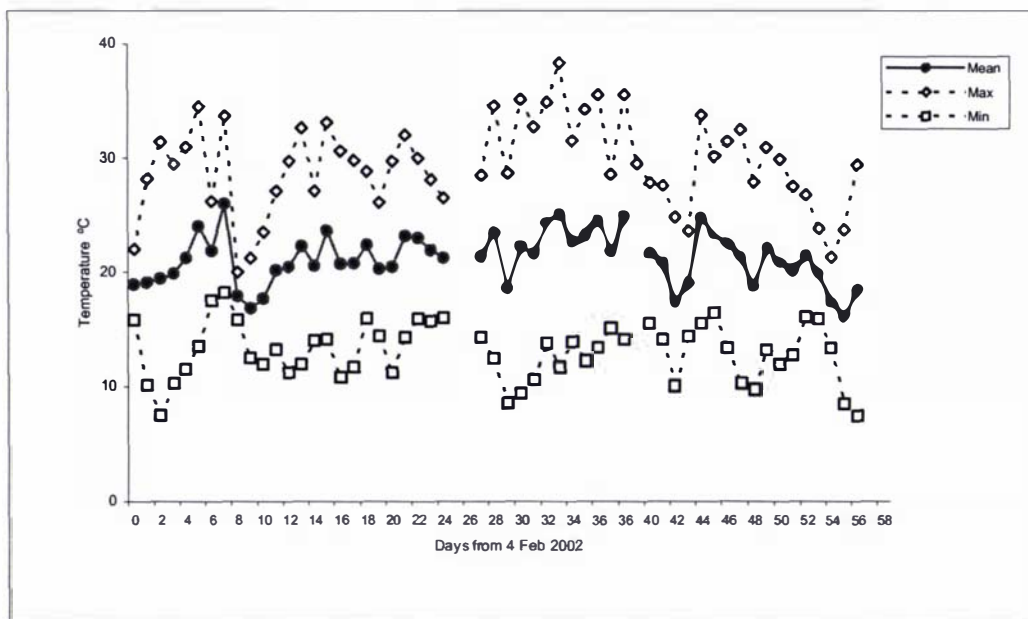


Figure 5.1 Mean, maximum and minimum temperature fluctuation during the experimental period (4 Feb to 3 April 2002) in the glasshouse.

5.3.2.2. Moisture

The irrigation regime was targeted to restore field capacity conditions in the pots (36% v/v). The readings on indicator pots indicated a mean volumetric soil moisture content of 37.4%, with a range of 35.3 – 39.6%.

5.3.2.3. Light

During the first period (4 Feb- 4 Mar) when the glasshouse was protected by a cover to prevent excessive temperature, mean PAR between 11 am and 1 pm was 856 $\mu\text{moles/m}^2/\text{s}$, which represented 49% of PAR transmitted (outside mean ambient PAR

was 1749 $\mu\text{mol}/\text{m}^2/\text{s}$). Thereafter, mean inside PAR (11 am to 1 pm) was 1271 $\mu\text{mol}/\text{m}^2/\text{s}$ and mean outside PAR 1496 $\mu\text{mol}/\text{m}^2/\text{s}$, which resulted in 85% of PAR transmitted. Average red to far red ratios inside and outside the glasshouse were similar (1.98 v 2.13). Figure 5.2 shows the average daily variation in PAR during five consecutive days during the second experimental phase.

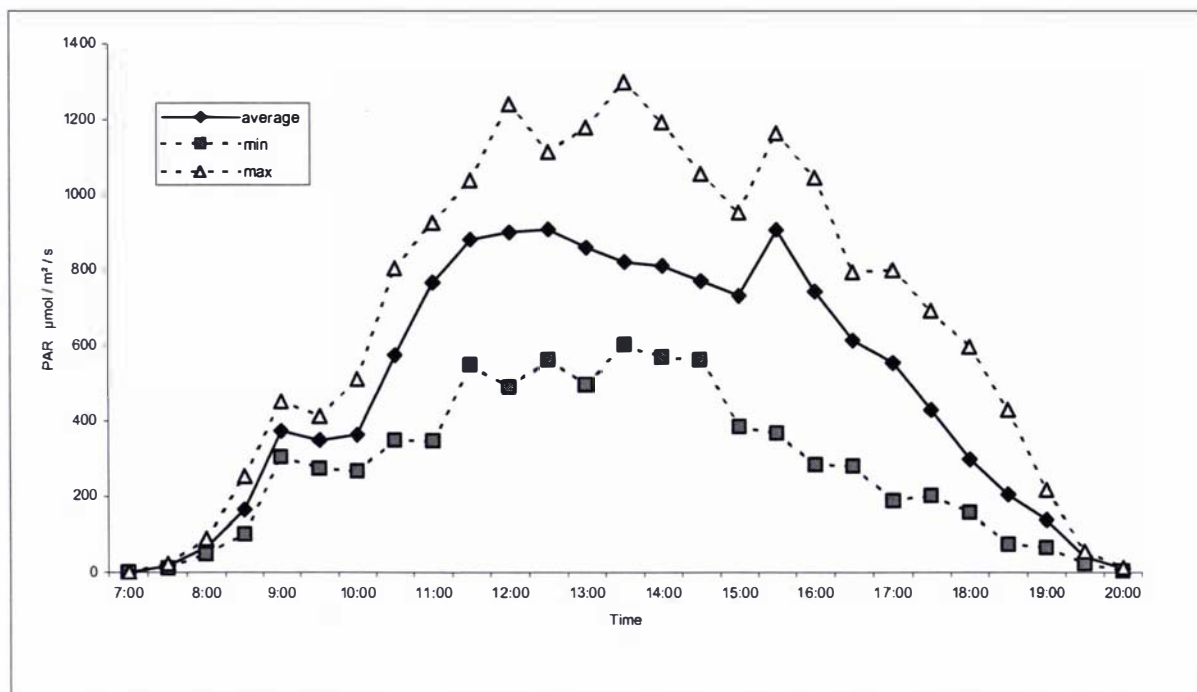


Figure 5.2 Variation in photosynthetically active radiation (PAR; 400-700nm) in the glasshouse, during five consecutive days of measurements (5-day average values).

5.3.3. Initial grass and legume measurements

Differential cutting treatments during the pre-experimental period achieved substantial contrasts in grass development. At the start of the experiment, short v tall swards had on average a higher tiller density ($356 \text{ v } 166 \pm 22.8$ tiller/pot; ($\pm$ SEM); $p < 0.001$), lower tiller size ($2.62 \text{ v } 12.7 \pm 0.68$ mg/tiller; $p < 0.001$), lower herbage mass ($1002 \text{ v } 2287 \pm 103$ mg DM/pot; $p < 0.001$), and lower average grass height ($3.4 \text{ v } 8.7 \pm 0.16$ cm; $p < 0.001$).

Subterranean clover and white clover plants grown in tubes had at the start of the experiment an average leaf mass of $287 \pm 159 \pm 17.7$ mg DM ($p < 0.001$) and a total above ground mass of $607 \pm 374 \pm 44.8$ mg DM ($p < 0.001$) respectively.

5.3.4. Effect of legume species

5.3.4.1. Variation of lamina height

The height of the companion grass component was similar in pots with SC and WC, except for two occasions (19 Feb and 4 Mar), where SC pots had slightly but significantly (at least $p < 0.05$) taller grass (Table 5.1).

Table 5.1 Average companion grass height (cm) for subterranean clover (SC) and white clover (WC) treatments at different dates.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
SC	5.9	6.2	6.5	7.6	6.3	7.5	0.08	***
WC	5.9	6.1	6.3	7.1	6.1	7.2		
SEM	0.08	0.09	0.09	0.14	0.12	0.10		
<i>p</i>	NS	NS	NS	**	NS	*		
	5 Mar	12 Mar	17 Mar	23 Mar	2 Apr		SEM	<i>p</i> ¹
SC	6.0	6.6	7.1	6.1	6.8		0.08	***
WC	5.8	6.5	7.0	6.1	6.8			
SEM	0.08	0.14	0.15	0.11	0.13			
<i>p</i>	NS	NS	NS	NS	NS			

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

A significant *spp* $\times$ *defoliation* interaction showed that legume height differed between SC and WC only in undefoliated (D0) plants, where SC was significantly (generally $p < 0.001$) taller than WC at all dates measured. On D1 pots, both legumes were defoliated and their heights were always similar (Table 5.2).

Table 5.2 Legume height (cm) for subterranean clover (SC) and white clover (WC) plants under two defoliation regimes (D0 and D1), at different dates.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
SC-D0	10.4	10.5	8.5	9.0	9.5	9.7		
SC-D1	2.7	4.2	5.4	6.9	3.2	5.4	0.19	***
WC-D0	9.2	7.5	7.0	6.9	6.8	7.9		
WC-D1	2.3	3.7	5.1	6.0	3.2	5.7		
SEM	0.28	0.28	0.28	0.26	0.22	0.25		
<i>p</i>	***	***	*	*	***	***		
	Mar 5	Mar 12	Mar 17	Mar 23	2 Apr		SEM	<i>p</i> ¹
SC-D0	10.3	9.8	9.8	9.6	9.8			
SC-D1	1.9	3.6	4.0	2.3	3.7		0.16	***
WC-D0	7.9	7.4	7.0	7.4	7.0			
WC-D1	1.3	3.6	4.3	2.6	4.2			
SEM	0.18	0.25	0.26	0.23	0.25			
<i>p</i>	***	***	***	***	***			

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

5.3.4.2. Legume responses

At the first harvest, SC plants had 56% more leaf mass, 29% more total above ground mass, and more than double the leaf area, than WC plants (Table 5.3). At the end of the experiment, the differences were larger, SC plants having 67% more leaf mass, 31% more total shoot mass, and 2.3 times more leaf area than WC plants ($p < 0.001$). WC plants had significantly (57%; $p < 0.001$; not shown) more leaves than SC plants. The light environment defined by the R/FR ratio at the base of the canopy, was similar for both legume species (Table 5.3).

Table 5.3 Effect of legume species (WC or SC) on legume leaf DM (mg DM/plant), total legume shoot DM (mg DM/plant), legume leaf area (cm²/plant), red to far red (R/FR) ratio at the base of the sward, and legume root DM (mg DM/plant), at two different harvest dates (mg DM/plant).

	SC	WC	SEM	<i>p</i> ²
Harvest 5 March¹				
Leaf DM	604 (6.138)	387 (5.694)	(0.0416)	***
Total shoot DM	1159 (6.795)	896 (6.490)	(0.0461)	***
Root DM ³	273	164	19.2	***
Leaf area	131.0 (4.160)	61.9 (3.364)	(0.0471)	***
base R/FR ratio	1.54	1.30	0.091	NS
Harvest 3 April¹				
Leaf DM	1756 (6.816)	1049 (6.441)	(0.0582)	***
Total shoot DM	3682 (7.506)	2807 (7.315)	(0.0464)	**
Leaf area	426.2 (5.342)	181.6 (4.525)	(0.0582)	***
base R/FR ratio	0.78	0.87	0.070	NS

¹Includes leaf and petiole defoliated during period. Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets. ²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).
³measured only on harvest of 5 March in legume plants grown on tubes.

5.3.4.3. Grass responses

The companion grass sward initially responded similarly to the presence of both legume species, except for a slightly but significantly higher ($p < 0.05$) dead grass component in WC pots at the 5 March harvest. However, at the end of the experiment, the grass sward growing with WC plants had a 28% higher tiller density ($p < 0.01$), but with a significantly lower tiller mass ($p < 0.01$). As a result, the total live and dead grass components were similar for SC and WC pots (Table 5.4).

Table 5.4 Mean grass DM (mg DM/pot), tiller density (tiller/pot) and tiller DM (mg/tiller) of swards grown along with white clover (WC) or subterranean clover (SC) plants, at two different harvest dates.

	SC	WC	SEM	<i>p</i> ²
Harvest 5 March				
Live grass DM	1630 (7.299)	1546 (7.265)	(0.0306)	NS
Dead grass DM	532 (5.965)	582 (6.126)	(0.0534)	*
Tiller density	368 (5.789)	404 (5.906)	(0.0503)	NS
Tiller DM	9.24 (1.765)	7.37 (1.681)	(0.0386)	NS
Harvest 3 April				
Live grass DM	2056 (7.568)	2126 (7.600)	(0.0359)	NS
Dead grass DM	741 (6.028)	695 (6.201)	(0.0844)	NS
Tiller density	305 (5.603)	389 (5.872)	(0.0636)	**
Tiller DM	8.90 (1.778)	6.94 (1.587)	(0.0462)	**

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.
²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

5.3.5. Effect of companion grass structure

5.3.5.1. Variation of lamina height

Differences in grass height between S2 and T8 were maintained ($p < 0.001$) throughout the experimental period (Table 5.5). Fluctuations of height observed on S2 plots were created by periodical cuts of the grass to target height.

Legume lamina height increased when the companion grasses were taller. However, differences were significant ($p < 0.001$) only when Co or S2 were compared with T8. Although a tendency for S2 having higher legume heights than Co was observed at many dates, this difference only was significant ($p < 0.05$) on 23 February (Table 5.6). A legume *spp* $\times$ *companion grass structure* interaction was detected for the dates 4 and 23 February and indicated that while SC was significantly taller than WC on Co and S2 pots (10.3 ν 7.6 cm; 5.4 ν 3.9 cm, and 11.0 ν 7.6 cm; 6.3 ν 4.4 cm, for SC-Co ν WC-Co

Table 5.5 Average companion grass height (cm) for short (S2) and tall (T8) treatments at different dates.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
S2	3.2	3.6	4.2	5.3	2.9	4.7	0.08	***
T8	8.6	8.7	8.6	9.4	9.5	10.0		
SEM	0.08	0.09	0.09	0.14	0.12	0.10		
<i>p</i>	***	***	***	***	***	***		
	5 Mar	12 Mar	17 Mar	23 Mar	2 Apr		SEM	<i>p</i> ¹
S2	1.6	3.0	3.9	2.2	3.7		0.08	***
T8	10.2	10.1	10.2	9.9	9.9			
SEM	0.08	0.14	0.15	0.11	0.13			
<i>p</i>	***	***	***	***	***			

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

Table 5.6 Effect of companion grass structure on legume height (cm), at different dates.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
Co	5.2	5.5	5.6	5.8	4.7	6.2	0.16	***
S2	6.0	6.3	6.0	6.5	5.3	6.7		
T8	7.2	7.5	7.9	9.2	7.1	8.7		
SEM	0.24	0.24	0.24	0.23	0.19	0.22		
<i>p</i>	***	***	***	***	***	***		
	5 Mar	12 Mar	17 Mar	23 Mar	2 Apr		SEM	<i>p</i> ¹
Co	5.0	5.2	5.3	5.1	5.2		0.14	***
S2	5.0	5.4	5.5	5.0	5.7			
T8	6.2	7.7	7.9	6.3	7.6			
SEM	0.16	0.22	0.23	0.20	0.22			
<i>p</i>	***	***	***	***	***			

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

and SC-S2 v WC-S2, in Feb 4 and Feb23, respectively; $p < 0.001$), on T8 pots SC and WC plants had similar lamina heights (12.3 v 11.1 cm, and 7.3 v 6.8 cm, in Feb 4 and Feb23, for SC-T8 v WC-T8, respectively).

5.3.5.2. *Legume responses*

Legumes growing in short (S2) or tall (T8) swards had at the first harvest a 21% ($p < 0.01$) or 37% ($p < 0.001$) reduction in leaf mass compared to control (Co) pots. At the end of the experiment, these differences grew to 32% and 46%, respectively. Legumes in T8 also had significantly ($p < 0.01$) less leaf mass than those in S2. Differences observed in total above ground mass followed the same pattern, and at the end of the experiment, S2 and T8 had 32% and 44% less ($p < 0.001$) total legume shoot mass than Co, respectively, while differences ($p < 0.05$) between S2 and T8 were 18% (Table 5.7).

The interaction *legume spp x grass structure* indicated that the total decline in shoot DM per plant between SC-Co and SC-S2 (4717 and 3511 mg DM/plant, respectively) was not significant ($p > 0.05$; although there was a tendency ($p < 0.1$)), while there was a 40% decline in total shoot DM between WC-Co and WC-S2 (4007 v 2388, respectively; $p < 0.01$). In T8, both species had significantly ($p < 0.001$) lower total shoot DM when compared to the corresponding Co level. However, while SC-T8 was significantly lower than SC-S2 (2819 v 3511 mg DM/plant, respectively; $p < 0.05$), WC-T8 and WC-S2 had similar total shoot DM (2026 v 2388 mg DM/plant, respectively; $p > 0.05$). The total stem DM (SC stem or WC stolon), as a component of the shoot DM, also varied at the end of the experiment between legume species, in response to the companion grass structure. There was a significant ($p < 0.001$) decline in total stem DM when WC-Co and WC-S2 were compared, but no further significant decline in WC-T8 (1794, 996 and 925 mg DM/plant, respectively). On the other hand, SC-Co and SC-S2 did not differ significantly ($p > 0.05$) in total stem DM, but total stem DM was significantly less in SC-T8 (1339, 1143 and 850 mg DM/plant, respectively; $p < 0.05$).

At the first harvest, legumes in Co and S2 had a similar leaf area ($p > 0.05$), while those in T8 had a 35-39% reduction ($p < 0.001$) in leaf area, when compared with S2 or Co,

respectively. At the end of the experiment, legume leaf area was not statistically significantly different ($p>0.05$) between Co and S2, while T8 legumes had 31% ($p<0.01$) less leaf area than those in S2, and 49% ($p<0.001$) less compared with Co (Table 5.7).

Root mass, measured on plants grown in tubes, was unaffected when Co and S2 were compared, while T8 showed a 30% reduction in root mass respective to S2 or Co (Table 5.7).

At the first harvest, the R/FR ratio at the base of the sward was highest when no grass was present (Co), and was significantly different to the lower values observed in S2 ($p<0.05$) or T8 swards ($p<0.001$), which were similar. At the end of the experiment, both S2 and T8 had a lower R/FR ratio compared to Co ($p<0.001$), while S2 had also a significantly ($p<0.01$) higher R/FR than T8 (Table 5.7).

Table 5.7 Effect of companion grass structure (Co: no grass; S2: short 2cm grass sward; T8: tall 8 cm grass sward), on average legume leaf DM (mg DM/plant), total legume shoot DM (mg DM/plant), legume leaf area (cm²/plant), number of leaves (legume), red to far red (R/FR) ratio at the base of the sward, and legume root DM (mg DM/plant), at two different harvest dates (mg DM/plant).

	Co	S2	T8	SEM	<i>p</i> ²
Harvest 5 March¹					
LeafDM	609 (6.162)	493 (5.904)	385 (5.681)	(0.0510)	***
Total shoot DM	1233 (6.865)	1012 (6.636)	838 (6.426)	(0.0564)	***
Root DM ³	242	244	170	23.5	*
Leaf area	113.4 (3.911)	106.6 (3.869)	69.4 (3.506)	(0.0576)	***
n leaves	82	63	52	5.8	**
base R/FR ratio	1.85	1.37	1.04	0.111	***
Harvest 3 April¹					
LeafDM	1892 (6.938)	1295 (6.626)	1020 (6.321)	(0.0712)	***
Total shoot DM	4362 (7.727)	2949 (7.355)	2422 (7.150)	(0.0568)	***
Leaf area	406.7 (5.079)	299.2 (5.044)	206.8 (4.677)	(0.0712)	***
n leaves	194	147	112	9.5	***
base R/FR ratio	1.32	0.74	0.41	0.085	***

¹Includes leaf and petiole defoliated during period. Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets. ²significance level: ***, $p<0.001$; **, $p<0.01$; *, $p<0.05$; NS, not significant ($p>0.05$).

³measured only on harvest of 5 March in legume plants grown in tubes.

No significant effect of companion grass structure was observed on WC stolon length at the 5 March harvest (Table 5.8). However, at the end of the experiment, WC on Co pots had on average almost 52% more stolon length ($p<0.01$), than the average of S2 and T8, which did not differ significantly ($p>0.05$).

In both harvests, the number of growing points was reduced on S2 and T8 compared to Co (25% and 40% less on March 4, and 33% and 53% less on April 3, for S2 ν Co and T8 ν Co respectively; $p<0.001$). Only in the last harvest, WC in S2 had significantly more (41%) growing points than in T8 ($p<0.05$). All treatments had similar number of SC branches in the first harvest, while significantly less SC branches were present at the end of the experiment in T8 compared to S2 ($p<0.01$) or Co ($p<0.001$) (Table 5.8).

Table 5.8 Effect of companion grass structure (Co: no grass; S2: short 2cm grass sward; T8: tall 8 cm grass sward), on WC stolon length (cm/plant), number of WC growing points (n/plant), and number of SC branches (n/plant), at two different harvest dates.

	Co	S2	T8	SEM	<i>p</i> ¹
Harvest 5 March					
WC stolon length	100.1 (4.381)	73.4 (4.125)	74.8 (4.011)	(0.1235)	NS
WC growing points	27.3	20.5	16.3	1.83	***
SC branches	14.4 (2.479)	11.1 (2.216)	10.5 (2.231)	(0.0917)	NS
Harvest 3 April					
WC stolon length	280.4 (5.119)	186.3 (4.675)	183.5 (4.710)	(0.0914)	**
WC growing points	50.6	33.8	23.9	2.77	***
SC branches	27.7 (2.889)	22.3 (2.752)	16.2 (2.331)	(0.0230)	***

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.

¹significance level: ***, $p<0.001$; **, $p<0.01$; *, $p<0.05$; NS, not significant ($p>0.05$).

5.3.5.3. Grass responses

Live grass DM in T8 was 110% higher in the first harvest and 63% higher at the end of the experiment, than in S2 ($p<0.001$; (Table 5.9)). While dead grass mass at the first harvest was four times higher in T8 ν S2, the difference increased to 5.8 times at the end of the experiment ($p<0.001$). Tiller density was 86% higher in S2 ν T8 in the first harvest ($p<0.001$) and 32% higher at the end ($p<0.01$). In contrast, tiller mass was almost six times higher on T8 ν S2 swards, for both harvests ($p<0.001$).

Table 5.9 Mean grass DM (mg DM/pot), tiller density (tiller/pot) and tiller DM (mg/tiller) of swards with contrasting companion sward structure, at two different harvest dates.

	Co	S2	T8	SEM	<i>p</i> ¹
Harvest 5 March					
Live grass DM	n/a	1011 (6.908)	2166 (7.657)	(0.0306)	***
Dead grass DM	n/a	225 (5.347)	889 (6.744)	(0.0534)	***
Tiller density	n/a	502 (6.171)	270 (5.524)	(0.0503)	***
Tiller DM	n/a	2.37 (0.838)	14.24 (2.607)	(0.0386)	***
Harvest 3 April					
Live grass DM	n/a	1588 (7.335)	2594 (7.833)	(0.0359)	***
Dead grass DM	n/a	211 (5.168)	1225 (7.061)	(0.0844)	***
Tiller density	n/a	395 (5.873)	299 (5.602)	(0.0636)	**
Tiller DM	n/a	2.33 (0.807)	13.51 (2.558)	(0.0462)	***

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.

¹ significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). n/a, not applicable.

5.3.6. Effect of root exclusion

The interpretation of root exclusion effects were influenced by the differences in soil volume between excluded (growing in tube) and non-excluded seedlings. Legumes grown in tubes (R0) had a lower development compared to the treatment with no root exclusion (R1). It was expected that soil volume constraints would not significantly limit seedling growth, as the experiment was designed to run for a short period, but the opposite was the case, especially in the second phase of the experiment, where differences in size between R0 and R1 legumes were greatest. Although size differences between R0 and R1 were apparent, no signs of obvious nutritional shortage were observed on plants during the experimental period.

Although, tabulated results in this section show absolute values for R1 and R0, and it is acknowledged that differences in legume plant size occurred, text comments mostly refer to relative responses of legume plants which were standardized respective to the control treatments in comparisons between companion grass structures (S2-R0 and T8-R0 relative to Co-R0; and S2-R1 and T8-R1 relative to Co-R1) or between defoliation treatments (R0-D1 relative to R0-D0; and R1-D1 relative to R1-D0), derived from

interaction tables (Table 5.14 to Table 5.17). Results are further discussed in sections 5.4.3 and 5.4.4.

5.3.6.1. Variation of lamina height

Grass lamina height was not affected by root exclusion, as R0 and R1 had similar heights at all dates measured during the experiment (Table 5.10).

Table 5.10 Average companion grass height for treatments with root exclusion (R0) and no root exclusion (R1), at different dates.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
R0	5.8	6.1	6.4	7.5	6.2	7.4	0.08	***
R1	6.0	6.2	6.5	7.2	6.1	7.4		
SEM	0.08	0.09	0.09	0.14	0.12	0.10		
<i>p</i>	NS	NS	NS	NS	NS	NS		
	5 Mar	12 Mar	17 Mar	23 Mar	2 Apr		SEM	<i>p</i> ¹
R0	5.9	6.6	7.2	6.1	6.9		0.08	***
R1	5.8	6.4	6.8	6.1	6.7			
SEM	0.08	0.14	0.15	0.11	0.13			
<i>p</i>	NS	NS	NS	NS	NS			

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

Legume height in plants with no root exclusion (R1) was greater than in R0 on 19 February ($p < 0.01$) and then from 4 March onwards ($p < 0.001$) to the end of the experiment. Between 5 March and 2 April, there was a significant ($p < 0.01$) *root exclusion* $\times$ *defoliation* interaction, which indicated that differences in legume height during that period were different only on plants without defoliation, while legume height was similar ($p > 0.05$) on defoliated (D1) plants (Table 5.11).

Table 5.11 Effect of root exclusion (R0: with root exclusion, R1: no root exclusion) on legume height (cm), at different dates, and interaction *root exclusion* $\times$ *defoliation*.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
R0	6.1	6.5	6.3	6.8	5.5	6.4	0.13	***
R1	6.2	6.4	6.6	7.6	5.8	8.0		
SEM	0.18	0.20	0.20	0.19	0.16	0.18		
<i>p</i>	NS	NS	NS	**	NS	***		
		5 Mar	12 Mar	17 Mar	23 Mar	2 Apr	SEM	<i>p</i> ¹
R0		4.9	5.5	5.6	5.0	5.7	0.11	***
R1		5.8	6.7	6.9	5.9	6.7		
SEM		0.13	0.18	0.18	0.16	0.18		
<i>p</i>		***	***	***	***	***		
R0	D0	8.2	7.7	7.4	7.7	7.6	0.16	***
R0	D1	1.7	3.3	3.8	2.3	3.8		
R1	D0	10.0	9.6	9.4	9.3	9.1		
R1	D1	1.6	3.8	4.4	2.6	4.2		
SEM		0.18	0.25	0.26	0.23	0.25		
<i>p</i>		***	***	***	***	***		

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

5.3.6.2. Legume responses

At the March harvest, legume plants grown in the pots with no root exclusion (R1) had 86% more leaf mass, 67% more total above ground mass and 3.3 times more leaf area than those grown in tubes (R0) (Table 5.12). At the end of the experiment, differences were much larger, R1 legume plants having four times more leaf mass and total above ground plant mass, and 8.4 times more leaf area than R0 plants ($p < 0.001$). The R/FR ratio at the base of the sward was significantly lower in the R1 ν R0 treatment ($p < 0.01$) at the end of the experiment.

Table 5.12 Effect of root exclusion (R0: with root exclusion, R1: no root exclusion) on average legume leaf DM (mg DM/plant), total legume shoot DM (mg DM/plant), legume leaf area (cm²/plant), number of leaves (legume), and red to far red (R/FR) ratio at the base of the sward, at two different harvest dates.

	R0	R1	SEM	<i>p</i> ²
Harvest 5 March¹				
Leaf DM	347 (5.696)	645 (6.135)	(0.0416)	***
Total shoot DM	769 (6.459)	1286 (6.826)	(0.0461)	***
Leaf area	45.0 (3.259)	147.9 (4.265)	(0.0471)	***
n leaves	43	88	4.8	***
base R/FR ratio	1.30	1.54	0.091	NS
Harvest 3 April¹				
Leaf DM	558 (6.149)	2247 (7.108)	(0.0582)	***
Total shoot DM	1304 (6.933)	5184 (7.889)	(0.0464)	***
Leaf area	65.0 (4.192)	542.8 (5.675)	(0.0582)	***
n leaves	71	231	7.7	***
base R/FR ratio	0.97	0.67	0.070	**

¹Includes leaf and petiole defoliated during period. Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets. ²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

In March, on WC plants grown with no root exclusion, stolons were 2 times longer than on plants grown in tubes ($p < 0.001$), and in April differences increased to 3.1 times (Table 5.13). There were 130% more WC growing points and 86% more SC branches in R1 v R0 in March, and 160% and 260% in April ($p < 0.001$), respectively.

Table 5.13 Effect of root exclusion (R0: with root exclusion; R1: no root exclusion), on WC stolon length (cm/plant), number of WC growing points (n/plant), and number of SC branches (n/plant), at two different harvest dates.

	R0	R1	SEM	<i>p</i> ²
Harvest 5 March				
WC stolon length	54.1 (3.832)	111.4 (4.512)	(0.1008)	***
WC growing points	12.8	29.9	1.07	***
SC branches	8.4 (2.005)	15.6 (2.612)	(0.0749)	***
Harvest 3 April				
WC stolon length	107.0 (4.435)	327.5 (5.233)	(0.0746)	***
WC growing points	20.0	52.2	2.26	***
SC branches	9.6 (2.137)	34.5 (3.178)	(0.0759)	***

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.

²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

Legume plants that grew under root exclusion had less severe defoliation effects on plant yield and leaf area, than those where roots were not excluded. In both cases and at both harvest dates, leaf DM, total shoot DM and leaf area were significantly ($p < 0.001$) reduced by effects of defoliation (Table 5.14). However, while legume defoliation reduced total shoot DM by 57% and 65% in the root exclusion treatment in March and April, respectively, plants with no root exclusion had a decline of 74% and 89%, at the same dates, respectively. Changes in leaf DM and leaf area followed similar patterns of response.

For the same interaction, similar effects were observed for stolon length, number of WC growing points and number of SC branches. In March, defoliation did not reduce these parameters significantly on plants with root exclusion, while significant ($p < 0.001$) declines were recorded on plants without root exclusion. In April, reductions were observed on both root excluded and non excluded treatments, but the decline was always of a much higher magnitude in the latter compared to the former (Table 5.15).

Table 5.14 Interaction between root exclusion and legume defoliation on average legume leaf DM (mg DM/plant), total legume shoot DM (mg DM/plant), and legume leaf area (cm²/plant), at two different harvest dates.

	R0-D0	R0-D1	R1-D0	R1-D1	SEM	p^2
Harvest 5 March¹						
Leaf DM	463 (6.085)	231 (5.307)	1018 (6.800)	272 (5.470)	(0.0589)	***
Total shoot DM	1079 (6.931)	459 (5.987)	2037 (7.512)	535 (6.140)	(0.0651)	**
Leaf area	76.3 (4.237)	13.6 (2.282)	269.8 (5.422)	27.1 (3.107)	(0.0666)	**
Harvest 3 April¹						
Leaf DM	746 (6.476)	370 (5.821)	3897 (8.062)	598 (6.154)	(0.0822)	***
Total shoot DM	1927 (7.438)	682 (6.428)	9302 (9.021)	1066 (6.756)	(0.0656)	***
Leaf area	120.3 (4.627)	9.6 (3.757)	1042.5 (6.684)	43.0 (4.665)	(0.0822)	***

¹Includes leaf and petiole defoliated during period. Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets. ²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

Table 5.15 Interaction between root exclusion and legume defoliation on WC stolon length (cm/plant), number of WC growing points and number of SC branches, at two different harvest dates.

	R0-D0	R0-D1	R1-D0	R1-D1	SEM	<i>p</i> ²
Harvest 5 March						
WC stolon length	58.1 (3.921)	50.2 (3.744)	149.7 (4.912)	73.2 (4.113)	(0.1426)	•
WC growing points	14.1	11.5	38.7	21.1	2.11	***
SC branches	9.1 (2.041)	7.7 (1.970)	22.3 (3.059)	9.8 (2.164)	(0.1059)	***
Harvest 3 April						
WC stolon length	149.3 (4.862)	62.7 (4.009)	577.3 (6.276)	77.7 (4.191)	(0.1055)	***
WC growing points	26.1	13.9	80.2	24.1	3.20	***
SC branches	11.4 (2.316)	7.7 (1.957)	50.3 (3.884)	15.3 (2.472)	(0.1073)	***

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.

² significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

There was also an interaction between the companion grass structure and root exclusion, whereby total shoot mass and leaf area of legume plants grown with root exclusion were not significantly reduced between Co-R0 and S2-R0, or S2-R0 and T8-R0 by increasing companion grass structure constraints. Only in April, the extreme Co-R0 : T8-R0 comparison of means was significantly different ($p < 0.01$) for shoot DM. However, legume plants grown with no root exclusion had a significant ($p < 0.001$) reduction in shoot DM mass from Co-R1 to S2-R1 on both dates (Table 5.16). Under root exclusion, leaf area was not significantly ($p > 0.05$) affected by companion grass structure, but with no root exclusion leaf area showed a tendency ($p < 0.1$) to decline between Co-R1 ν S2-R1, but was significantly ($p < 0.001$) reduced between S2-R1 ν T8-R1. In April, the R/FR ratio at the base of the sward was lower ($p < 0.001$) for non-excluded treatments in the Co level, but did not differ between root exclusion treatments in S2 or T8.

Table 5.16 Interaction between companion grass structure and root exclusion on total legume shoot DM (mg DM/plant), legume leaf area (cm²/plant), and red to far red (R/FR) ratio at the base of the sward, at two different harvest dates.

	Total shoot DM	Leaf area ¹	Total shoot DM	Leaf area ¹	R/FR ratio
	Harvest 5 March	Harvest 5 March	Harvest 3 April	Harvest 3 April	Harvest 3 April
Co – R0	393 (6.576)	44.0 (3.218)	620 (7.112)	58.5 (4.076)	1.72
Co – R1	825 (7.155)	182.7 (4.604)	3165 (8.342)	752.9 (6.082)	0.93
S2 – R0	343 (6.526)	46.9 (3.404)	623 (6.976)	80.4 (4.399)	0.76
S2 – R1	644 (6.745)	166.3 (4.334)	1969 (7.734)	518.0 (5.690)	0.71
T8 – R0	305 (6.276)	44.1 (3.155)	432 (6.710)	56.1 (4.101)	0.44
T8 – R1	465 (6.576)	94.7 (3.856)	1608 (7.589)	357.5 (5.252)	0.37
SEM	(0.0798)	(0.0815)	(0.0803)	(0.1007)	0.121
<i>P</i> ²	*	***	*	***	**

¹Includes leaf and petiole defoliated during period. Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets. ²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). R/FR ratio for harvest 5 March did not show a significant *grass structure* $\times$ *root exclusion* interaction ($p > 0.05$, not shown).

Similarly, WC stolon length was not significantly ($p > 0.05$) affected in plants growing under root exclusion, when submitted to contrasting companion grass structure treatments, in contrast to WC plants grown without root exclusion, which had a shorter stolon length in T8-R1 ν Co-R1 ($p < 0.05$) in March, and S2-R1 ν Co-R1 in April ($p < 0.01$) (Table 5.17). On both harvest dates, there was a significant ($p < 0.001$) reduction in WC growing points in plants without root exclusion (R1), while no significant change was recorded in WC with root exclusion (R0). The number of SC branches counted on plants with root exclusion in April was similar under the different grass structure regimes, while plants under no root exclusion had a reduction in SC branches, from Co-R1 to T8-R1 ($p < 0.001$), but also from Co-R1 to S2-R1 ($p < 0.05$). In March, SC branches were not statistically different between treatment combinations (not shown).

Table 5.17 Interaction between companion grass structure and root exclusion on WC stolon length (cm/plant), number of WC growing points and number of SC branches, at two different harvest dates.

	WC stolon length		WC grow.pts.		SC branches
	Harvest 5 March	Harvest 3 April	Harvest 5 March	Harvest 3 April	Harvest 3 April
Co – R0	50.2 (3.795)	122.1 (4.591)	13.5	19.5	9.6 (2.180)
Co – R1	150.0 (4.966)	438.7 (5.646)	41.1	81.6	45.7 (3.599)
S2 – R0	52.0 (3.871)	108.2 (4.374)	12.5	24.5	10.8 (2.286)
S2 – R1	94.9 (4.379)	264.4 (4.975)	28.4	43.1	33.7 (3.219)
T8 – R0	60.3 (3.830)	87.6 (4.340)	12.4	16.0	8.3 (1.945)
T8 – R1	89.4 (4.193)	279.4 (5.079)	20.2	31.8	24.0 (2.717)
SEM	(0.1746)	(0.1292)	2.58	3.92	(0.1315)
<i>P</i> ²	*	*	**	***	*

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.

²significance level: ***, *p*<0.001; **, *p*<0.01; *, *p*<0.05; NS, not significant (*p*>0.05).
For harvest 5 March, number of SC branches did not differ significantly (*p*>0.05; not shown).

5.3.6.3. Grass responses

There was no significant (*p*>0.05) main legume root exclusion effect on grass DM, tiller density or tiller mass (Table 5.18). However, a *grass structure x root exclusion* interaction showed that, at the end of the experiment, in S2 live grass mass was greater in R0 v R1 (1753 v 1422 mg DM/pot, respectively; *p*<0.01), while no differences were present in T8 (2484 v 2705 mg DM/pot, for R0 v R1 respectively; NS). The same interaction indicated that tiller density in S2 was higher in R0 v R1 (441 v 349 tiller/pot, respectively; *p*<0.05), while the opposite was the case at the T8 level (243 v 355 tiller/pot, in R0 v R1, respectively; *p*<0.05). There was also a *root exclusion x legume defoliation* interaction, which showed that live grass mass was higher on pots where legumes were defoliated, but only at the R1 level (2331 v 1796 mg DM/pot, for R1-D1 v R1-D0, respectively; *p*<0.001). When legumes were grown in tubes within the grass canopy, no significant differences were recorded (2152 v 2086 mg DM/pot, for R0-D1 v R0-D0, respectively; NS). A similar situation occurred for tiller density, R1-D1 having a higher tiller density than R1-D0 (429 v 275 tiller/pot, respectively; *p*<0.01), but R0-D1 and R0-D0 had similar tiller density (352 v 332 tiller/pot, respectively; NS).

Table 5.18 Mean grass DM (mg DM/pot), tiller density (tiller/pot) and tiller DM (mg/tiller) of swards grown with or without root exclusion (Ro: with root exclusion; R1: no root exclusion) with a legume plant, at two different harvest dates.

	R0	R1	SEM	<i>p</i> ²
Harvest 5 March				
Live grass DM	1584 (7.285)	1592 (7.279)	(0.0306)	NS
Dead grass DM	514 (6.025)	601 (6.066)	(0.0534)	NS
Tiller density	387 (5.824)	384 (5.871)	(0.0503)	NS
Tiller DM	8.92 (1.760)	7.69 (1.685)	(0.0386)	NS
Harvest 3 April				
Live grass DM	2119 (7.625)	2063 (7.542)	(0.0359)	NS
Dead grass DM	737 (6.110)	700 (6.118)	(0.0844)	NS
Tiller density	342 (5.731)	352 (5.744)	(0.0636)	NS
Tiller DM	8.58 (1.716)	7.26 (1.649)	(0.0462)	NS

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets. ² significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

5.3.7. Effect of legume defoliation

5.3.7.1. Variation of lamina height

There was no effect of legume defoliation on the height of the companion grass sward (Table 5.19), whereas lamina height in defoliated legumes was always significantly ($p < 0.001$) lower than in undefoliated plants (Table 5.20).

Table 5.19 Average companion grass height for treatments without legume defoliation (D0) or with legume defoliation (D1), at different dates.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
D0	5.9	6.2	6.5	7.4	6.3	7.3	0.08	***
D1	5.9	6.1	6.4	7.3	6.1	7.5		
SEM	0.08	0.09	0.09	0.14	0.12	0.10		
<i>p</i>	NS	NS	NS	NS	NS	NS		
	5 Mar	12 Mar	17 Mar	23 Mar	2 Apr		SEM	<i>p</i> ¹
D0	5.9	6.4	7.0	6.1	6.8			
D1	5.9	6.6	7.1	6.1	6.9			
SEM	0.08	0.14	0.15	0.11	0.13			
<i>p</i>	NS	NS	NS	NS	NS			

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

Table 5.20 Effect of legume defoliation (D0: no defoliation, D1: defoliated) on legume height (cm), at different dates.

	4 Feb	7 Feb	11 Feb	19 Feb	23 Feb	4 Mar	SEM	<i>p</i> ¹
D0	9.8	9.0	7.7	8.0	8.2	8.8	0.13	***
D1	2.5	3.9	5.3	6.4	3.2	5.6		
SEM	0.26	0.20	0.20	0.19	0.16	0.18		
<i>p</i>	***	***	***	***	***	***		
	5 Mar	12 Mar	17 Mar	23 Mar	2 Apr		SEM	<i>p</i> ¹
D0	9.1	8.6	8.4	8.5	8.4		0.11	***
D1	1.6	3.6	4.1	2.5	4.0			
SEM	0.13	0.18	0.18	0.16	0.18			
<i>p</i>	***	***	***	***	***			

¹significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$). SEM, standard error of the mean.

5.3.7.2. Legume responses

Legume defoliation had strong effects in reducing legume leaf mass and total above ground mass on both harvest dates ($p < 0.001$). In D1, leaf mass was reduced by 66% and 79%, total shoot mass suffered a reduction of 68% and 84%, and leaf area was also significantly ($p < 0.001$) reduced by 88% and 95%, on March 4 and April 3 harvests, respectively, compared to D0 (Table 5.21). Legume root mass, measured in plants in tubes only, was 39% lower ($p < 0.001$) in plants that were defoliated, compared to D0 (Table 5.21)

The R/FR ratio at the base of the sward was lower in D0 v D1, but only at the end of the experiment ($p < 0.001$) (Table 5.21). A *grass structure x legume defoliation* interaction showed that D1-Co v D0-Co, and D1-S2 v D0-S2 treatments had higher R/FR ratio (1.76 v 0.89, and 1.10 v 0.38, respectively, $p < 0.001$), while D1-T8 and D0-T8 did not differ significantly (0.51 v 0.31, $p > 0.05$) (Table 5.21).

Table 5.21 Effect of legume defoliation (D0: no defoliation, D1: defoliated) on average legume leaf DM (mg DM/plant), total legume shoot DM (mg DM/plant), legume leaf area (cm²/plant), number of leaves (legume), red to far red (R/FR) ratio at the base of the sward, and root DM (mg DM/plant), at two different harvest dates (mg DM/plant).

	D0	D1	SEM	<i>p</i> ²
Harvest 5 March¹				
Leaf DM	741 (6.443)	251 (5.389)	(0.0416)	***
Total shoot DM	1558 (7.222)	497 (6.063)	(0.0461)	***
Leaf area	172.6 (4.829)	20.3 (2.695)	(0.0471)	***
Root DM ³	272	165	23.5	***
n leaves	91	40	4.8	***
base R/FR ratio	1.44	1.40	0.091	NS
Harvest 3 April¹				
Leaf DM	2321 (7.269)	484 (5.988)	(0.0582)	***
Total shoot DM	5615 (8.230)	874 (6.592)	(0.0464)	***
Leaf area	581.5 (5.656)	26.3 (4.211)	(0.0582)	***
n leaves	260	42	5.5	***
base R/FR ratio	0.52	1.12	0.070	***

¹Includes leaf and petiole defoliated during period. Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets. ²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

³measured only on harvest of 5 March in legume plants grown in tubes (R0).

WC stolons were also strongly affected by defoliation, showing a reduction of stolon length of 41% ($p<0.01$) and 81% ($p<0.001$) in D1 v D0, at the March and April harvest dates, respectively (Table 5.22).

Defoliated WC plants had 38% less growing points in March and 64% less at the end of the experiment ($p<0.001$), compared to intact plants. Similar reductions in SC branches was observed (43% and 64% less in D1 v D0; $p<0.001$) in March and April (Table 5.22).

Table 5.22 Effect of legume defoliation (D0: no defoliation, D1: defoliated), on WC stolon length (cm/plant), number of WC growing points (n/plant), and number of SC branches (n/plant), at two different harvest dates.

	D0	D1	SEM	p^2
Harvest 5 March				
WC stolon length	103.9 (4.416)	61.7 (3.929)	(0.1235)	**
WC growing points	26.4	16.3	1.83	***
SC branches	15.2 (2.550)	8.7 (2.067)	(0.0749)	***
Harvest 3 April				
WC stolon length	363.3 (5.569)	70.2 (4.100)	(0.0746)	***
WC growing points	53.2	19.0	2.26	***
SC branches	32.5 (3.100)	11.5 (2.215)	(0.0759)	***

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.
²significance level: ***, $p<0.001$; **, $p<0.01$; *, $p<0.05$; NS, not significant ($p>0.05$).

5.3.7.4. Grass responses

Mean grass DM, tiller density and tiller mass were similar on D1 and D0 treatments at the first harvest date. However, at the end of the experimental period live grass DM was 16% higher, while tiller density was increased 29% on swards where legumes were defoliated (D1), compared to D0 swards (Table 5.23). As was shown in Section 5.3.6.3, this was mainly so in pots where there was no root exclusion.

Table 5.23 Mean grass DM (mg DM/pot), tiller density (tiller/pot) and tiller DM (mg/tiller) of swards grown with a defoliated or un-defoliated legume plant, at two different harvest dates.

	D0	D1	SEM	<i>p</i> ²
Harvest 5 March				
Live grass DM	1603 (7.281)	1573 (7.283)	(0.0306)	NS
Dead grass DM	510 (6.014)	604 (6.077)	(0.0534)	NS
Tiller density	367 (5.821)	405 (5.874)	(0.0503)	NS
Tiller DM	8.14 (1.732)	8.46 (1.713)	(0.0386)	NS
Harvest 3 April				
Live grass DM	1940 (7.491)	2242 (7.676)	(0.0359)	***
Dead grass DM	733 (6.121)	703 (6.108)	(0.0844)	NS
Tiller density	303 (5.606)	390 (5.869)	(0.0636)	**
Tiller DM	7.92 (1.661)	7.92 (1.704)	(0.0462)	NS

Means in brackets are log-transformed with corresponding standard error of the mean (SEM) also in brackets. Original means without brackets.

²significance level: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; NS, not significant ($p > 0.05$).

5.4 DISCUSSION

The following discussion will be focused on the present experiment only, since connections with the field experiments along with other implications will be considered in Chapter 6 (General Discussion). General contrasts resulting from companion grass structure, root exclusion, and defoliation treatments, are depicted in Plate 5.3.

5.4.1. Legume species

The height of the tallest leaf in SC plants was taller than that of WC plants only when plants were not defoliated. If they were defoliated, lamina height between species was similar. Westoby (1976), observed that the main determinant of height in subterranean clover was petiole length, which tended to keep pace with increasing sward height, and leaves were not shaded, except in extreme conditions (Dennis and Woledge, 1981). At some stages during the first phase of the experiment, when companion grasses were tall (T8), both legumes reached similar lamina heights, indicating the capacity of WC to

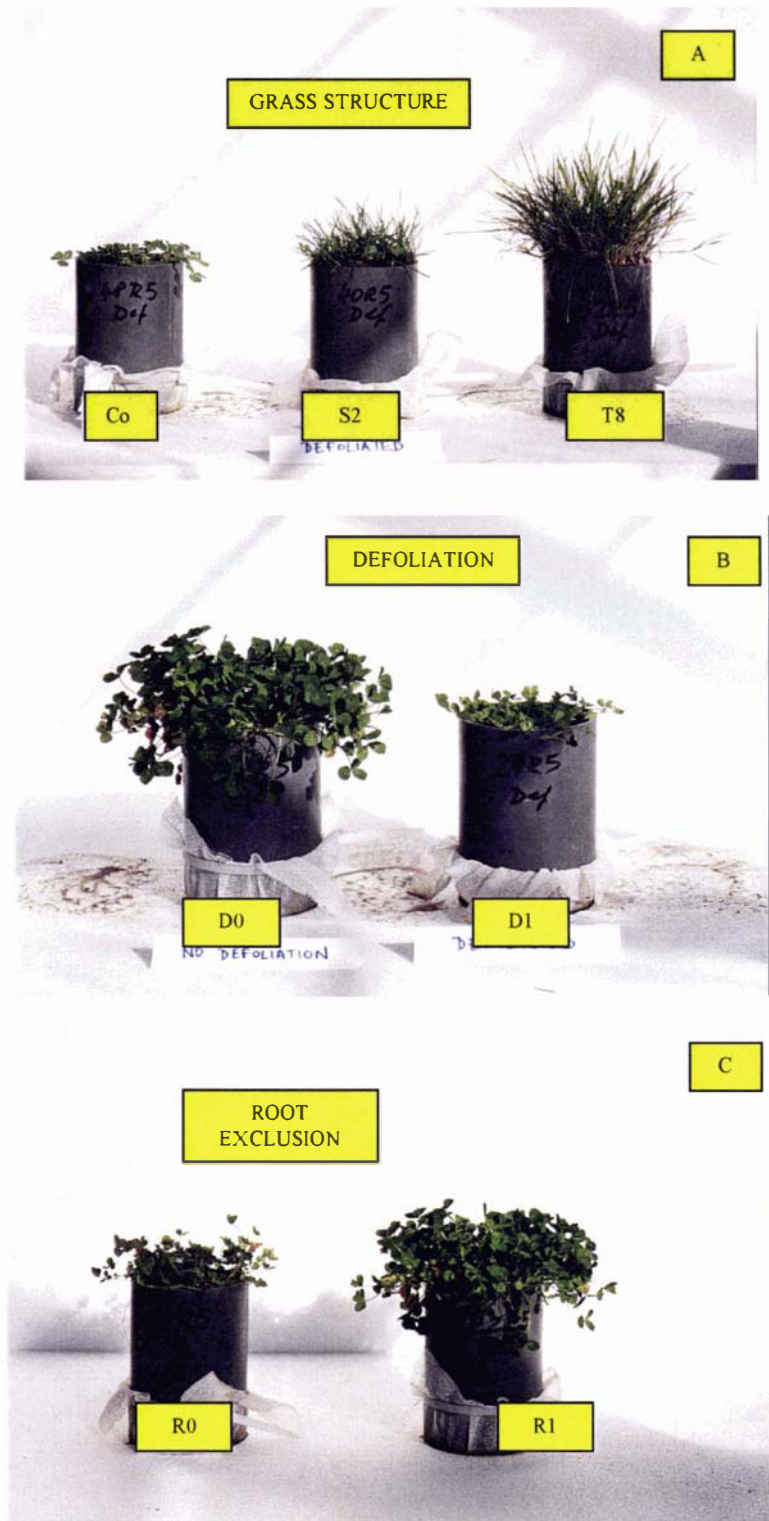


Plate 5.3 Main treatments in glasshouse experiment. Effects of companion grass structure (A), legume defoliation (B), and root exclusion (C).

explore the top layers of the sward especially by petiole elongation as has been reported by Wilman and Acuña (1993). SC plants were larger than WC plants at both harvest dates, with more leaf and total shoot mass (Table 5.3), two thirds more root mass, and more than double the leaf area. The greater number of leaves per plant in WC (57% more) did not compensate fully for the smaller area per leaf ($3.28 \text{ v } 1.06 \text{ cm}^2/\text{leaf}$, in April, for SC and WC, respectively). It is thus suggested, that SC plants in this sense may have had competitive advantages over WC. The competitive ability of subterranean clover when growing in mixtures with different grass species has been reported elsewhere (Cotterill, 1990, Berg and Kruger, 1991, Du and King, 1999). An indication for this was also the lower grass tiller density observed at the end of the experiment in pots with SC, while WC grew in a more crowded environment (Table 5.4).

5.4.2. Companion grass structure effects

The lamina height of legumes in short (S2) pots was always higher than that of grasses, and legumes seemed to be overtopping grasses, while the opposite occurred in T8 treatments, especially during the second phase of the experiment (Table 5.5 and Table 5.6). Furthermore, legume root mass was not affected by a short companion grass sward, when roots were excluded (R0), while there was a 30% reduction in root mass when under T8 conditions (Table 5.7). It is therefore likely that light was a constraint for legumes only in the T8 treatment.

Legume plant size and leaf mass were reduced proportionally more when Co (no above or below ground inter-specific competition) was compared to S2 (mainly below ground inter-specific competition) conditions, than when submitted to T8 (above and below ground inter-specific competition). For example, at the end of the experiment the average reduction in legume plant size (above ground) from Co to S2 was 1413 mg (32% of size in Co), but from S2 to T8 was only 527 mg (12% of size in Co) (Table 5.7). It is suggested, that below ground (root) competition as observed in this experiment, may be of more importance than above ground (shoot) competition, as has

been reported by Boatman and Haggard (1983) and indicated in the majority of cases reviewed by Wilson (1988).

The reduction in total shoot DM in S2 compared to Co at the end of the experiment (3 April), was more dramatic in WC (40%; $p < 0.01$) than in SC (25%; $p < 0.1$), and the overall 32% reduction in shoot DM per plant in S2 compared to Co (Table 5.7) seems to have been strongly influenced by the average 34% reduction in WC stolon length per plant (Table 5.8) (45% reduction in stolon mass; Section 5.3.5.2) and by a 32% average reduction in leaf DM per plant (Table 5.7). On the other hand, the further overall 18% total shoot DM reduction in T8 was mainly caused by the 20% reduction observed in SC shoot DM ($p < 0.05$), triggered by 26% less SC stem production, in T8 compared to S2, while at the same time WC total shoot DM was reduced only 15% (NS). Overall, total shoot DM in T8 compared to Co declined 40% in SC compared to almost 50% in WC, and there was an indication that in WC, total shoot DM was relatively more depressed by a short dense sward than in SC (Section 5.3.5.2). At the end of the experiment overall legume leaf area was reduced significantly only in T8, which was a consequence of a reduction in WC growing points and in SC branches, which resulted in a 42% decline in the number of leaves, when Co and T8 are compared. There was probably a limitation exerted by the taller sward in T8 and consequently lower R/FR ratio at the base of the sward, as has been reported by Thompson (1990) and Wilman and Acuña (1993).

5.4.3. Root exclusion effects

The fact that legume growth was affected by differences in soil volume of plants growing in tubes for root exclusion compared to those grown without root exclusion was considered previously in Section 5.3.1. Constraints presented to growth in tubes are likely to have been more related to nutritional factors rather than moisture, since irrigation was closely monitored and no soil moisture deficit was recorded. From the interaction tables presented in Section 5.3.6.2 it is interesting to comment on the

differences observed between relative responses of R0 and R1 legume plants when subjected to different companion grass structure and defoliation treatments.

For example, when responses for R0 and R1 were analysed relative to the respective control treatment (Co) (derived from Table 5.16), a significant (22%; $p < 0.05$) decline in total shoot DM was observed between C0-R1 and S2-R1 in the March harvest, while no significant change occurred between C0-R0 and S2-R0. Furthermore, the reduction observed for total legume shoot DM between S2 and T8 was only significant ($p < 0.05$) between S2-R0 and T8-R0. Larger differences were observed at the end of the experiment (3 April), when total shoot mass of legume plants with root exclusion (R0) was not affected in S2, while those without exclusion (R1) had a 38% decrease in total shoot mass, when Co-R1 and S2-R1 are compared. When the light environment was more limited (T8), total shoot DM of plants with root exclusion had a reduction of 30%, compared to S2, while for the same comparison plants without root exclusion had a further but not significant (NS; $p > 0.05$) 18% reduction (Table 5.16). Overall, R0 plants had a reduction of 30% in total shoot mass (when Co and T8 are compared), while R1 plants were reduced by 49% (Figure 5.3). This pattern was also consistently observed in other variables, like stolon length (40% reduction) and number of WC growing points (47% less), when S2-R1 is compared with C0-R1 at the end of the experiment, while no significant differences occurred between S2-R0 and Co-R0 (derived from Table 5.17). From these results, under the conditions of the present experiment, below ground competition was likely to have played a major role in limiting above ground plant variables, while effects of light constraints seemed to be of a secondary importance. This is in line with results discussed in Section 5.4.2 and also agrees with findings reported elsewhere (Donald, 1958, Harper, 1981, Boatman and Haggard, 1983, Wilson, 1988).

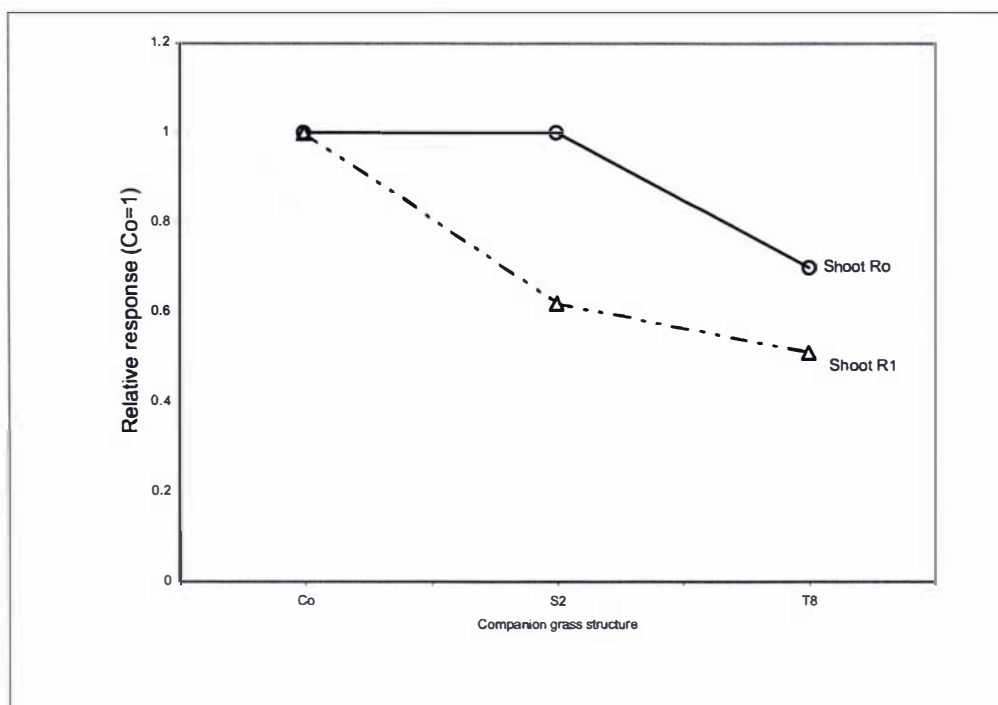


Figure 5.3 Above ground (shoot) yield of legume plants in swards with contrasting companion grass structure, relative to the control treatment (Co), when grown with root exclusion (R0) or without root exclusion (R1).

5.4.4. Defoliation effects

The effects of defoliation were generally the strongest observed during the experiment (which is also a reflection of the high intensity of defoliation exerted on experimental plants), and interactions with the root exclusion factor were detected for some variables.

Effects of defoliation were cumulative and differences, although very significant in the March harvest, were much larger at the end of the experiment. In April, defoliated legume plants had 95% less leaf area than intact plants, which was a combined effect of an 84% reduction in leaf numbers and a reduction in leaf size (calculated as leaf area divided by leaf numbers) to almost a quarter of that observed on undefoliated plants, leading to a 79% reduction in leaf mass. This resulted in a decline of 84% in total above ground legume mass (Table 5.21).

Severe and frequent defoliation has been found to reduce legume plant size (Boatman and Haggard, 1984, Lawson *et al.*, 2000), a consequence of a decline in both leaf numbers and leaf area (Blaikie and Mason, 1990), reduction in nodes and branching

activity (King *et al.*, 1978, Curll and Wilkins, 1985, Newton and Hay, 1996), lower stolon elongation rate (Lawson *et al.*, 2000), a reduction in carbohydrate reserves (Lawson *et al.*, 1998), and a lower N fixation and photosynthetic rate (Ryle *et al.*, 1985). Although defoliation created conditions for a better light environment at the base of the sward at the end of the experiment (Table 5.21), the intensity of removal of leaf tissue had a negative impact on number of WC growing points and SC branches, which declined by 64 and 65%, respectively, while WC stolons were on average 81% shorter in defoliated plants (Table 5.22). Repeated severe defoliation also may in time compromise legume persistence, by limiting WC spread in the sward (Nie *et al.*, 1998), or affecting SC seeding potential if defoliation continues during flowering (Collins *et al.*, 1983).

In April, there was 30% more grass DM and a 56% higher tiller density developed on treatments with legume defoliation, in which legume roots were not excluded, while no differences occurred where grass and legume roots were not excluded (Section 5.3.6.3), indicating that legume plants were competing more successfully when no root competition was present. Defoliation effects observed on plants with root exclusion (R0) were much lower than those recorded on treatments without root exclusion (R1) (Table 5.14 and Table 5.15), and differences in most variables measured were of higher magnitude at the end of the experiment, with a sharper decline in R1 v R0 in leaf (-85 v -50%, respectively) and total shoot mass (-89 v -65%, respectively) (Figure 5.4). Similarly, there was a much more pronounced reduction in WC stolon length (-87% v -58%), number of WC growing points (-70 v -47%), and number of SC branches (-70% v -32%), when R1 v R0 are compared, respectively (Table 5.15). Defoliation causes a reduction in root elongation (Evans, 1973) and lower shoot DM, lower number of leaves and lower leaf area are correlated with less root growth (Blaikie and Mason, 1990). In this experiment, root mass in root-excluded and defoliated (R0-D1) legume plants was reduced by 39% in March, while at the same time total shoot mass declined by 68% (Table 5.21). In R1, differences observed in legume leaf and shoot mass, leaf area, stolon length, number of WC growing points, and SC branches, between defoliated and

undefoliated plants were much larger than those recorded in R0 (Table 5.14 and Table 5.15), suggesting that repeated selective defoliation (as in this experiment) may have a proportionally stronger effect when opportunity for root competition is present.

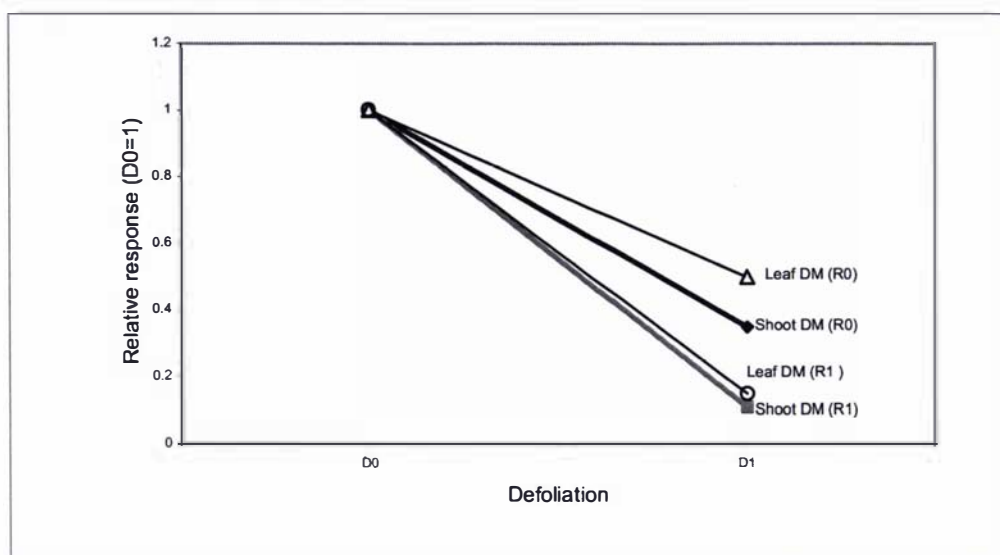


Figure 5.4 Leaf DM and total shoot DM yield of legume plants under defoliation (D1), relative to undefoliated plants (D0), when grown with root exclusion (R0) or without root exclusion (R1).

5.5 CONCLUSIONS

From the factors studied, severe selective legume defoliation had the strongest effect on legume growth, reducing plant size, leaf area, vegetative stem development and branching, especially when in combination with root competition.

Below ground (root) competition was seen to play a major role in limiting legume shoot growth. This was suggested from the results indicating a proportionally much stronger reduction in legume shoot DM when legume plants were growing in a short grass sward (lower light limitation) than when additionally subjected to a taller grass environment (higher light limitation), and from higher magnitude relative reductions in plants without root exclusion.

Both legume species were affected by the above and below ground constraints imposed, while subterranean clover was on average slightly less affected than white clover.

CHAPTER 6

GENERAL DISCUSSION

6.1 INTRODUCTION

An adequate content of legumes has been highlighted as an important factor in sustaining production and nutritive value of pastures (White, 1990). This is especially relevant in hill country pastures, where the use of artificial nitrogen is limited by economic constraints, and the maintenance of high levels of dry matter production relies on cheap N inputs from symbiotic nitrogen fixation by legumes. The philosophy of pasture improvement in New Zealand hill country has been largely based on oversowing with legumes and topdressing with superphosphate, to stimulate legume establishment and production (Suckling, 1975). However, legume content in hill country pastures is traditionally very low, and medium-long term sustainability of hill country systems is at risk. Numerous factors have been identified as influencing low legume abundance and persistence in hill swards, but their relative magnitude and their likely interactions need further consideration.

The issue of low legume content in hill country pastures provided the focus of this thesis, with the objective of determining the relative importance of management and environmental factors that affect legume abundance, both in summer-moist (Ballantrae; 40°19' S, 175°50' E) and summer-dry (Waipawa; 40°00' S, 176°23' E) situations. The first set of experiments (Chapter 3) was designed to evaluate the relative impacts of selected factors on legume abundance, expressed in terms of legume content on a dry matter basis. The following experimental set (Chapter 4) focused on the main factors

that had greatest influence on legume abundance in the first studies (grass suppression and soil-P status) concentrating on the two most contrasting sites, and looking at residual effects as well as allowing some comparisons between sites and years. Rotational grazing by sheep was also included as a potentially important factor here. Finally, in Chapter 5, the effect of companion grasses and defoliation on individual legume plants was also tested under glasshouse conditions (Table 6.1).

In this general discussion attention will first focus on the main differences between the experimental sites, especially in relation to temperature and moisture patterns, followed by a brief analysis of the general magnitude of responses to different factors at the two more contrasting sites during the two years of pasture evaluation. Responses observed at different sites will be compared, and main results will be highlighted, with special reference to the overriding effect of grass suppression on legume abundance in the sward. Finally, some implications of the results and possible practical considerations will be considered, followed by a summary of conclusions of the work.

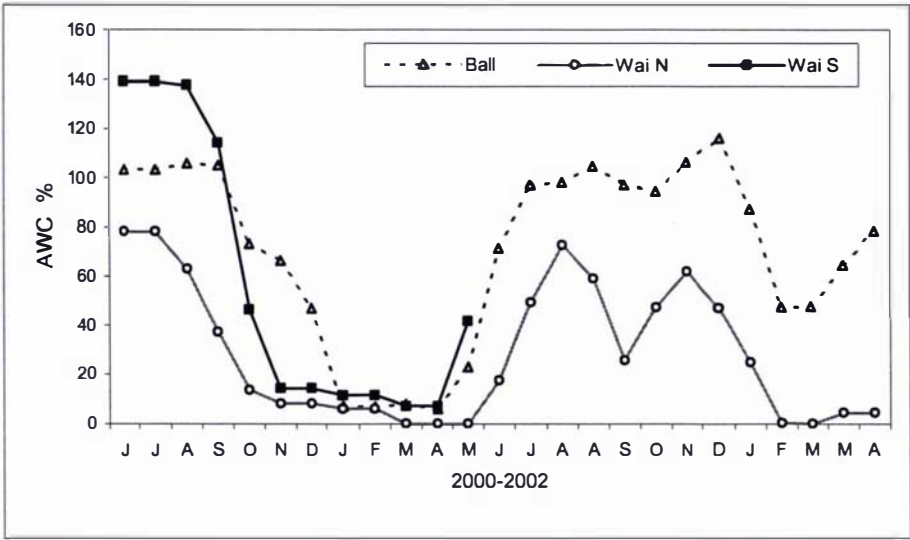
Table 6.1 Summary of field and glasshouse experiments conducted.

Experiment	Location	Factor	Period
1. Chapter 3	<u>3 locations:</u> - Waipawa * (N aspect) - Waipawa * (S aspect) - Ballantrae **	<u>Effects on legume abundance of:</u> - Cutting height (h3/h7) - Grass suppression (H0/H1) - Soil-P status (HP/LP) - N application (N0/N50)	May 2000-April 2001
2. Chapter 4	<u>2 locations:</u> - Waipawa * (N aspect) - Ballantrae **	<u>Effects on legume abundance of:</u> - Cutting / Grazing (C/G) - Grass suppression (H0/H1/H2) - Soil-P status (HP/LP)	May 2001-April 2002
3. Chapter 5	- Plant Growth Unit (Massey University, Palmerston North)	<u>Effects on WC/SC plants of:</u> - Companion grasses (Co/S2/T8) - Root exclusion (R0/R1) - Defoliation (D0/D1)	February 2002-April 2002

*Hawke's Bay region; ** near Woodville; h3=cutting at 3 cm height; h7=cutting at 7 cm height; H0= no grass suppression; H1= grass suppression in autumn 2000; H2=grass suppression in autumn 2001; HP= high soil-P status (Olsen >28); LP= low soil-P status (Olsen 13-15); N0= no nitrogen fertiliser application; N50=50 kg/ha nitrogen fertiliser applied in autumn; C= periodic cutting management; G=rotational mob-grazing with sheep; Co= no companion grasses; S2= short companion grasses cut back to 2 cm height; T8= tall companion grasses >8 cm height; R0= with root exclusion; R1= no root exclusion; D0= no legume defoliation; D1= with legume defoliation; WC=white clover; SC= subterranean clover.

6.2 SITE CONTRASTS

Experimental sites were chosen in contrasting environments of the North Island and corresponded to both north and south aspects in a summer-dry area (Waipawa), and an east face in a summer-moist location (Ballantrae). The soil moisture contrasts between sites are depicted in Figure 6.1. The Waipawa north aspect was always the driest site, especially in the first year, where very low moisture levels were recorded from October onwards. The soil moisture in the south aspect also showed a sharp decline, but this occurred in late spring, and moisture levels during summer never dropped below wilting point. During the second year, apart from a drop in soil moisture in September, levels in the north aspect of Waipawa were maintained over spring and early summer, declining towards late summer. Soil moisture at the Ballantrae site was near field capacity over winter to early spring, dropping thereafter to low levels in mid-summer (year 1) and maintaining adequate soil moisture over summer in year 2. The patterns of soil moisture had profound effects on the pasture dynamics of the Waipawa north aspect (Chapter 3 and 4). In the first year harvests had to be discontinued due to absence of significant growth, while in year 2 summer production accounted for more than one third of total herbage accumulation and more than 40% of WC production, indicating that soil moisture status is a key factor in determining pasture responses from year to year.



Sites: Wai N= Waipawa north aspect; Wai S= Waipawa south aspect; Ball= Ballantrae

Figure 6.1 Seasonal variation of the available water capacity (AWC, 10 cm soil depth) in three contrasting hill country sites.

The general annual temperature pattern was similar at the three sites studied (Figure 6.2). However, differences between sites were apparent, as the north aspect in Waipawa had higher mean soil temperatures earlier in the season compared to the other sites. At this site and for both years, mean soil temperatures dropped below 9-10°C (where nitrogen fixation and growth are restricted (Evans *et al.*, 1976, Frame and Newbould, 1986, Brock *et al.*, 1989) only for a very short period in mid-winter, and mean temperatures above 16°C (the lower end of temperature range where adequate clover performance can be expected (Frame and Newbould, 1986), extended from October to at least April. In both years, the Waipawa south aspect showed the highest winter-summer thermal amplitude. It tended to show the lowest mean soil temperatures in winter and the period in which mean temperature exceeded 16°C extended from late spring to late summer only. The Ballantrae site had intermediate temperature conditions in winter and had a colder spring-summer than the Waipawa sites in year 1, while similar mean temperatures were recorded on the three sites from mid-spring to late summer in year 2.

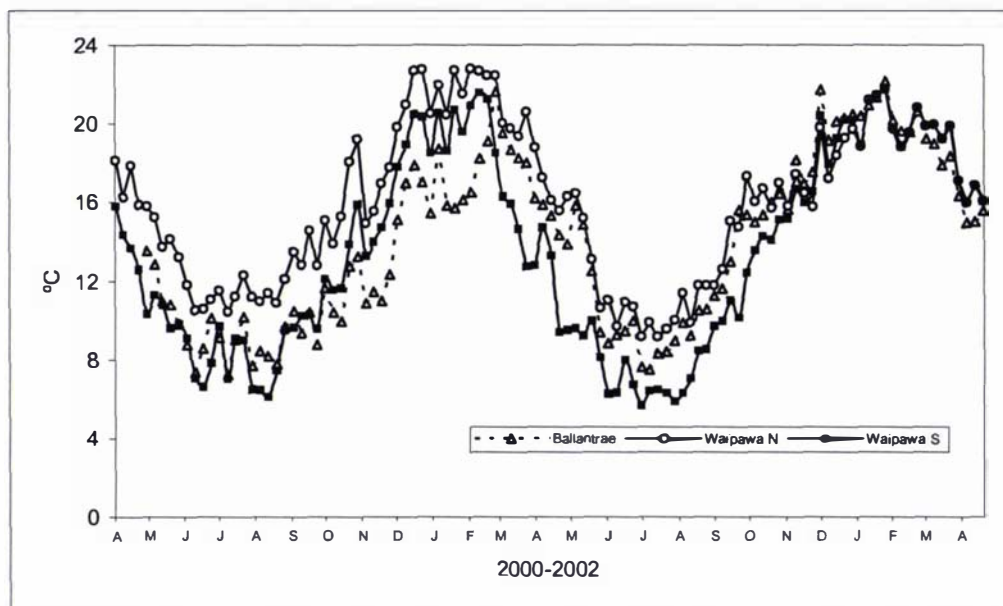


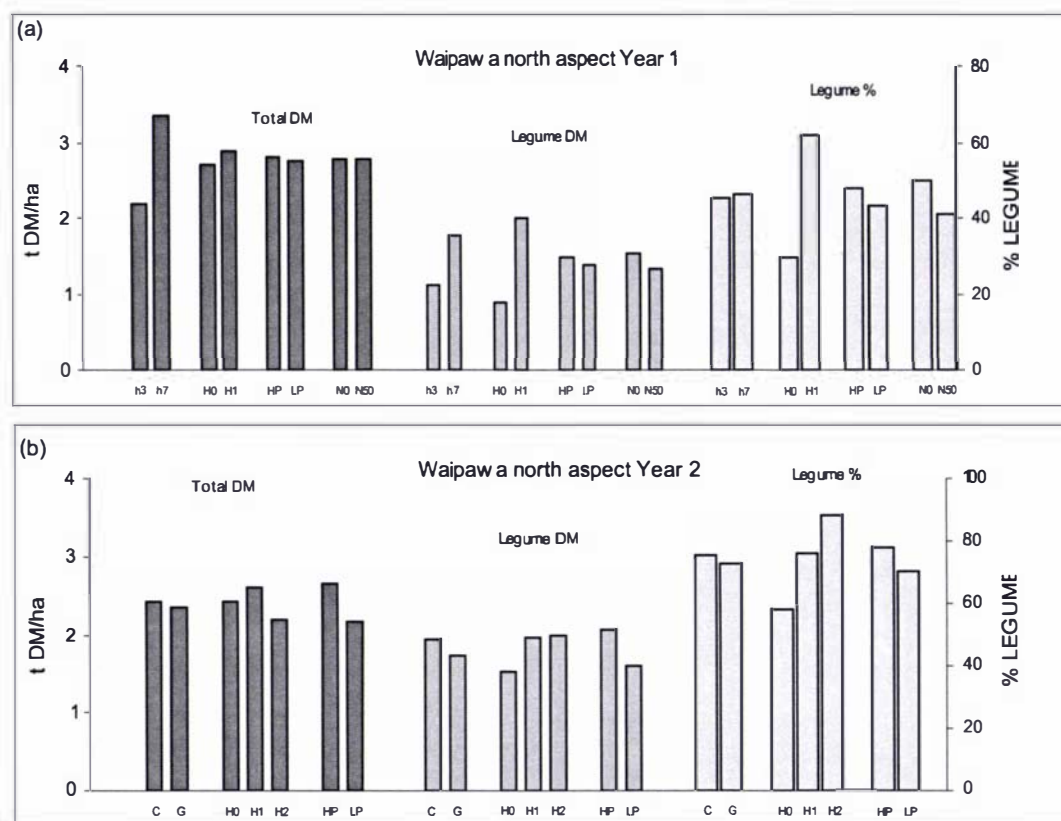
Figure 6.2 Seasonal variation of the mean soil temperature (10 cm) for three contrasting hill country sites (weekly averages).

The thermal and moisture patterns observed on the Waipawa north aspect (especially in year 1) are more suited to annual species, like subterranean clover, that will grow in late winter and spring, producing seed before the onset of the dry summer period. In the colder sites (Waipawa S aspect and Ballantrae) temperature restrictions for adequate legume growth will operate in winter and early spring, and higher temperatures combined with adequate late spring-summer moisture conditions will better suit perennial legumes like white clover. However, white clover is present in Waipawa N aspect and can be boosted with favourable summer seasons as was the case in year 2 (Chapter 4).

6.3 MAGNITUDE OF RESPONSES

The effect of several factors influencing legume abundance in hill pastures were studied in field experiments. Although some interactions between factors were detected, these were commonly confined to particular months within years, while the main factors had generally very highly significant effects ($p < 0.001$; Tables 3.1; 3.22; 4.2; 4.23). Some interactions with a more consistent pattern over the season are considered later in this

chapter. The magnitudes of the main factor effects on average standing biomass, legume standing biomass, and legume content (%), during the main legume-growing season, are presented for both years for the Waipawa north aspect (Figure 6.3) and the Ballantrae site (Figure 6.4).

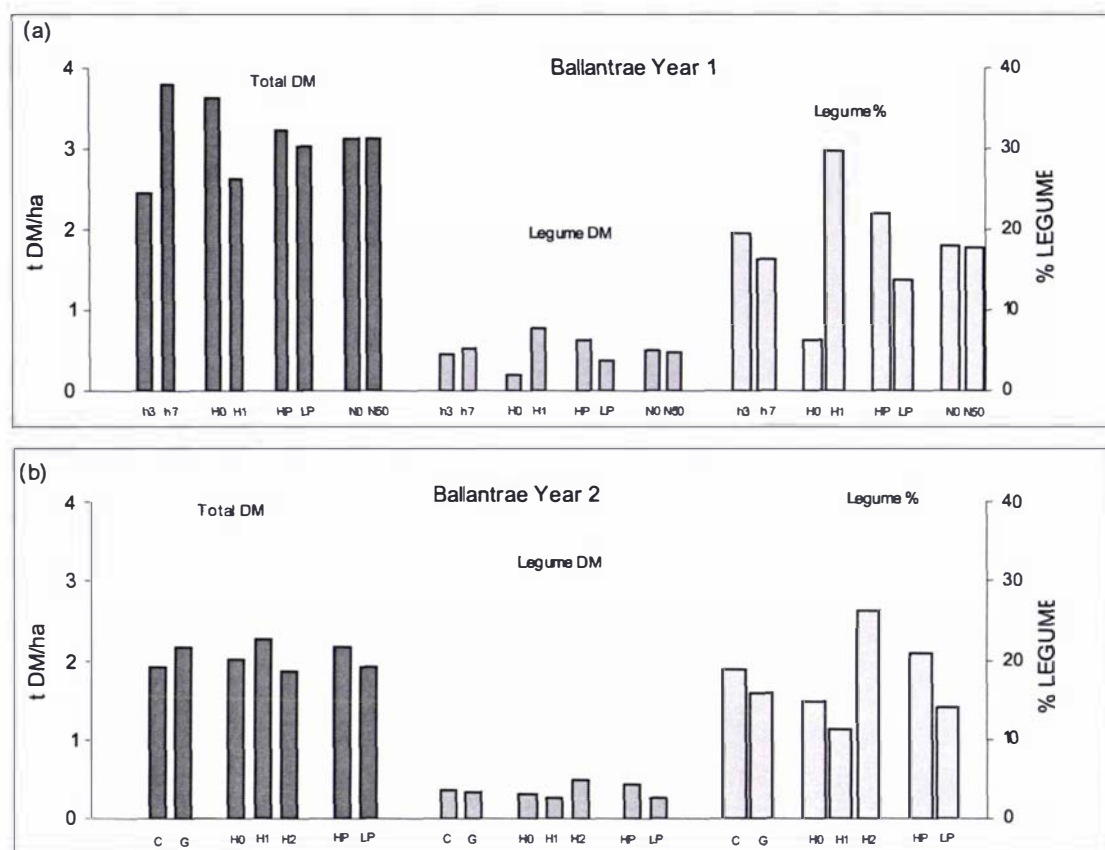


Adapted from tables: 3.4; 3.6; 3.8; 3.10; 4.5; 4.12; 4.17; h3=cutting at 3 cm height; h7= cutting at 7 cm height; H0= no grass suppression; H1=grass suppression in autumn 2000; H2=grass suppression in autumn 2001; HP= high soil-P status (Olsen >28); LP=low soil-P status (Olsen 13-15); N0=no nitrogen fertiliser application; N50=50 kg/ha nitrogen fertiliser applied in autumn; C=periodic cutting management; G=rotational mob-grazing with sheep.

Figure 6.3 Average total standing biomass, legume standing biomass and legume content of hill country pastures during the main legume-growing period on Waipawa north aspect in September-December 2000 (a) and September-December 2001 (b). Average responses to cutting height (h3, h7), grass suppression (H0, H1, H2), soil P status (HP, LP), nitrogen application (N0, N50), and defoliation management (C, G).

Both in Waipawa and Ballantrae, the factor that had the strongest effects in changing legume content in the swards was the application of selective herbicide to achieve grass suppression (H1 and H2). Average effects were strongest in the first year, with more than double the legume standing biomass and legume content in Waipawa, and about four times more in Ballantrae, when the untreated resident pasture was compared with

the sward treated with grass suppressant. Changes due to grass suppression in swards in the second year were in the order of 50% and 80% higher in legume content in Waipawa and Ballantrae respectively.



Adapted from tables: 3.25; 3.27; 3.29; 3.31; 4.27; 4.33; 4.39; b3=cutting at 3 cm height; h7= cutting at 7 cm height; H0= no grass suppression; H1=grass suppression in autumn 2000; H2=grass suppression in autumn 2001; HP= high soil-P status (Olsen >28); LP=low soil-P status (Olsen 13-15); N0=no nitrogen fertiliser application; N50=50 kg/ha nitrogen fertiliser applied in autumn; C=periodic cutting management; G=rotational mob-grazing with sheep.

Figure 6.4 Average total standing biomass, legume standing biomass and legume content of hill country pastures during the main legume-growing period in Ballantrae in December 2000-March 2001 (a) and December 2001-March 2002 (b). Average responses to cutting height (h3, h7), grass suppression (H0, H1, H2), soil P status (HP, LP), nitrogen application (N0, N50), and defoliation management (C, G).

The increase in the soil phosphorus status also had important effects on legume biomass and legume content, especially at the Ballantrae site, where in both years increments of 65-70% in legume biomass and 50-60% in legume content were recorded (Figure 6.4). Other factors had relatively less influence on legume abundance in the sward. In the first year, the taller cutting height (h7) increased average standing biomass by 53%, but the average sward legume content was largely unchanged (Figure 6.3).

Due to the overriding effect of grass suppression on legume abundance in these hill swards, the emphasis of the following discussion will focus mostly on considerations related to that factor.

6.4 FACTORS AFFECTING LEGUME ABUNDANCE IN HILL COUNTRY

6.4.1. Grass suppression

The removal of grass competition through the application of a selective herbicide in autumn (grass suppression) had very strong effects on legume abundance at the locations studied. Grass suppression was achieved at the three sites in year 1 (Chapter 3) and also at both locations in year 2 (Chapter 4). The availability of open spaces created in the pasture allowed legumes to colonize. This occurred mostly through seedling recruitment in the Waipawa north aspect, where moisture and temperature conditions were adequate, especially for subterranean clover germination, but white clover and other legumes (especially suckling clover and clustered clover) were also responsible for the increase in legume abundance at that site. In the colder sites of Waipawa south aspect and Ballantrae, although grass was efficiently suppressed by herbicide application in autumn, legume (and particularly WC) increase had a delayed response, and open spaces in the sward remained as bare ground for a substantial part of the winter. In the south aspect of Waipawa, chewings fescue took advantage of the low WC growth in winter to colonise part of the bare ground created, as it was more resistant to herbicide treatment, and therefore conditions for WC establishment and spread in spring were less favourable. In Ballantrae, treated swards remained with very low biomass over the winter period, but WC had to compete with broadleaved weeds in spring and summer, which also may have reduced the response in legume abundance to grass suppression, although WC content in the sward and WC growing point density increased substantially at these sites.

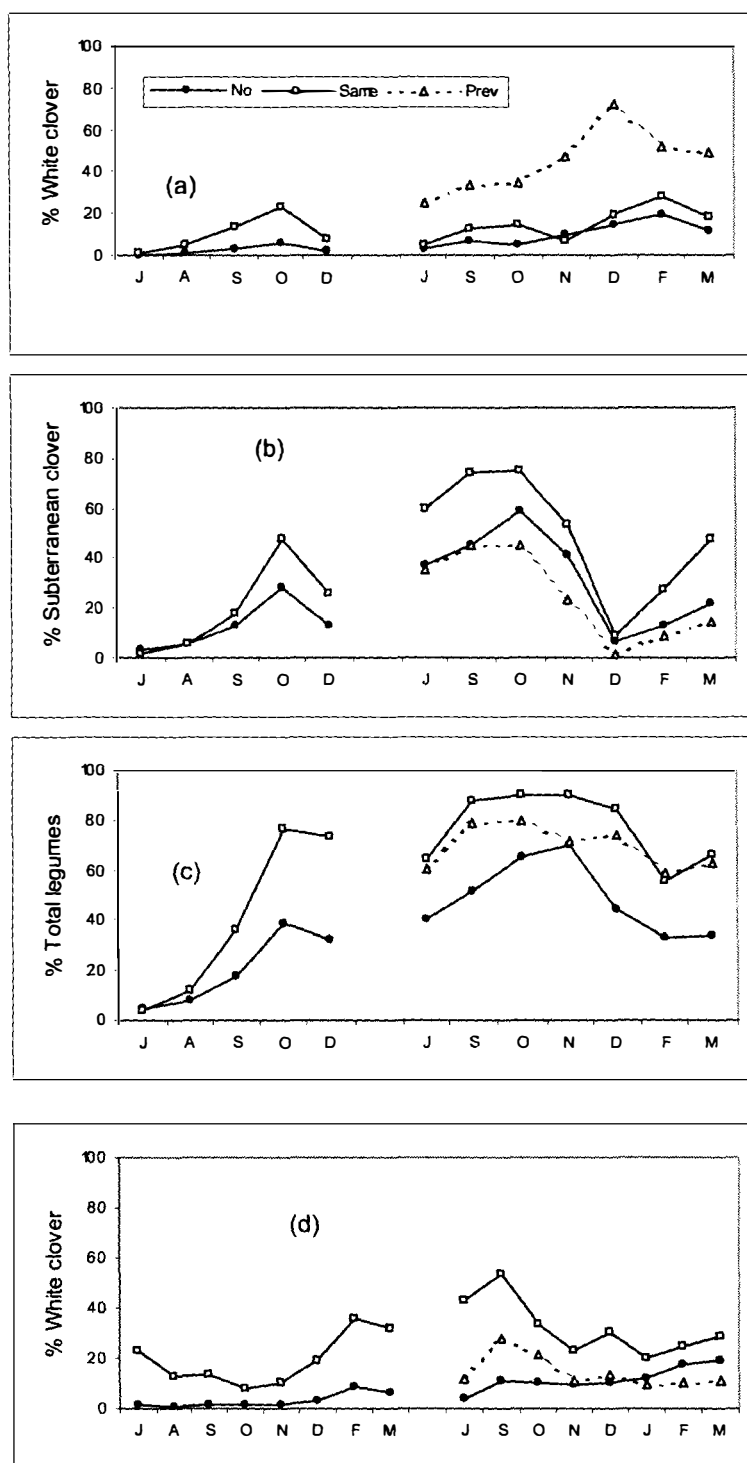


Figure 6.5 Legume content of swards that were not subjected to grass suppression (No), grass suppression in the current year (Same), or with grass suppression in the previous year (Prev), in Waipawa north aspect (a,b,c) and Ballantrae (d).

Of the factors included in this study, grass suppression was by far the most significant factor enhancing legume abundance at all sites. Through the removal of above and below ground competition from grasses, legumes developed in an environment with less

constraints to growth, branching was stimulated, and leaf and stem production was consequently increased (e.g. tables 5.16 and 5.17). It is likely that in the more advanced stages of the season, when open spaces have been colonised, intra-specific competition will be playing a role (Hill and Gleeson, 1988), as well as competition between legume species, especially SC and WC (Smith and Crespo, 1979, Hill and Gleeson, 1990).

The effects of grass suppression on legume abundance in both years are summarised in Figure 6.5 for the Waipawa north aspect and Ballantrae sites. After the increase of SC and WC and total legume abundance in year 1, in Waipawa, higher SC abundance occurred in plots with recent (same year) grass suppression, while the residual effect of grass suppression produced swards with lower SC abundance compared with the resident pasture (Figure 6.5 b). However, pastures treated in the previous year had much higher WC content in year 2 than untreated or recently treated swards (Figure 6.5 a), and in the former total legume content was also more evenly distributed through the growing season (Figure 6.5 c), the growth patterns of WC and SC permitting a more stable legume offer throughout the growing season, as was also observed by Hill and Gleeson (1988). It would be interesting to evaluate the response under more limiting soil moisture conditions, as WC growth is likely to be affected (Brock and Kim, 1994), and legume patterns would probably resemble more those on the original sward.

As reported earlier, the two years had contrasting soil moisture profiles (Figure 6.1), which had a strong influence on legume abundance in Waipawa, especially in the north aspect. In year 1, although very contrasting swards were generated through grass suppression, there was no significant growth during summer due to limiting soil moisture. During the second year, soil moisture was adequate in spring and early summer, which encouraged legume growth, and legume abundance increased. The higher SC abundance in year 2 (Table 4.12) may also be related to plots being managed under a cutting regime in the previous season, which may have better suited the reproductive cycle of this annual legume and therefore increased seed set (Sheath and Boom, 1985b, Conlan *et al.*, 1994). The higher soil moisture levels, especially in late

spring-summer, allowed WC to achieve high abundance on swards that had been under grass suppression in the previous year (H1; Table 4.12). It is also noteworthy that higher soil moisture in late spring-summer of year 2 allowed pasture growth to be sustained during the otherwise dry summer period (e.g. Table 4.14). Subterranean clover seedlings were recruited from the soil seed bank (e.g. Table 4.13) and, if soil moisture increase was short-lived, it could have led to a 'false strike' (Sheath and Macfarlane, 1990b). It is interesting that high levels of legume abundance can be achieved in years with a better soil moisture profile, and therefore the spring-summer soil moisture patterns in summer-dry hill country areas will play an active role in the definition of legume abundance (Korte and Quilter, 1990), and the magnitude and shape of responses to factors such as grass suppression will be subordinated to soil moisture. It is important to remember that hill soils usually have low water storage capacity, with less than 50% of rainfall being effective in replenishing soil moisture for plant use, which makes them highly dependent on rewetting frequency rather than total rainfall (Bircham and Gillingham, 1986).

In the summer-moist site at Ballantrae, in both years WC content increased through removal of grass competition (Tables 3.28; 4.34), but responses were not long-lasting, as in year 2 previously treated swards tended to revert to original levels of legume content (Figure 6.5 d), showing a high resilience to the treatment imposed. Figure 6.6 shows how grass suppression induces a shift of botanical composition towards higher WC content in the first year, but that in the following year the balance returns towards grass dominance. High resilience of hill country pastures, especially those dominated by browntop, is reported by Nicholas (1999).

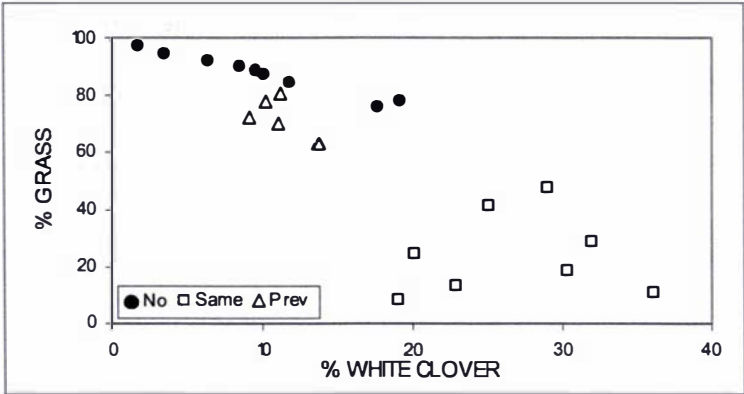


Figure 6.6 Relationship between grass content and white clover content in the sward under no grass suppression (No), grass suppression in the current year (Same), and grass suppression in the previous year (Prev), during the main legume-growing season (December-March). Ballantrae.

Similarly, it can be seen in Figure 6.7 that the removal of grass competition produced a short-term shift from a relatively dense grass sward, to a sward with low tiller population density but generally with a higher white clover growing point density. This situation again reversed in the following year, as tiller density increased and growing point density declined.

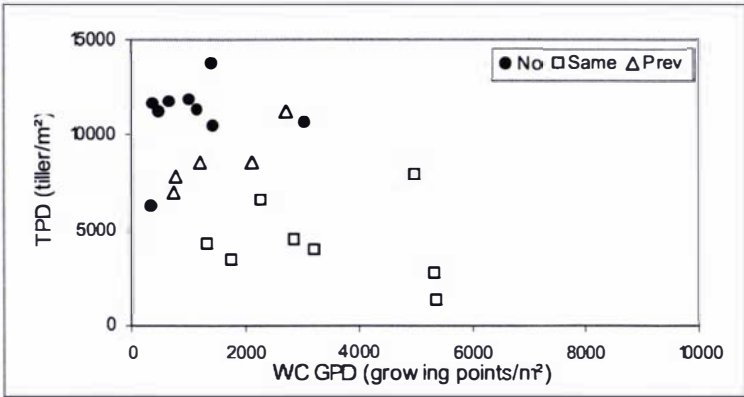


Figure 6.7 Relationship between grass tiller population density (TPD) and white clover growing point density (GPD) under no grass suppression (No), grass suppression in the current year (Same), and grass suppression in the previous year (Prev), during the main legume-growing season (December-March). Ballantrae.

6.4.2. Soil-P status

The white clover component was the botanical fraction that usually responded to higher soil-P levels, and increased WC standing biomass, WC content and WC production in both years were observed in response to the use of fertiliser P (e.g. Tables 3.29; 3.30; 4.39; 4.40). Subterranean clover was much less responsive to phosphorus application, but it responded to higher P levels when there was no grass suppression (i.e. in resident swards where grass competition was present). In grass suppressed pastures, lower soil-P levels seemed to be capable of sustaining SC growth, and increments in soil-P status had no effect (Tables 3.8; 4.17), a situation also reported by Dodd and Orr (1995b). Although some interactions occurred for WC in specific situations, the general trend was to increase WC abundance and production at high soil-P status, and this was more marked in swards that had grass suppression in the previous year in Waipawa, or the same year in Ballantrae. More favourable soil moisture patterns in the summer-dry area during year 2 generated stronger overall responses to P application. In year 2, LP swards in Waipawa produced on average 4.6 t DM/ha of total legumes, which ranged from 2.9 t DM/ha on H0 plots (not suppressed) to 5.7 t DM/ha on H1 plots (grass suppressed in the previous year). It is noteworthy that these high levels of legume production for hill country pastures could be sustained with a relatively low P status in the soil, and this highlights both the influence of adequate seasonal soil moisture patterns in summer-dry hill country, and the effect of removal of grass competition. Soil P was unevenly distributed in the profile, with higher concentrations in the top soil layers even on LP plots (Figures 4.5; 4.10), and P availability may have been boosted by higher soil moisture in spring-summer of year 2 in Waipawa (Blennerhassett, 1998).

6.4.3. Nitrogen application

Nitrogen effects on legume abundance were of a lower magnitude than the effect of grass suppression or soil-P status, and were significant only at the Waipawa sites

(Tables 3.10; 3.11; 3.20; 3.21). The application of 50 kg/ha nitrogen in autumn increased total biomass present in winter (Waipawa north aspect) or spring (Waipawa south aspect) and, especially in the former, SC abundance was depressed. The negative effects of N application on legume abundance were mostly on swards with no grass suppression, which suggested that these were mostly related to grass competition factors rather than to direct negative effects of nitrogen on legumes (Luscombe and Fletcher, 1982, Eltilib and Ledgard, 1988). In fact, white clover was largely unaffected by N application.

In the summer-moist location at Ballantrae, no effect on total biomass production or legume abundance was recorded, apart from a decline in growing point density. Soil N levels were not recorded in this experiment, and it is likely that the dense grass dominant pastures at this site were also a reflection of higher soil N levels (Lambert *et al.*, 1982), which would minimise responses to low doses of N application. The tendency in H1 plots for a rapid reversion of the grass suppressed sward to original grass and clover levels similar to H0 would also support this suggestion.

6.4.4. Defoliation management

Low swards (h3) usually had higher legume abundance than tall swards (h7) at some stages of the season (Tables 3.15; 3.26), except for the Waipawa north aspect, where the opposite was the case (Tables 3.4; 3.5), particularly due to higher SC content and standing biomass on h7 swards compared to h3 swards. Cutting height interacted with grass suppression in the denser swards of Waipawa south aspect in spring and Ballantrae in summer of year 1 (Chapter 3), the consequence being that the effect of removing grass competition on the increment of total legume abundance was higher in tall swards than in short swards. This is in line with the results obtained on the responses of individual legume plants (Chapter 5), where intense defoliation reduced above-ground shoot DM, WC growing points and SC branches. From those results, non-defoliated or

laxly defoliated plants are expected to grow and spread faster when released from grass competition.

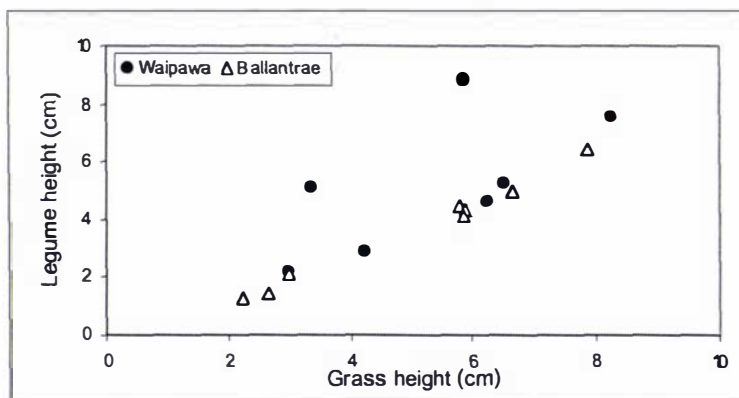


Figure 6.8 Relationship between grass height and legume height (cm) during the 2001-02 growing season in Waipawa north aspect and Ballantrae.

The higher relative responses to grass suppression compared to defoliation management indicates that grass-clover competition had a strong influence, which may be explained through the elimination of above and below ground competition from grasses. Results from the glasshouse experiment (Chapter 5) showed that legume plant size and leaf mass were reduced when plants were subjected to competition with short grasses, but additional competition for light (by taller companion grasses) had proportionally less effect (Table 5.7). Similarly, total shoot DM of legume plants that grew in root-exclusion tubes were not affected by a short companion grass sward, while plants without root exclusion had a sharp decrease (38%) in total shoot DM, when results are expressed in a relative scale referred to the respective control treatment (Co) (Figure 5.3). Despite the fact that the root exclusion factor implied different soil volumes to be explored by the legume plants, the relative responses were very consistent. These results support the view that root competition may have been a stronger limitation to legume abundance compared to above-ground competition, as has been also found by other authors (Harper, 1981, Wilson, 1988). The smaller effect of above-ground competition may be partially explained through the capacity of clover to adapt its lamina height according to grass height, which permits clover leaves to explore the upper layers of the

canopy, where light conditions are more favourable (Figure 6.8 and Table 5.6), as stated by Dennis and Woledge (1982) and Marcuvitz and Turkington (2000).

Management effects (cutting/grazing contrast) on legumes in year 2 were characterised by a moderate decline in total legume abundance in Waipawa (Table 4.9), and a white clover decline in Ballantrae (Table 4.31) under grazing conditions (Chapter 4). At Waipawa however, SC was more abundant under cutting conditions (Table 4.9), while WC and other legumes were more abundant under grazing. At this site, it was observed that on plots that had grass suppression in the previous year, WC was more abundant on grazed than cut plots. With the lower post-grazing heights of legumes in grass suppressed plots (Figure 6.9 a) compared to untreated plots, SC may have lost competitive advantages over WC (Smith and Crespo, 1979). This was also seen at an individual plant level in the glasshouse experiment (Chapter 5), where undefoliated SC achieved taller lamina heights than WC, while both had similar heights when defoliated (Table 5.2).

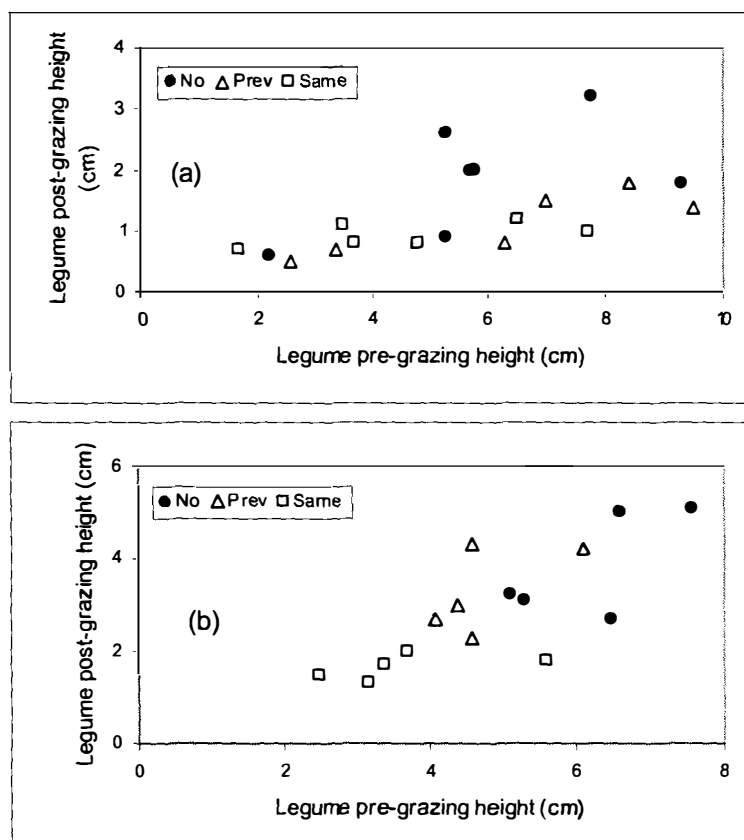


Figure 6.9 Pre- and post-grazing legume height of swards with no grass suppression (No), with grass suppression in the current year (Same) or grass suppression in the previous year (Prev) in Waipawa (a) and Ballantrae (b).

At Ballantrae, grazing had negative effects on WC abundance, which may be related to preferential grazing of clover-rich plots (especially in plots with grass suppression in the same year; Figure 6.9 b) (Penning *et al.*, 1997, Cosgrove *et al.*, 2002), but also partially to higher grass accumulation on grazed plots in late spring-summer (especially non-suppressed plots) and the partial failure of rotational sheep grazing to control grass growth during that period, a problem that was present in both sites. High intensity of defoliation caused legumes to reduce plant size, above- and below-ground biomass, WC growing points and SC branches, affecting overall plant yield (Chapter 5).

The effects of grazing on legume abundance in the swards studied were less than expected. The rotational grazing system with sheep, although of relative high intensity,

was unable to control explosive reproductive grass growth, so rank pasture developed, especially in unsuppressed plots, and grazing uniformity was increasingly more difficult to achieve in the latter part of the season. The combination of intensity and higher frequency of defoliation by intensive set stocking with sheep may impose more limiting conditions to legume abundance and persistence than in this experiment, as was observed with repeated intense defoliation of individual clover plants in the glasshouse experiment, with a strong reduction in plant size and branching (Chapter 5). This is likely to limit WC spread in the sward (Brock *et al.*, 1989), as well as causing a major disruption of the reproductive cycle in SC, and consequently affecting seed set (Chapman *et al.*, 1986, Chapman, 1992).

6.5 IMPLICATIONS AND CONSIDERATIONS

The answer to the question of why there is generally low legume abundance in hill country swards is complex, as no individual factor explains this by itself (Figure 6.10). Hill country pastures are subjected to various environmental conditions, which also change between seasons and years. Soil moisture is probably a key factor in summer-dry areas, as it was seen to be the leading factor in determining legume responses on both years studied. The suppression of grasses, especially through removal of root competition, interacted with soil moisture, and generated strong increases in legume abundance in swards. These in turn interacted with soil-P status, as legume abundance (and particularly WC) could be further boosted at higher soil phosphorus levels. Defoliation management was an additional modifying factor by influencing the relative abundance of sward components through factors like selective defoliation, defoliation frequency and intensity, and its effects on vegetative spread and/or seed set of legumes. Autumn nitrogen application at levels of 50 kg N/ha, only had comparatively minor effects on legume abundance on some sites, and seemed to act especially through the negative impact of increased grass competition on legumes.

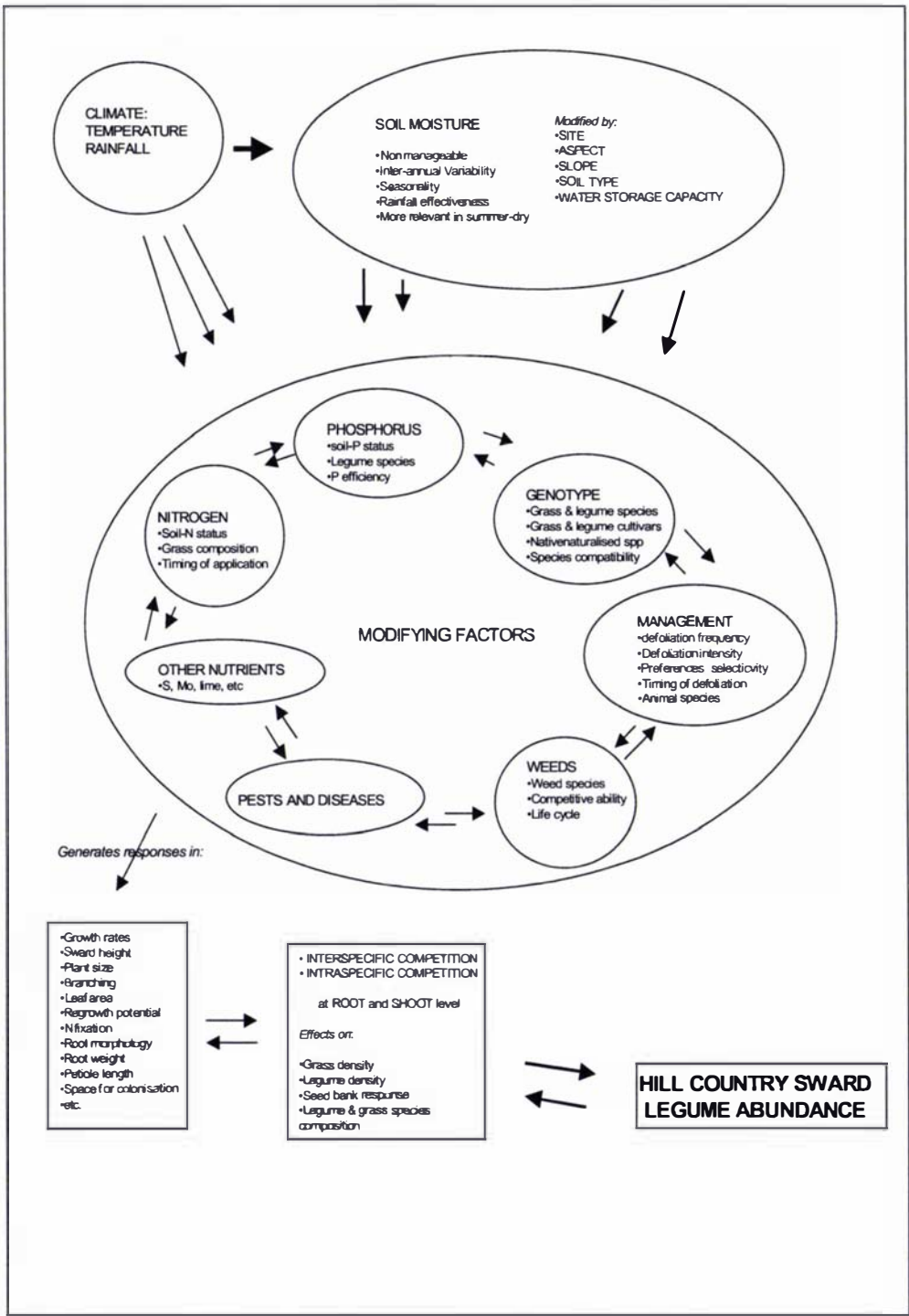


Figure 6.10 Conceptual summary of factors affecting legume abundance in hill country swards.

The lower tiller density of grasses in the Waipawa north aspect allowed open spaces to be colonised, either by annual legume seedlings (especially subterranean clover), vegetative white clover spread, or even white clover germination. Under “normal” summer-dry hill country conditions, soil moisture will limit pasture growth by late spring, annual legumes will complete their life cycle, and white clover will be suppressed by moisture stress. Very low growth and negligible legume abundance will be observed over the summer period under those circumstances. During the late winter-spring period where soil moisture is adequate, competition from grasses was a limiting factor for legume growth, and the suppression of that competition resulted in a boost of legume abundance, as new open spaces could be colonised by clovers. White clover increased in abundance on grass suppressed swards, with a build-up of the growing point density by the end of the season.

At Waipawa, in late-spring-summer, adequate soil moisture at a time when temperature is optimal for legume (especially white clover) growth will result in an increase in legume abundance and the legume season will be extended, as white clover will be capable of expressing growth potential, especially if a high density of growing points is available, as was the case in swards with grass suppression in the previous year.

In the summer-moist area (Ballantrae) soil moisture is usually not a major limitation for pasture growth, and swards are dominated by grasses with high tiller population densities. Grass competition becomes a major issue here in limiting legume abundance, particularly white clover abundance, as this is by far the most important legume in this area. The suppression of grass had a strong effect by increasing growing point density in white clover, as both above and below ground competition from grasses was removed. Although shading is a detrimental factor for legume abundance as observed in the comparison of h3 and h7 cutting heights, root competition had a much stronger effect, and the release from it caused legume abundance to increase considerably. In contrast to the Waipawa north aspect, the residual effect of grass suppression at Ballantrae was not long-lasting, and legume abundance was similar to non-suppressed swards. Broad-

leaved weeds also proliferated shortly after grass suppression, which imposed a limitation to a higher legume increase, while grasses tended to re-colonise their lost space in the pasture. In the north aspect of Waipawa, the presence of a fast-germinating winter annual legume like subterranean clover takes immediate advantage of available space in the sward and becomes a dominant species under those circumstances, delaying grass repopulation. White clover makes a more substantial contribution in summer, but only if soil moisture conditions are favourable, as in year 2.

It is important to point out that in Waipawa the higher average legume abundance observed in non-suppressed swards (H0) in year 2 was probably also due to the cutting management imposed in the previous year, which resulted in lower tiller population density and the absence of deleterious selective defoliation, which is also likely to better suit the subterranean clover reproductive cycle, by allowing seed set and adequate regeneration in the following autumn. This evidence would support recommendations for partial fallowing of pastures to allow re-seeding and improve legume abundance through better subterranean clover regeneration and/or white clover spread in the sward.

On the other hand, mob grazing with high grazing pressure during flowering is very likely to limit subterranean clover seed set and diminish repopulation. Systems combining high frequency of defoliation and selective defoliation of legumes, under relatively high grazing pressure, as in many set stocking systems used in hill country, will stress individual plants, reduce branching and spread, and legume abundance will be adversely affected, while higher tiller population density at low sward heights will impose higher degrees of root competition on clover. This is likely to be aggravated if drought conditions are prevalent. However, there is evidence that under set stocking SC plants adopt a prostrate growth habit with the relative stable sward height that ensures adequate flower and seed development.

The use of selective herbicides is effective to control grasses in the short term, but there are likely to be economic and environmental limitations to its use as a practical management tool. The fast reversion of treated summer-moist pastures to the original

sward poses also a further limitation, as the effect is short-lived. Therefore, the preferred approach appears to be for management systems that allow adequate pasture utilisation, while not imposing a particular strain on legume plants, i.e. systems that discourage legume selection and do not attempt extreme utilisation in every grazing event.

These results have shown that there is potential for the improvement of legume abundance in hill country pastures, and that very high levels of legume biomass can be sustained, especially in areas where subterranean clover is a main component of the botanical composition. This can be achieved even at relatively low soil-P status (Olsen P 13-15). The control of grass competition appears to be a major factor, particularly when soil moisture constraints are not present. Lower grazing pressure and less selective defoliation management (e.g. by mixed systems with cattle) or the strategic use of fallowing periods, together with adequate P fertility to stimulate white clover, may allow adequate legume regeneration as well as permitting the maintenance of legume abundance in time.

6.6 CONCLUSIONS

- The first objective of this thesis (to determine the effects of pasture cutting height, grass suppression, soil-P status and nitrogen application on legume species abundance in contrasting environments) was researched in three different environments during year 1 (2000-2001). The suppression of grass competition was the factor that caused the most marked changes in short-term sward composition, with an increase in legume abundance occurring at all sites. Higher soil-P status added to a bonus in legume abundance, especially in those swards where white clover was present as a major component of botanical composition. Altering pasture cutting height or applying nitrogen in the autumn had comparatively minor effects on legume abundance.

- When rotational grazing with sheep was explored as a factor to be compared with cutting management of the sward in two contrasting sites in year 2 (second objective), it was concluded that defoliation managements played a secondary role in affecting legume abundance of swards, at least in the short term. Residual effects of grass suppression treatments from the previous year proved to be important in increasing legume abundance and determining legume species composition, especially in pastures on the driest site (Waipawa north aspect). The contrasts in temperature and especially soil moisture patterns between sites and between years highlighted the relevance of soil moisture as a key factor in determining legume abundance and production, mainly in the summer-dry areas.
- The effects of companion grasses and legume defoliation on the growth of individual white clover and subterranean clover plants studied under more controlled conditions in a glasshouse (third objective) indicated that severe defoliation had very strong effects in reducing plant size, leaf area, vegetative stem development and branching. Moreover, root competition from grasses was seen to significantly limit clover shoot growth, this effect being of more importance than the limitation of light by shading.
- From the results obtained, and to establish the relative importance of the factors studied (fourth objective), it can be argued that soil moisture, imposed by site and/or inter-annual variation, is the leading factor that will interact with the other factors to finally determine legume abundance at a particular site. The relative importance of factors affecting legume abundance in hill pastures may be summarised from these experiments as follows: soil moisture > grass suppression > soil-P status > defoliation management > nitrogen application. However, some of these factors have been noted to interact, and relationships can acquire higher levels of complexity.

- When soil moisture is adequate, and particularly in summer-moist environments, competition from grass, and especially below ground competition, seems to be a major constraint to legume abundance. Managements that encourage high tiller population density, combined with a high frequency and intensity of legume defoliation, will encourage grass competition and put legumes in a disadvantaged position, and will ultimately reduce legume abundance. This is likely to be the case of intensive set stocked systems managed with sheep.
- This study has highlighted the relative importance of factors that influence legume abundance of swards under different conditions. It has been shown that pasture composition can be dramatically modified and legume amounts be increased to more desirable levels, but also that these changes can be short-lived, particularly in the summer-moist sites, where hill pastures showed a high degree of resilience to revert to the original sward. The extreme dependence on the non-manageable characteristics of seasonal and inter-annual soil moisture profiles in dryland areas makes it more difficult to predict and to maintain a high and more stable legume abundance over time. However, in this environment a high potential of legume abundance was shown to be achievable with adequate soil moisture, even at lower soil-P status. In summer-dry areas, the combination of limiting soil moisture, intensive grazing to low residual heights, and the preferential grazing of legumes over grasses, is likely to severely limit white clover growth and spread, as well as subterranean clover growth and seed set, therefore compromising legume abundance in the following season.

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