SOME ASPECTS OF THE COMPETITION BETWEEN SEEDLINGS OF GORSE (*ULEX EUROPAEUS* L.) AND "GRASSLANDS NUI" PERENNIAL RYEGRASS (*LOLIUM PERENNE* L.)

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ABSTRACT

Two glasshouse trials were conducted with "Grasslands Nui" perennial ryegrass (*Lolium perenne* L.) and gorse (*Ulex europaeus* L.) grown in boxes separately as monocultures and as mixtures forming a replacement series. The first trial was continued for 22 weeks after sowing to assess the effects of defoliation at 2 and 4 cm in comparison with controls. Defoliated treatments were cut 14, 18 and 22 weeks after sowing and the harvested dry matter weighed. In the second trial, the response of the two species to eight fertilizer treatments (nil, N, P, K, NP, NK, PK and NPK) was assessed 18 weeks after sowing.

In trial one, Nui grew faster than gorse and produced more dry matter over all harvest periods. The proportion of gorse in mixtures increased with repeated cutting, while the Nui decreased.

Over all harvest periods, gorse growth was depressed in mixtures with Nui and even with the smallest proportion of ryegrass (1 Nui to 3 gorse), total weights of gorse shoots were reduced by about 75%. The total root and whole plant dry weights followed a similar pattern as did the numbers of root nodules. The ratios of shoot:root weights were higher in mixtures than in monoculture.

With gorse, between the first and second cuts the low cut treatment outyielded the high cut but with subsequent cuts the low cut plants made less growth. Total shoot, root and whole plant weights and root nodule numbers were depressed by both defoliation treatments in comparison with the uncut controls and the depression was greater with the lower than the higher cutting level. The shoot:root ratio and side shoot numbers were higher in the defoliated than in the undefoliated treatments.

The total growth of Nui was not significantly reduced when grown in mixtures at ratios of 1 gorse to 3 Nui or equal numbers of each. At the 1 Nui to 3 gorse ratio, however, Nui growth was reduced by almost 20%. The shoot:root ratios and number of tillers per box were higher in monocultures than in mixtures.

Cutting reduced the final dry weights of Nui. The number of tillers was also decreased while the shoot:root ratio was increased. The effects of the second and third cuts were greater than those of the first cut but there was no significant difference between the two cutting heights.

Analysis based on de Wit's competition model showed that Nui was more competitive than gorse for most of the yield components measured and suggested that in most cases the two species were competing for different space. Gorse was at a competitive disadvantage when grown in association with Nui, both in the defoliated and undefoliated treatments. Increasing the proportion of ryegrass in mixtures severely restricted the growth of gorse seedlings. The high growth rate of Nui led to suppression of gorse by shading and the effect was accentuated by defoliation.

In the second trial, gorse produced a greater dry weight of shoots than roots while with Nui a greater weight of root was produced than shoot. As in the first trial, the grass made considerably more growth than the gorse. In the mixtures which contained 75% gorse and 25% Nui plants, the dry matter production of gorse shoots + roots was only 16% of the total of the two species. Nodule production per plant was reduced by about half.

Gorse dry weights,nodule numbers and shoot:root ratios were higher with all treatments containing P than in the controls or boxes treated with N, K or NK. Fertilizer treatments did not affect the proportion of gorse shoots in the mixtures but there was a reduction in the roots with P treatments.

With the grass also, all P-treated boxes yielded more shoot and root dry weights and tillers than the control or N and K treatments. The total plant dry weight was higher than the control with all fertilizers except K. In contrast with gorse addition of P fertilizers reduced the shoot:root ratio.

The use of fertilizers and defoliation in relation to the control of gorse seedlings in the field has been discussed.

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1. INTRODUCTION

The word competition in relation to plant ecology was first defined by Clements in 1907 and quoted by Clements, Weaver and Hanson (1929). He wrote, "Competition is purely a physical process. With few exceptions, such as the crowding of tuberous plants when grown too closely, an actual struggle between competing plants never occurs. Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors. In the exact sense, two plants no matter how close do not compete with each other so long as the water content, the nutrient material, and the light are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins". One aspect not mentioned by Clements is the type of interaction involving substances released from one plant which have an influence upon another, particularly an inhibitory influence. This type of interaction is known as allelopathy (Tukey 1969; Whittaker and Feeny 1971; Whittaker 1975) and was observed as early as 1832 (Krebs 1973).

The use of the word competition to describe interactions between plants has been criticized by Harper (1961; 1964) because it lacks an independent scientific meaning and has a different significance in such fields as sports, games, economics and animal ecology. Instead he prefers to use the word interference to describe those effects which are caused by the proximity of neighbours. He defines plant interference as the response of an individual plant or species to its total environment as this is modified by the presence and/or growth of other individuals or species. He also distinguishes between competitive and non-competitive interference between pasture species. Competitive interference describes a situation where one species directly affects the growth of another by competing for a resource or resources potentially equally available to both. Non-competitive interference on the other hand occurs when one species is favoured by the presence of another. The latter can be illustrated by the example of a grass growing in the presence of a legume which fixes atmospheric nitrogen and makes it available to the grass. It could also apply to the protection of one species protected from grazing by thorny tree branches or a coarse unpalatable species. Donald (1963), however, argues that, "despite the confusion that has at times occurred in the use of the word competition, it seems that if it is used in its original meaning, and according to the biological concepts of Clements, it is well suited to a clearly delineated set of biological situations. There is no reason to discontinue the use of this simple and effective term."

An important feature of most natural ecosystems is that the overall habitat varies so that no single species ever dominates large areas to the exclusion of all others. Monospecific stands are thus less common than multispecific and pure cultures are rarely found, except in such extreme environments as swamps or saline areas of limited extent. Even in a monoculture, intraspecific competition takes place when one individual grows sufficiently close to another to modify the avilable supplies of water, nutrients, light, etc. and thus decreases its rate of growth (Milthorpe 1961; Donald 1963).

In natural plant communities, the climax vegetation represents the position of relatively greates equilibrium between the vegetation and its environment (Tansley 1953). Tropical grasslands, however, are not natural climax communities but have mostly been induced by pastoral farming or fire or are maintained by the constant cutting of brush for fuel (Whyte 1962). Over the greater part of Central and East Africa, for example, the climax vegetation appears to be some type of forest, woodland or bush (Little and Ivens 1965; Pratt *et al.* 1966). Grasses may occur in these vegetation types but they are normally the dominant species. Many ecologists cited by West (1965) consider tropical grasslands to be artificial because they grade into a forest on their more humid boundary and into bush on their arid boundary. Because of the fact that the present appearance and composition of vegetation give a poor indication of the true potential of a site, for East African rangelands, Pratt *et al.* (1966) have classified them by employing two complementary systems. The first is defined primarily by climate but incorporates vegetation and land-use descriptions and the second comprises vegetation types which are recognized by their forms and relative contributions of woody plants and grass.

True grasslands are rare in the tropics but may result from too much or too little moisture or from low temperatures. Thus the existance of open 'mbuga' grasslands in East Africa is due to water-logging during the rainy season, steppe grasslands are due to limited precipitation and alpine grasslands result from the low temperatures occurring at high altitude. Such grasslands do constitute climax vegetation types and can be relatively easily maintained by good grazing management.

Rangelands carry natural or semi-natural vegetation which provide feed for domestic and wild animals (Semple 1970). They are unsuitable for development of aritificial pastures because of the scanty and erratic rainfall. Man-made pastures are normally developed from forest or woodland under mesic conditions. The basic problems are those of removing the existing native vegetation and controlling the regrowth. In New Zealand, for example, much of the 8.5 million ha of sown pasture (Leonard 1973) has been developed from subtropical rainforest. Problems inevitably arise from native species establishing as the first stages of reversion to forest but more serious problems occur as a result of the introduction of species from abroad. Of the native woody species which tend to reinvade grassland, the most important is manuka (*Leptospermum scorparium* J.R. & G. Forst), which is the main nurse plant of the indigenous forest. This plant has remarkable powers of regeneration from seed and can readily reinvade pastures. Of the introduced brush species, gorse is the most important. It occupies about 40,000 ha of potentially highly productive land (Currie 1959) and has taken over more than 500,000 ha of low producing, mostly unploughable hill country where it is much harder to eradicate (Mason, 1973). The dormancy and longevity of the seed in the soil and the plant's capacity to regenerate after burning or cutting are the main factors involved in the persistence of the gorse problem.

During pasture establishment on land cleared from gorse, many seeds germinate which can rapidly re-establish the infestation. Gorse seeds are hard and remain in the soil for many years. In areas being cleared from gorse, Moss (1959) recorded 35,000,000 viable seeds of gorse per ha. The importance of these buried seeds is emphasized by Anon (1973) who points out that only 12,000 germinating seeds can completely smother one ha of good land in three years.

The reversion and invasion of brush species into New Zealand pastures (Levy 1970) has been the result of poor pasture vigour due to poor management leading to the depletion of organic matter and mineral nutrients. There has also been a loss of top-soil on much steep country. Seedling invasion is less of a problem if the pasture can be ketp thick and stock numbers are sufficient to kill the bush seedlings or keep them under control. In practice, on much hill country it is difficult to maintain sufficient grazing pressure owing to fluctuations in weather and soil type, and to such factors as pugging, slips and the high cost of fencing (Currie 1959). Nevertheless, mob-stocking with at least 200-750 sheep per ha (see section 2.3.5.4) for short periods is an effective method of limiting the invasion of woody weed seedlings and is strongly recommended as a management practice in gorse control schemes.

Rolston and Sineiro-Garcia (1974) in defoliation work on gorse, subjected seedlings to various intensities of cutting. The results showed that only seedlings defoliated well below the cotyledons were killed. From field observations they concluded that a grazing intensity sufficient to defoliate seedlings below the cotyledons is difficult to achieve in practice. However, it is probable that other factors associated with grazing may be important in controlling seedlings especially treading and pulling effects.

The use of fertilizers is also important in the establishment of pasture after clearing gorse or other woody weeds. High levels of nutrients are needed to obtain the most vigorous growth of pasture species and vigorous pasture growth offers the greatest degree of competition to bush seedlings. Practical gorse control recommendations stress the importance of heavy top-dressing in combination with oversowing (Matthews 1975, 1976; Anon 1974a).

The pasture species sown must also be highly competitive. Although it may be too early to recommend "Grasslands Nui" perennial ryegrass, generally studies have shown the superiority of this variety over ARiki and Ruanui in total dry matter production, seasonal production, persistence and compatibility with clover (Armstrong 1978). The superior qualities include a rapid growth rate, ability to produce more with age and the ability to withstand the hard grazing pressure which is necessary under mob-stocking.

A better knowledge of the processes involved in pasture establishment throw more light on the factors that can be controlled and the methods available for the improvement of production. These include seedbed preparation, time of sowing, seed quality, fertilizer application, good grazing and pasture management. Together they should be directed towards maintaining as vigorous a cover as possible in order to smother established weeds and inhibit the establishment of seedlings. Control of gorse through pasture competition is more important than chemicals because seedlings come up after the chemical has gone and because chemical control is expensive and alters the pasture composition.

Pasture species have been the subject of a considerable amount of work on competition, particularly the associations of grasses and legumes (Herriott 1958; Donald 1963; Harris, 1968). Little information is available, however, on the competition between pasture species and weeds and woody weeds have been especially neglected. The present investigation has been conducted to study the nature of the interactions between seedlings of gorse and "Grasslands Nui" perennial ryegrass when subjected to a range of defoliation and fertilizer treatments under glasshouse conditions. It is hoped that a better understanding of the competition between these two species will show up weaknesses of the weed that can be exploited in the development of improved methods of control.

2. LITERATURE REVIEW

2.1 PASTURE DEVELOPMENT

The modern New Zealand pasture has been developed from native rainforest in North Island and from beech forest (*Northofagus* spp.) or tussock grassland in South Island (Levy 1970). Where development was poor or as a result of ineffective management the pasture readily reverts to indigenous scrub weeds such as manuka or is invaded by introduced scrub weeds, such as gorse which flourishes in almost pure stands (Mason 1973). Of the total area of pasture currently being developed, a quarter is being established following the breaking in of ground previously covered in bush, scrub, fern and secondary growth or tussock (White 1973a). In the light of improved knowledge for the solution of pasture establishment problems (Inversen 1956; Herriott 1958; Brougham 1959) whatever techniques are used should conform to well defined principles, and if these principles are followed there is no reason why pasture development should not be successful. The main factors involved in the development of pasture from virgin land or the reclamation of pastures infested with scrub weeds are as follows:

(a) The destruction of the resident vegetation (see section 2.3.5.)
(b) The preparation of a suitable seedbed (see section 2.1.1)
(c) Provision of adequate nutrients (see section 2.2)
(d) Seeding technique including choice of seed mixture, seed treatment, sowing rate, time and method of sowing.
(e) Initial and subsequent management of the sown pasture species
(f) Treatments applied for control of gorse or other bush species.

2.1.1 Seedbed Preparation

The type of seedbed preparation employed will depend on the soil, the climatic conditions, the existing vegetation and the sowing method adopted. It may vary from the conventional intensive cultivation (Sears *et al* 1955; Cross 1956; Baker 1969), through reduced cultivation methods involving the use of herbicides, burning or grazing (Baker 1970, 1977; Baeumer and Bakermans 1973; White 1973a, 1973b; Carter and Saunders 1969; Matthews 1970) to the complete lack of preparation involved in oversowing by air on non-arable land (Levy 1970; Suckling 1966, 1975; White 1973b). Because the majority of areas being developed in New Zealand are non-arable as a result of steep slopes, stony nature or poor drainage, the methods based on minimum and zero cultivation techniques are of particular interest.

2.1.1.1 Conventional Tillage

In ploughable country, ploughing with a mouldboard or disc plough is usually the first stage of seedbed preparation. In hill country it is usually possible to plough only the ridges and contours. However, the steep hill sides may be worked over by giant discs or root rakes. The final objective in all situations is to produce a well-drained, weed-free, fine, firm, moist and even seedbed (Sears *et al* . 1955; Blackmore 1960; Herriott 1958; White 1973a). A well consolidated seedbed prevents pasture seeds from being sown too deeply (Sears *et al*. 1955; Blackmore 1960) and ensures intimate contact between the small seeds, the soil particles and the soil solution, thus providing a favourable medium for germination and penetration of the root (Servis and Ahlgren 1955; Herriott 1958). However, care must be taken to prevent the development of surface crusts which may form following heavy rain after sowing and which hinder seedling emergence and result in increased loss of moisture (Armstrong 1937). A rather loose tilth above the seed provides good aeration and gives optimum seedling emergence (Ahlgren 1945; Herriott 1958).

2.1.1.2 Burning

Burning existing vegetation before oversowing on unploughable land is the accepted practice in the control of gorse and other scrub weeds (Miller *et al*. 1955; Suckling 1966; Brodie 1950; Moss 1959; Yeates 1951; Matthews 1975, 1976). In spite of being an important tool in land clearing, burning generally has only temporary effects on woody species so that other control methods such as herbicides or grazing management also have to be used. While Suckling (1966; 1975) and Levy (1970) report successful establishment of pasture on the ash from burning gorse or other scrub species, others, including Blackmore (1957), Cullen (1966a; 1971a; 1966b; 1972), Marshall (1972) and Janson and White (1971a) emphasize the importance of plant cover, especially of dead vegetation, for the early establishment of pasture. Such a cover provides a favourable micro-environment for the growth of young grass and clover seedlings.

In wetter areas the main factor limiting the establishment of pasture species after burning off woody vegetation is probably competition for light. In relatively arid areas with a sparse cover of native species however, such as the tussock grassland of the South Island of New Zealand, competition for moisture is more important as a limiting factor. It is therefore important in drier areas that some cover should remain after a burn and if this cannot be achieved oversowing should be delayed for a year to allow a cover to re-establish. In wetter areas, controlled grazing should be applied at frequent intervals after oversowing to reduce competition for light and nutrients (Cullen 1966a, 1970; Marshall 1972).

2.1.1.3 Grazing and Trampling

Close grazing before and after oversowing has been found to improve the establishment of pasture species in wetter areas (Sears 1950a; Suckling 1959, 1966, 1975; Douglas *et al.* 1965; Cullen 1971a) but has had no effect or has reduced establishment in drier areas as shown by Cullen (1966a, 1966b) and Dowling *et al.* (1971). The best results are obtained if existing vegetation is grazed quite short prior to sowing in order to open up the sward and allow the seed to reach the soil surface.

The effects of hoof cultivation have been tested by Suckling (1959, 1966, 1975) and Levy (1970). Trampling with sheep before and immediately after oversowing was shown to help the oversown seed to fall directly on to the ground. Under wet conditions animal hooves were also found to leave impressions which formed ideal sites for seed germination. The utility of the method appears to be restricted to small areas because of the intensive management involved.

2.1.1.4 Herbicides

Many workers have found that herbicide treatment of existing vegetation is an expedient way to reduce competition and promote the establishment of improved pasture species (Beggs and Leonard 1959;

Blackmore 1962, 1965, 1967; Douglas *et al.* 1965; Winch *et al.* 1966; Janson and White 1971a; Cullen 1971a). Depending upon the type of vegetation to be killed the herbicides used may include dalapon, amitrole, paraquat, diquat, glyphosate and dicamba alone or in various combinations. Paraquat is currently the most widely used herbicide for this purpose becuase of its high activity and lack of residual effect. (Allen 1967).

Herbicides, kill the existing vegetation and leave a cover of dead vegetation. The soil surface has been reported by Janson and White (1971a) and by Blackmore (1967), to remain moist, friable and free from crusts after the application of a dalapon/amitrole mixture. By reducing the transpiration of weeds and thus cutting down competition for moisture, by reducing shading and by improving the soil surface conditions, the germination, radicle penetration and early seedling survival of oversown pasture species have been greatly improved in experiments by McWilliam and Dowling (1970) and by Janson and White (1971a). This technique is more important for the establishment of combinations of grass and lucerne than for clovers, which will establish well among native vegetation even without the use of herbicides (Cullen 1971a, Janson and White 1971a).

2.1.2 Time of Sowing

Successful pasture establishment will depend upon the presence of adequate moisture levels in the soil during and after sowing. This is ensured by sowing at the time of the year when effective moisture is most reliably available and temperatures are optimum for germination and development (Campbell 1968a, During *et al.* 1963; Cullen 1961, 1970, 1971a, 1972; Musgrave 1976).

In the South Island, late winter and early spring are the seasons during which most oversowing of clovers is done (Lobb 1958; During *et al.* 1963; Cullen 1969, 1971a, 1972). Over this period the soil is usually moist, conditions are favourable for the survival of the inoculant, competition from the existing herbage is at a minimum and temperatures are increasing. If oversowing is left until late spring, however, moisture deficiency and drying winds may desiccate the young seedlings and eventual establishment is likely to be poor (Ludecke *et al.* 1969; Wilson 1973). In the North Island, where climate is warmer during winter, autumn oversowing is also successful

(Suckling 1954, 1960, 1966, 1975; Toxopeus 1971). Subterranean clover must be sown in autumn if it is to flower and produce seed in the following summer, and thus maintain itself as an annual (Suckling 1966; Smethan 1973a). In lower rainfall areas, autumn sowing is less reliable than winter and in those South Island districts with a severe winter, frost lift can also cause damage to autumn sown seedlings (White 1973b; Clifford 1975).

Vigorous growth of grasses is not common in much unploughable hill country because of the low fertility of the soil and the competition from the existing cover of woody plants (Suckling 1966). When grasses are introduced under conditions of low soil fertility, as has been shown in areas like Te Anau, in South Island, they may remain in a suppressed state during the first year or two, though eventually they may come to equal grasses sown in cultivated land (Cullen 1971a, 1972; Marshall 1972). These findings emphasize the fact that the ability to survive may be just as important as good germination. Autumn may be the best time to introduce ryegrass and clover by oversowing because the existing vegetation can be burnt more effectively during the late summer/autumn period (Cullen 1971a).

2.1.3 Methods of Sowing

Methods of sowing vary depending on the degree of seedbed preparation. In intensively prepared seedbeds based on a sequence of tillage operations, pasture seeds are drilled or broadcast. Special direct-drilling techniques have been developed for use with reduced or zero-tillage systems, in association with chemical or other treatments applied to kill existing vegetation (Baker 1969, Taylor 1969). Seedbed treatment is reduced to a minimum with oversowing techniques, in which seed is placed on the surface of uncultivated land.

2.1.3.1 Drilling

Drilling into an intensively prepared seedbed has the advantages that the seed is sown into moist soil, at an even depth and spacing. If seed and fertilizer are drilled simultaneously, there is the added advantage that the seed is brought into close proximity with the fertilizer (Duffee 1940; Sears *et al* 1955). The combined operation of seeding and fertilizer application has the advantage that reduced rates of seed and fertilizers can be used (Cross 1959; Cullen 1971b). For example, Sears *et al.* (1955) found that superphosphate drilled at a rate of 125 kg/ha was as effective as 375 kg/ha broadcast after sowing. However, where inoculated legume seed is sown fertilizer toxic to rhizobia must be avoided (Hastings *et al.* 1966).

2.1.3.2 Broadcasting

Broadcasting is a quicker and cheaper method of sowing seed than drilling (Cross and Glenday 1956; Cross 1959; Watkin and Vickery 1965; Baker 1969; Stonebridge and Mackie 1969; Clifford 1975) but otherwise is in no way superior. With broadcasting, the sowing depth and spacing of the seed is less precise and higher rates of seed and fertilizers are needed to obtain results comparable with drilling. Seed theft by insects and birds is also high with broadcast sowing. If it is necessary to use this method, it should be confined to situations where conditions for rapid germination are ideal. It is clear, therefore that broadcast should be discouraged as a method of sowing except where passage of land vehicles is impossible or uneconomical.

2.1.2.3 Direct Drilling

Direct drilling is normally performed by some type of hoe coulter which exposes sufficient soil to allow the seeds to strike, preceded by a vertical disc to cut surface trash (Cooper and Morris 1973; Baker 1977). It is desirable that harrowing or rolling should follow seeding (Baker 1977).

An essential feature of direct drilling techniques is the need for effective seed burial to minimize seed loss by birds and rodents. Burial of the seed is also necessary to provide suitable moisture conditions for germination and emergence and to buffer against desiccation of the emerging radicle and plumule (Carter and Saunders 1969). In addition the practice has a potential for conserving soil moisture and structure (Matthews 1970). In spite of these advantages, one of the problems of direct drilling is the mechanical difficulty of sowing under dry soil conditions (Hunt 1964; Baeumer 1970; Leonard 1973).

2.1.3.4 Oversowing

For the development of unploughable hill country, oversowing is the normal method of introducing improved pasture species and is normally done either from the air or broadcasting by hand from the ground. The use of aircraft has become especially important in New Zealand since the 1950s (D.A. Campbell 1968; Anon 1975). It is estimated that about 80% of hill country farms and 20% of cultivatable farms have been sown with the aid of aircraft (D.A. Campbell 1968).

The efficiency of aerial oversowing has been studied for about 30 years (D.A. Campbell 1948, 1968; Lynch 1951; Scott 1965, 1970, 1975; Scott and Grigg 1970; Charlton and Grant 1977; Ritchie and Davis 1977). For the best results, it is recommended that wherever possible seeds should be applied from an altitude of less than 60 m (Campbell 1969) with crosswinds less than 10 km/hr (Charlton and Grant 1977). The poor distribution of seed caused by wind-drift may be improved by increasing the weight of light grass seed through pelleting (Scott 1965) so that it does not separate from the heavier legume seed before reaching the ground (D.A. Campbell 1948, 1968; Scott 1965, 1975). Pelleting also assists in penetration of the top cover and improves the contact of the seed with the soil (Marshall 1972). Better results are achieved when seeds are distributed in two applications, preferably from different directions (Charlton and Grant 1977), than from a single application (Suckling 1966; Marshall 1972). Overall success depends upon the skill of the pilot in distributing the seed evenly (Miller and Mountier 1959).

Over 2.4 million ha of hill country pasture are topdressed with fertilizer each year by aircraft in New Zealand (Anon 1974b). The common practice of adding seed to the fertilizer during topdressing (Lynch 1951; Scott 1965, 1970) is being discouraged because of the high degree of separation of seed from fertilizer which is likely to occur in crosswinds. The seed may become completely separated from the fertilizer and consequently fail to establish in the unfertilized strips. The practice is still widely used however, to reseed poor quality pastures (Anon 1947b).

Trials by Miller and Mountier (1959) have shown that the distribution of granular superphosphate from aircraft is also very uneven, with proportionately less being deposited towards the edges of the swaths (Scott 1965, 1970). The distribution is improved when the fertilizer is applied in overlapping swaths (Scott 1965, 1970) and the best results are obtained when topdressing is done in calm conditions from altitudes of less than 60 m (Campbell 1969).

2.1.4 Depth of Sowing

Depth of sowing influences seedling emergence and the choice of an optimum depth depends mainly on seed type and size and the physical conditions of the seedbed (Brougham 1969). The fact that pasture seeds are mostly small, means that shallow sowing is essential for good establishment (Sears *et al.* 1955; Cullen 1966c; Herriott 1958). The optimum depth has been found to be within the range 5-30 mm, the larger seeds being sown at the greater depths (Herriott 1958; Cullen 1966c; Popay and Saunders 1975). Increased sowing depths may be desirable in drier areas so that the seed can be sown into moist soil. However, seeds sown too deeply may fail to emerge if the food reserve is exhausted before the plumule reaches the surface. With legumes in particular the sowing depth is limited by the limited extension growth of the hypocotyl (Black 1959). Furthermore, Arndt (1965) has shown that the shoots of seeds placed at a depth of 38 mm are faced with 2.5 times as much soil resistance as those sown at 13 mm.

2.1.5 Choice and seed treatment of seeds

The factors to consider are seed quality, the type of seed mixture, the seeding rate and the various pre-sowing treatments which may be applied in order to improve germination.

2.1.5.1 Seed Quality

Good seed, although it may be high in price, is never truly expensive. On the other hand poor seed is always a bad investment and, in the long run, may prove more costly than higher priced seed of known purity and germination. New Zealand is fortunate in having a seed certification scheme which guarantees high quality seed to farmers.

High grade seed must have the power to germinate and grow vigorously. It must also be free from impurities and true to type

(Levy 1970). The factors which can affect germination and vigour include age, storage conditions, disease, dormancy and hardseededness. Impurities in seed vary, but the commonest are inert matter, seeds of other crops and weed seeds.

2.1.5.2 Choice of Seed Mixture and Seeding Rate

The majority of pasture seeds sown in this country are made up of varieties of perennial ryegrass (*Lolium perenne* L.), Italian ryegrass (*Lolium multiflorum* L.), cocksfoot (*Dactylis glomerata* L.), crested dogstail (*Cynosurus cristatus* L.), timothy (*Phelum pratense* L.), red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), subterranean clover (*Trifolium subterraneum* L.) and lotus (*Lotus* spp.).

The choice of species to be sown should be adapted to the local conditions in terms of climate, soil fertility and the purpose for which the pasture is being established. The mixture used will vary depending on whether the pasture will be of long or short duration, whether it is intended for use as hay, silage, seed production or grazing and on the type of animals being carried. In unploughed country, the major purpose of oversowing is to improve production by changing the botanical composition to increase dry matter production and quality. Species of a more permanent nature are better for grazing than short-lived species as the latter die out sooner and are replaced by weeds.

In areas of medium rainfall, a survey of 150 seed mixtures was made by Harris (1968) to find the species most commonly used. Ryegrass was present in all the mixtures surveyed and white clover in all but two of them. The success of these two species is due to their compatibility, to the fact that the clover supplied nitrogen to the grass (Sears 1953) and because the production from the two species together is greater than from either alone. The high production is a result of differences in the times of peak growth of the two species (Lambert *et al.* 1969), differences in leaf orientation and in light interception characteristics. The two species also differ in rooting depth (Klapp 1943; Jacques 1943), and in water utilization patterns (Mitchell and Kerr 1966) but both are well adapted to hard grazing under different climatic conditions. However, ryegrass and white clover may be complemented or replaced by other species. Cocksfoot, subterranean clover and lucerne (*Medicago sativa* L.) are better suited to low rainfall areas, while in high rainfall areas, it may be useful to include a proportion of lotus major in the mixture (Suckling 1966). In more difficult conditions, as on steep slopes and slips, some of the lower fertility species such as browntop (*Agrostis tenuis* L.), crested dogstail, danthonia (*Danthonia* Spp.), etc. are included so as to get a quick, early establishment.

Present pasture mixtures have changed considerably from the bush burn mixtures involving more than 20 species much used for oversowing in the past (Levy 1970). With increased knowledge of pasture species the trend has been to use simpler mixtures which will offer the maximum competition to gorse and other brush seedlings and attract stock onto the area to play their part in control (Brougham 1969; Ward 1971). Many mixtures to-day consist of two grass and two legumes or even one grass and one legume (Harris 1968; Brougham 1969).

Similarly, over the past 25 to 30 years, seeding rates have been reduced (Brougham 1954, 1969; Lynch 1966; Cullen 1966c). This is important so that the more aggressive species in the mixture should not hinder the establishment of the slower establishers.

2.1.5.3 Seed Treatment

Processing of seed before sowing may include treatment for breaking dormancy, inoculation, coating or pelleting and protective treatments against pests and diseases. Inoculation involves the addition of suitable *Rhizobia* bacteria to legume seed to ensure the early formation of nodules and a high nitrogen-fixing ability. Coating or pelleting is the covering of the seed with a layer of finely powdered, non-acid nutrient material formulated with an adhesive. An inoculum may or may not be included in the coating. Inoculation is essential where legumes are being introduced and the appropriate rhizobia are absent or present in insufficient numbers (Greenwood 1964; Hastings *et al.* 1966; Greenwood and Pankhurst 1976). Numerous workers have found that seed coating or pelleting improves establishment (Vartha and Clifford 1969, 1973; McWilliam and Dowling 1970; Scott 1975).

The importance of seed treatment in New Zealand is shown by the fact that approximately 1452 tonnes of legume seed either inoculated or coated and inoculated was sown in 300,000 ha of pasture from 1973 to 1974 (McKinnon *et al.* 1977). The demand is bound to increase due to the development of hill country where the required rhizobia are lacking (Greenwood 1964; Greenwood and Pankhurst 1976).

2.1.6 The Growth of Young Plants

2.1.6.1 Germination

Germination involves the resumption of active growth on the part of the embryo resulting in rupture of the seed coat and protrusion of the embryonic root and shoot. The germination process depends on several factors including favourable moisture, temperature and light conditions. Oxygen is also important but is likely to become a limiting factor only where drainage is poor (Jones 1972a).

During germination the seeds imbibe water and the process is faster in legumes than in grasses (McWilliam *et al.* 1970a; Jones 1972b). With seeds sown on the surface, uptake of water is likely to be slower than for buried seed because of the reduced seed-soil contact (Sedgley 1963; Manohar and Heydecker 1964). Also, moisture loss by evaporation from the seed will be greater with seed on the surface, especially for seeds with relatively large surface areas, such as subterranean clover (Harper and Benton 1966). Because of the rapid fluctuation in moisture levels at the soil surface, there is likely to be a greater response to improvements in the environmental and plant factors which influence germination (McWilliam and Dowling 1970; McWilliam *et al.* 1970a, Dowling *et al.* 1971). Thus to maximize germination on the soil surface, it is important to increase uptake of moisture by such techniques as seed coating and at the same time to minimize evaporative losses by providing protective cover or shade. However, considerable differences exist between species in their ability to germinate under sub-optimal moisture conditions. Perennial ryegrass, for example, is capable of germination and development at higher moisture stress levels than pasture legumes, which may well be an important factor in the superior establishment of this species under field conditions (Campbell 1968b).

Temperature influences not only the total germination but also its onset and speed. For most species the optimum germination temperature is between 20 and 30^{o}C (McWilliam *et al.* 1968, 1970a, 1970b;

Springfield 1970; Quinlivan 1970; Murtagh 1970), rates being low below 5^{o}C, increasing to a maximum at 20-30^{o}C and thereafter falling sharply. With clovers, germination is less affected by low temperatures than with grasses (Stapledon and Wheeler 1948; Rachie and Schmid 1955).

2.1.6.2 Seedling Emergence

The term seedling emergence may be defined as the appearance of the shoot above the soil surface and the attachment of the radicle to the soil. The optimum conditions for emergence of seedlings in cultivated seedbeds where seeds are placed below the soil surface are provided by a fairly loose soil with high water-holding capacity above the seed. In this situation lighter soils prove better than heavy soils (Herriott 1958). The plant aspects of seedling emergence are associated with the rates of elongation, the robustness and penetrative strengths of the shoot and radicle. According to Leslie (1968) these characteristics are modified by temperature, water relations and light. Seed size is important because it determines the depth from which emergence can take place (Herriott 1958).

With grass seeds the endosperm and scutellum remain at the depth at which the caryposis was placed, while the plumular bud and its ensheathing coleoptile are carried towards the soil surface by elongation of the mesocotyl (Brown 1960). In a favourable environment, emergence of temperate pasture grasses from the soil takes place in 6-8 days from a sowing depth of about 10 mm (Jones 1971).

Legume seeds have no endosperm, the food reserves being stored within the cotyledons. The cotyledons and the plumular bud are carried to the soil surface by the elongation of the hypocotyl. After emergence, the cotyledons soon unfold and become the initial photosynthetic organs of the seedling. In a favourable environment, interval from sowing to seedling emergence in legumes is 5-7 days (Jones 1972b), a slightly shorter period than that for the associated grass seedlings.

2.1.6.3 Root-entry

With a seed germinating on the soil surface, entry of the radicle into the soil is necessary in order to anchor the seedling and to allow uptake of water. Radicles exposed on the surface before penetration are susceptible to desiccation and to damage from insects and birds (McWilliam *et al.* 1968, 1970a). Losses during this stage can seriously limit the success of surface sowing.

Under simulated field conditions, a poorly structured soil surface was found to be better for root penetration than a finely structured surface (Dowling *et al.* 1971; Campbell and Swain 1973). Success in the field may be dependent on a dead plant cover which increases the roughness of the soil surface, protects exposed radicles from desiccation and, by reducing moisture loss from the soil surface keeps it moist and soft (Evans and Young 1970). In general, the root-entry of grasses is superior to that of legumes (Dowling *et al.* 1971; Campbell and Swain 1973). The factors thought to account for this include better anchorage of the seedling, better angle of entry of the radicle and a smaller radicle diameter. The faster root-entry rate of grasses is a valuable attribute because it shortens the period during which the radicle is exposed to desiccation or insect attack.

2.1.6.4 Factors Affecting Growth and the Nature of Competition

The main factors likely to restrict seedling growth are soil and air temperature, moisture, nutrients and light intensity. Allelopathic effects and diseases may also be important. Nutrients and moisture can be manipulated to some extent through the addition of fertilizers and irrigation. However, little can be done to change temperature or light conditions, but adequate understanding of their effects is necessary for the optimum exploitation of pasture species.

2.1.6.4.1 Temperature

Pasture legumes tend to germinate and emerge slightly more quickly than grass seedlings, but their early post-emergence development is slower. At 20^{o}C perennial ryegrass seedlings have been shown to start increasing in weight five days after emergence (Anslow 1962). With white clover, however, the plumule develops relatively slowly and at 12^{o}C stem elongation does not start for two months after emergence (Mitchell 1956).

The threshhold and optimum temperatures for the growth of temperate forage species is 5.5^{o}C and 20-30^{o}C, respectively (Blackman 1936; Calder and Davies 1965; Cooper and Tainton 1968). According to Hogg and Moore (1976) the optimum temperature for nitrogen fixation is approximately 25°C but the optimum for tillering in grasses is 15°C which is lower than for the rate of leaf production.

2.1.6.4.2 Moisture

Moisture may be supplied by precipitation and irrigation. Better growth and production are normally achieved when plants are growing closest to field capacity. During dry conditions, this moisture level can be maintained under irrigation but it is rarely possible in practice to maintain pasture at field capacity for economic reasons. Under field conditions growth will depend on a plant's adaptability and efficiency in exploiting the available water supply from all soil horizons (O'Brien *et al.* 1967; Ellen *et al.* 1970; Harries *et al.* 1974). This is achieved by a rapid rate of root extension, both in the sense of reaching lateral unexploited soil moisture before other plants and in gaining access to deeper supplies through a deep-rooted habit of growth.

2.1.6.4.3 Nutrients

After emergence, the subsequent growth of seedlings id dependent on an adequate external source of nutrients. Legumes have an advantage over grasses in their rapid absorption of calcium, magnesium and other multivalent ions; while grasses compete more strongly for potassium, sulphate, phosphates and nitrates (Mouat and Walker 1959).

In legumes, the rhizobia introduced with the seed are able to infect the root 3-4 days after germination so that legumes are independent of the soil for their nitrogen supply (Jones 1972b). For active nodulation and nitrogen fixation, however, the soil pH, molybdenum and cobalt level should be maintained at the optimum. Although, strong stimulation of grass growth by fertilizers increases tillering, dry matter and leaf area per plant (Langer 1966, 1973), high levels of nitrogenous fertilizer in the early stages of pasture development are detrimental to legumes (Sears 1950b: Herriott 1958; Spedding and Dickmahns 1972; White 1972a).

2.1.6.4.4 Light Intensity

Light intensity, duration and quality are determined by the latitude, time of the year, atmospheric conditions and elevation (Bula and Massengale 1972). The most important effect of light intensity in seedlings is in relation to the rate and efficiency of photosynthesis (Watson 1956; Brougham 1958; Donald 1951, 1963; Cooper 1970; Rhodes 1973). Although all species increase in photosynthetic efficiency as the light intensity increases, light saturation is lower for temperate (20,000 - 30,000 lux) than for tropical species (up to 60,000 lux or more) (Cooper 1970; Spedding and Dickmahns 1972).

Clovers are more light demanding plants than grasses (Blackman 1938) and the most marked response of both plants to low light intensity is a reduction in root growth and the formation of stolons, and tillers. Normally for clovers, the growth of roots suffers more from low light intensity than that of shoots (Langer 1973).

In an establishing pasture, competition between species for nutrients and water commences in advance of competition for light (Donald 1963; Rhodes 1970). At a later stage in development, competition for light generally becomes more important (Milthorpe 1961). Competition for light begins when one leaf shades the other. That is why in very dense communities, competition for light begins almost immediately the seedlings emerge (Bennett 1960; Jones 1972a).

When a crop is sown, crop and weeds begin growth together. Aspinall and Milthorpe (1959) using a mixture of spring barley and white persicaria (*Polygonum lapathifolium* L.) emerging on the same day in pots, found that after four weeks the effect of the persicaria on barley was relatively slight, whereas the effect of barley on the persicaria was great. This was due to the fact that the persicaria was much smaller at emergence than the barley, and could not overcome this initial disadvantage. That the size of the plant at emergence and its subsequent relative growth may influence its early competitive ability has been shown by Black (1957, 1958) using small and large seeds of subterranean clover. In mixtures, after 11-12 weeks from sowing, 97% of the light was being intercepted by plants growing from large seeds and the rest by the suppressed, small seedlings. As indicated by Milthorpe (1961), the success of any species in mixtures depends on its size at emergence, and its relative growth rate from emergence relative to that of the other. Differences between species in shoot dry matter production and survival also exist. A perennial weed like gorse under conditions of strong competition may be able to survive for a long time without making much growth, but remaining capable of growing rapidly once the competition is removed.

2.1.6.4.5 Allelopathic Interaction

Interactions which involve substances released from one plant exerting an influence upon another are known as allelopathy (Tukey 1969; Hale 1971; Scott 1975). This problem has been most clearly identified in New Zealand where legumes are being established in swards dominated by *Notodanthonia* spp. (Beggs 1961, 1964; Janson and White 1971b). On the Wither Hills and Waikari in South Island, many establishment failures have been found to be due to extremely poor nodulation. There is now strong evidence that the failure of white clover and lucerne to establish is associated with the presence of living *Notodanthonia* (Parle 1964) and heat-stable water-extractable toxin has been obtained from the rhizosphere of living plants. The most successful nodulation has been found to occur with these pre-sowing treatments most effective in the destruction of the grass, thereby terminating production of the material toxic to rhizobia. Oversowing seven weeks after the destruction of the grass by chemical methods has given excellent results (Janson and White 1971b).

2.2 FERTILIZERS

Fertilizers are made up of the essential elements needed for the health, normal growth and development of pasture species. Those elements required in large amounts are classified as macro-elements and include nitrogen (N), phosphorus (P), potassium (K), sulphur (S), magensium (Mg) and calcium (Ca). Elements required in small amounts are the micro-elements or trace elements and include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B) and chlorine (Cl). These elements are held and supplied by the soil and the amount present depends upon the nature of the parent rocks and processes of soil formation (Wells 1968). When they are inadequate or lacking or plants cannot extract them sufficiently to establish and make good growth, they must be introduced in the form of fertilizers.

2.2.1 Calcium

The requirements of lime for pasture establishment in New Zealand have been clearly established by During (1961, 1962, 1972), Cullen (1971a) and McLeod (1976). On very acid soils, large amounts of lime are required initially to raise the pH to the optimum level of 6.0 to 6.5 (Miller 1968; McNaught and During 1970; During 1972). The maintenance rate of liming will depend upon the critical pH of the soil, the interval between applications, the soil type and the climate (During and McNeur 1975).

Much of the improvement in pasture establishment in response to liming on acid soils has been shown to be due to reducing the acidity from a strongly acid to a near neutral reaction. This results in increased availability of Mo, Ca, Mg, N, P and Na; decreased availability to plants of Mn, B, Cu, Zn, Fe and Al and increased activity of micro-organisms and earthworms (Coleman *et al.* 1958; Munns 1965; Miller 1968; During 1972; Widdowson and Walker 1971; McLeod 1976). Phosphorus which at low pH levels is strongly bound in Al and Fe complexes, becomes more available on liming and the toxicity of elements such as Al, Mn and chromium (Cr) (more soluble under acid conditions) is reduced. Liming of course provides an increased supply of the major element Ca and helps to ensure satisfactory nodulation of legumes and nitrogen fixation. Legumes germinating on infertile sites of high acidity do not usually survive long because the nodule bacteria are sensitive to acid conditions (Widdowson and Walker 1971).

In some soils, however, a relatively low pH may still be compatible with good establishment. Pelleting legume seeds with lime, for example, may eliminate the need for heavy ground application of lime to improve nodulation (Lowther 1974, 1975a, 1975b). It is important to remember that through increasing the soil pH, liming leads also to greater availability of molybdenum (Paton 1956; During 1961, 1962, 1972). In some situations, the use of inexpensive forms of molybdenum can wholly substitute for liming as shown by Healy (1955) and During (1962, 1972). In During's experiments, for example, 140 g/ha of sodium molybdate raised the pH from 5.6 - 5.8 to 6.5. In practice, however, the use of lime pelleted seed or small applications of molybdenum is not satisfactory in establishing pastures on such soils as deep acid peats and gumlands, which need both heavy lime applications and the addition of molybdenum (During 1972).

2.2.2 Nitrogen

Virgin soils being developed as pastures are normally low in soil nitrogen (Cullen 1966a, Cullen and Grigg 1971; During 1972) as evidenced by the response of grass to N applications. In the absence of N, grasses grow very slowly and show symptoms of extreme N deficiency, but clovers become the dominant species. The effect of small amounts of N, of the order of 10 kg/ha, is normally to improve grass establishment more than that of clovers (Cullen 1966a, 1971a, 1971b). Cullen (1971a), however, considers that, as mixtures can be successfully established in the absence of N, the use of N would not be justifiable on most New Zealand soils. Thus the main source of N in New Zealand is from legumes (Anon. 1975) and conditions are favourable for clover growth and nitrogen fixation over most of the country. Much information is also available on the nutrient requirements and grazing management of clover/grass mixtures (Levy 1970; Smethan 1973b). By supplying those nutrients which can be limiting for early clover growth, clovers develop better than grasses in the early stages and, as the clover grows vigorously, nitrogen levels are built up. Initially the nitrogen is available to the clovers and then later is shared with the associated grass species. When the nitrogen supply is adequate, the grasses begin to compete with the clover, not only for N but also for other nutrients which initially were freely available to the clovers (During 1972).

Thompson (1974) reports that, like clovers, gorse does not respond to nitrogen applications and that it is suppressed by vigorous clover growth, probably through overshadowing.

2.2.3 Phosphorus

In the native state most New Zealand soils are P deficient (Saunders 1965; During 1972) and require high initial applications for good pasture establishment and growth. P deficient soils such as those being developed in Te Anau and Taupo districts, have to be limed also to increase the availability of the applied P.

On soils low in available P, the principle of applying small amounts of P in precision bands in cultivatable lands before planting has been found highly effective for pasture establishment and growth

(Parson *et al.* 1953; Sears *et al.* 1955; Oohara *et al.* 1970; Cullen 1971b). This technique, however, is difficult to apply in uncultivatable country.

P aids clover growth and establishment, but has little effect on grass establishment (Cullen 1971a; Scott 1973). However, after establishment, in the presence of optimum levels of N, grasses are stronger competitors than legumes for P (Donald 1963; Jackman and Mouat 1970). Where grass/clover pastures rely almost entirely on N fixation for their nitrogen supply, large amounts of P have to be used because the demands of the grasses must be met before the needs of the clovers can be satisfied. In Thompson's (1974) work, gorse was found to respond to P in the same way as clovers, as evidenced by increases in dry matter, height and density. A similar increase in gorse dry matter production with application of P has been reported by Knight (1968).

2.2.4 Potassium

New Zealand soils are high in K (Metson 1959, 1968) and During (1972) estimates 250 - 600 kg K/ha to be available to plants. Virgin soils have higher levels possibly because of the proximity of the sea and the consequent effect of salt cycling on many soils (Metson and Blackmore 1968). After burning there is also an extra share of K being released from the ash (Miller *et al.* 1955; Ahlgren and Ahlgren 1960). The concentration of available K tends to be higher in top soil than in the subsoil (Metson 1968; Lee and Metson 1977).

Grasses compete more than legumes for available K according to During (1972) and as shown by the experiments of Blaser and Brady (1950).

2.2.5 Magnesium

Magnesium is an essential element in the chlorophyll molecule of green plants and available Mg Levels appear to be generally adequate in New Zealand (Metson 1974; Metson and Gibson 1975). The availability of Mg is generally higher in top-soil and low in the subsoil, although there are exceptions. Heavy application rates of K and Ca combined with low pH reduce the uptake of Mg (Metson 1968; 1974).

2.2.6 Sulphur

S is essential for the building of plant protein and demand for this element increases with increased uptake of N (Walker and Adams 1958; Metson 1969). Most of the S in the soil is in the organic form and only becomes available to plants after mineralization by microorganisms. On many soils, mineralization of organic matter is considered too slow to allow the maximum plant growth (Walker 1955, 1957). Other minor sources of available S are from the atmosphere in industrialized areas and from the sea in coastal areas (Blackmore *et al.* 1968; Bailey 1972).

Because of widespread S deficiency in many New Zealand soils, fertilizers containing S are used at sowing (Walker 1955, 1957; Blackmore *et al.* 1968; Metson 1969). Where the S deficiency is small, the superphosphate commonly used in hill country, which contains 11% S, may be sufficient. Sulphur-fortified super is used where the S deficiency is greater than the deficiency of P.

Competition for available S occurs in associations of legumes and non-legumes, to the detriment of the legume where the supply is limiting (Walker 1957; Walker and Adams 1958). Grass is very efficient at utilizing S and will utilize up to 95% of what is available.

2.2.7 Molybdenum

Molybdenum is required for the proper functioning of the symbiotic relationship between living nodule bacteria and the plant (Wells 1968). Levels of 0.5 - 1.0 ppm are optimum for legume growth and this may be supplied by the application of about 140 g/ha of sodium molybdate (56 g Mo) every 4-6 years (Jones and Ruckman 1973; Jones 1976a; McLeod 1976; Lobb 1953). Gorse seedlings have also been observed to respond more to phosphorus and boron in the presence of Mo (Knight 1968).

Most Mo deficient soils are acidic and liming often results in the release of sufficient Mo to meet the plant's requirements. Where the Mo concentration in pasture is high due to its natural occurrence or to an imbalance induced by heavy limint or excessive use of Mo fertilizer, Cu levels are low (Cunningham *et al.* 1956; Wells, 1968.

2.2.8 Manganese

Mn is essential for plants because of its involvement in photosynthesis. In most soils Mn is present in large quantities and no deficiencies have been reported in New Zealand (During 1972). More Mn is available at low pH than at low Ca levels (Scott 1973). Since the majority of New Zealand soils are naturally moderately or strongly acid, excess availability of Mn rather than the opposite is the problem. Toxic levels of Mn in some soils may interfere with the role of Mo in nitrogen fixation. Liming corrects both Mn toxicity and the Mn/Mo antagonism (Walker *et al*. 1955a, 1955b, During *et al*. 1960; Scott *et al*. 1963; Widdowson and Walker 1971).

2.2.9 Boron

The need of plants for B is discussed by Miller (1968) and Smith and Middleton (1976). Its availability is often critically depressed by liming (Paton and Hoskings 1970; During 1972; Miller 1968) and by dry conditions (Smith 1973-74) because it is concentrated in the top horizon of the soil. On the other hand, adequate levels of S increase the concentration and uptake of B in pasture (During *et al*. 1960; Miller 1968). The response of pasture species has been recorded by During *et al*. (1960), Smith (1973-74), Smith (1976) and Sherrell (1973-74). Sherrell, for example, recorded an increase of 10-36% in the dry matter of ryegrass/clover as the result of an application of 1.15 kg B/ha in the form of borax.

2.2.10 Zinc

Zn is another essential microelement but its deficiency is unknown in New Zealand pastures (During 1972). This may be either because most soils naturally contain an adequate level or because of the widespread use of superphosphate which contains appreciable quantities of zinc (Wells 1968).

2.2.11 Copper

Cu is similarly essential, lucerne being more sensitive to deficiencies than clovers and clovers more sensitive than grasses (During 1972). Applications of lime, Mo and heavy rates of superphosphate are known to reduce the copper concentration of plants in general.

2.2.12 Iron

Fe is important in the synthesis of chlorophyll. Most soils in New Zealand contain large amounts of Fe and any deficiency symptoms could be due to overliming which reduces its availability (Wells 1968).

2.2.13 Chlorine

Wells (1968) reports that plants require larger amounts of Cl than the other micro-elements and that crops require at least 3.5 kg Cl (equivalent to 6.0 kg Na Cl)/ ha per year. Fortunately, Cl occurs in relatively large quantities in soils, being higher in the organic matter than in the mineral fraction. Coastal regions exposed to winds from the sea also contain higher contents than regions sheltered from the sea.

2.2.14 Cobalt

Although cobalt is not an essential micro-element, for most plants it is essential in small amounts for the growth of *Rhizobium* bacteria while they are living within the roots of legumes. Co deficiency severe enough to affect legume nodulation is rare in New Zealand. However, it has been reported to occur on pumice soils of the North Island and in Nelson and Southland in the South Island (Wells 1968; During 1972) where cobaltised superphosphate is used annually. Co deficiency in animals results in bush sickness.

2.3 GORSE AS A WEED

2.3.1 Taxonomy

The genus *Ulex* has been the subject of much study. It is classified in the tribe *Genisteae* of the family *Leguminosae*. It consists of about 20 species which are natives of W. Europe and N.W. Africa (Clapham *et al.* 1962). The most common species in the British Isles is *U. europaeus* L. (common gorse, furze or whim). In New Zealand, *U. europaeus* and *U. gallii* are reported as occurring, *U. europaeus* being very much the commoner species (Matthews 1975).

2.3.2 Economic Importance and Distribution

Gorse has been employed for purposes such as green manure, hedging, building, firewood, soil improvement and as a forage crop (Ritchie, 1930; Tansley, 1953; Jobson and Thomas 1964). In New Zealand, *Pinus radiata* L. seedlings have been found to grow better under gorse bushes than in the open, possibly because of its effect on the soil (Will, 1966). Its nutritive value as a forage crop has been determined by O'Donovan *et al.* (1959) who found gorse to be a good source of cerotene. Jobson and Thomas (1964) likewise found gorse to be a good source of protein of high digestibility and of calcium and sodium, but showed that it was high in fibre content and low in phosphorus, magnesium and most of the more important trace elements.

Because of its uses, gorse has been introduced into many temperate countries, including the United States (Pryor and Dana 1951; Warren and Youngberg 1968; Simmonds 1967), Argentina (Whythe *et al.* 1953), Chile (Simmonds 1967), India (Chinnamani *et al.* 1965), Eastern and Southern Australia (Parson 1973), Tasmania (Parson 1973) and New Zealand (Allan 1940; Matthews 1975).

In New Zealand, gorse was recorded for the first time in the Bay of Islands in 1835 by Charles Darwin (Moss 1960). It was introduced partly as a fodder plant, partly to provide shelter on exposed areas like the Canterbury plains and partly for making hedges (Moss 1959, 1960; Little 1960). On arable land, cultivation kept it under control, but seed spread freely into neighbouring gullies and stream beds. On second class hill country where the sward was thin, and the grazing animals too few to prevent the establishment of seedlings, gorse rapidly invaded pasture land (Levy 1970; Lynch 1973). Moss (1960) records that, by 1900 gorse had already been declared a noxious weed in the second schedule of the New Zealand Noxious weeds act. Whatever its original use, gorse is now widespread. It has colonized wastelands, neglected or abandoned farms, road embarkments, river verges, old quarry sites and is now one of the worst enemies of farmers and foresters (Mason 1973).

2.3.3 Biology of Gorse

Knowledge of gorse biology is important as a better understanding of the weed is needed for the development of improved methods of control. It is important to know how the plant establishes, grows, reproduces, spreads and any other factors which may influence its success as a weed.

2.3.3.1 Development and Growth

The development of gorse can be conveniently divided into three stages, namely juvenile, adult seedling and adult plant. The juvenile stage takes the form of a leafy seedling which develops thin trifoliate leaves after the two thick cotyledons have expanded (Fig. 1) The last compound leaf marks the end of the juvenile stage which may last from 2-7 months, during which time the plant is soft and palatable to livestock (Millener 1961).

The adult seedling stage is characterized by the production of simple leaves which are narrower, smaller, more pointed and eventually become spiny. These may be called leaf spines. During this stage rapid extension growth takes place and the spines which are modified primary branches begin to develop in the axils of the simple leaves. The stem spines are sharply pointed and bear leaves and secondary or tertiary spines (Fig. 2.). The smaller primary branches live for many months after which many of them die back and eventually fall off. Even during this stage the plant remains quite palatable and is readily eaten by animals (Small 1968).

The adult stage begins with the development of accessory buds which grow into accessory branches. These branches grow in the axils between the leaf spines and the primary stem spines. They bear further leaf spines and subsidiary stem spines. The accessory branches grow in length for one season after which the majority make no further growth (Skipper 1922). The accessory branches which undergo a gradual increase in thickness thus form the framework of the plant. The bushes grow up and outwards leaving many dead spiny branches and twigs inside the outer fringe of living shoots. This type of growth accounts for the highly inflammable nature of gorse bushes under dry conditions (Bean 1972). The maximum height of gorse in Britain is quoted as 2 m by Tansley (1953) and Gilbert-Carter (1936), though under more favourable conditions it may attain more than 4.5 m (Skipper 1922). Under New Zealand conditions bushes may grow up to 6.3 m (Moss 1959). The adult root system is highly branched with a well defined tap root which penetrates to a considerable depth (Grubb *et al.* 1969), thus

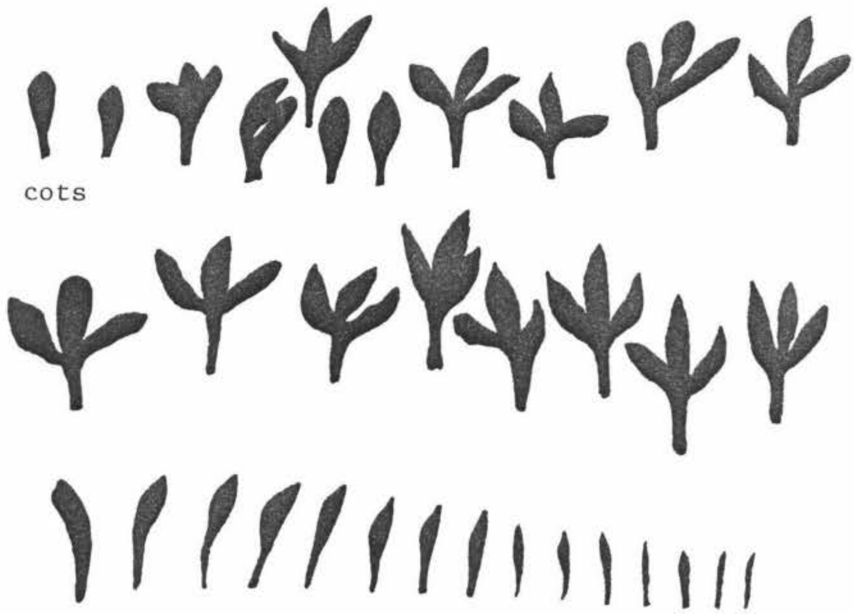


Figure 1. Leaf sequence in a typical gorse seedling (Millener 1961)

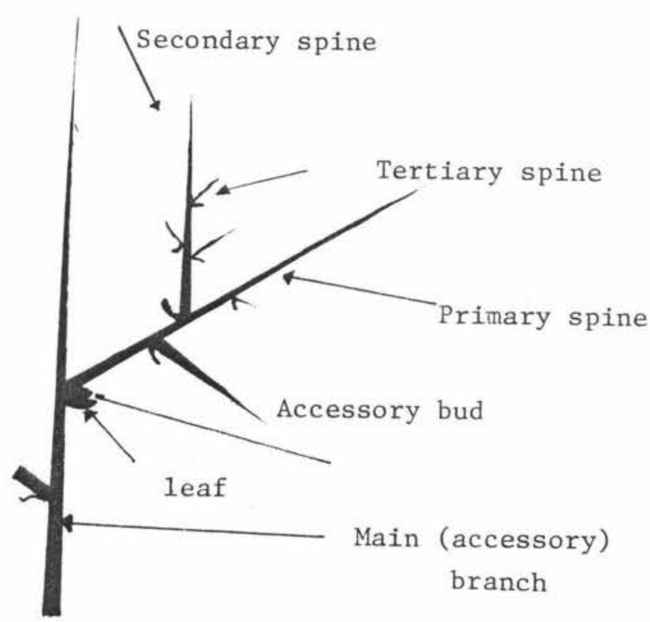


Figure 2. The morphology of the mature shoot system (Millener 1961)

enabling it to draw on deeper soil moisture during dry periods (Egunjobi 1967). The thorns of adult gorse are regarded more as adaptations to drought and strong light than as a protection against grazing animals (Rikli 1943). This view is also held by Millener (1961) and Bieniek and Millington (1967, 1968). Under glasshouse conditions short day-lengths have been shown to prolong the juvenile stage, while long days hasten development to the adult seedling stage (Millener 1961). Field observations by Duncan (1971) in New Zealand have shown that seedlings germinating in summer form thorns during autumn, while seedlings germinating in the autumn do not form thorns until the following spring, thus prolonging palatability to the grazing animal.

2.3.3.2 Phenology

In Britain, gorse seedlings do not flower until at least 18 months old and the plant is day-length neutral (Fryer and Evans 1968). In New Zealand, two flowering periods; a minor and a major one are reported by Miller (1970) as opposed to a single flowering period in Britain (Tansley 1953). The major period extends from July to December, the minor from February to May. The situation in the field is not well defined because there are variations according to locality and seasons. According to Ivens (personal communication), flowering in New Zealand is better regarded as a single very prolonged period.

Fruiting and shedding of seed takes place about two months after flowering. Seed production varies with the flowering period, fewer seeds being produced during the minor flowering period (Miller 1970). The average number of seeds per pod range from 0 - 2.7 and from 1 - 9 during the minor and major flowering periods respectively according to Moss (1959). The lower production during the minor flowering period is possibly due to a lack of pollinating insects, but seeds from both periods are of equal viability.

2.3.3.3 Dispersal

For all practical purposes, gorse spreads entirely by seed and the mechanisms involved include explosion of the pod, as well as transport by birds, animals and man, wind and water (Moss 1959, 1960). The explosive mechanism is important as seeds can be thrown more than 5 m from the bush when wind and temperature are high. The role of birds is uncertain as trials have shown that although eaten, seeds are not found in the droppings. There is evidence that animals can carry gorse seeds in their coats and in mud on their hooves. Man is also responsible for spread through movement of mud on boots or the wheels of farm machinery. Water is important and although the seeds sink, they may be carried considerable distances in fast flowing streams or floods. In hill country, seeds may be carried down with soil and debris in washouts.

2.3.3.4 The Seed Problem in the Soil

Gorse seeds are variable in colour, shape and size (Butler 1976) and there are 145-160 seeds per gram (Hutchinson 1967; Butler 1976). Much gorse seed is dormant at maturity because of the hard seed coat which enables it to remain viable for long periods in the soil although conditions may be suitable for germination.

Seeds are found below the soil surface in large numbers and are mostly dormant. Charter (1931) recorded 9,100 seeds/m^2 in England. In New Zealand, Butler (1976) reported 7,500/m^2 down to a depth of 10 cm under a 20 year old stand. Most seeds are found close to the surface and Moss (1959) recorded 96% in the top 5 cm though ploughing and the activity of earthworms bury seed at greater depths. Seeds may also be buried by larger burrowing animals, such as mice, moles and rabbits (Fryer and Evans 1968) and by mass soil movements (Parson 1973).

Dormant seeds can remain viable for many years even when no further seed production occurs. The presence of dormant seeds after clearing is one of the main reasons for the high cost and prolonged nature of gorse control programmes. Numerous cases have been reported where cultivated land has been free from gorse for many years, only to be reinfested after ploughing (Moss 1959). At one site Moss recorded up to 21 viable seeds per m^2 in a pasture free of gorse for 26 years while a block of land cleared the year before had 3,600 viable seeds/m^2. The decline in seed numbers with time is presumably due mainly to germination or decay. Moss (1959) and Butler (1976) report annual seed losses through decay of 6.8 and 8-9%, respectively. A hot fire was observed by Moss (1959) to reduce the gorse seed population by 57% while Rolston and Sineiro-Garcia (1974) noted an estimated number of more than 100 young seedlings per m^2 in a newly established pasture following a burn. From field observations, therefore it is clear that temperature and possibly light are important factors in the breaking of dormancy of gorse seed.

Under controlled laboratory conditions, the dormancy of gorse seed may be broken by boiling, dry heat, mechanical scarification and the use of concentrated sulphuric acid. Butler (1976) using concentrated sulphuric acid for 0.5 and 1.0 hour decreased hard seed numbers from 50% to less than 3%. Without dormancy breaking treatment, seed extracted from the soil germinates better than seed collected freshly from pods, Moss (1959) recording 2% from the former. However, there were no differences after the dormancy breaking treatment.

An improved understanding of dormancy is important if seeds are to be germinated predictably under experimental conditions. If dormancy could be broken in the field the problem of reinfestation from seed would be greatly simplified and it would only remain to control stump regrowth (Miller 1970). However, as yet, dormancy breaking in the field is not possible, practical recommendations are based on preventing germination by maintaining a tight sward to reduce the number of sites where gorse may germinate and establish. In practice problems arise when the sward is opened up by overgrazing, pugging, slips, droughts, diseases and insects. Under these situations the areas affected should be regrassed as soon as possible (Henderson and Popay 1976).

2.3.4 Gorse Ecology

Gorse thrives on a great variety of soils (Grubb *et al.* 1969; Small 1968; Tansley 1953) but within a fairly limited climatic range (Small 1968; Miller 1970). Within its normal climatic range and in medium to high rainfall areas, gorse is very troublesome in pastures (Bascand 1973; Egunjobi 1967).

Gorse is also an indicator of past human activities (Levy 1970; Lynch 1973). In W. Europe it occurs largely on disturbed soils, waysides and on edges of commons and heaths, but scarcely invades *Callunetum* heather (Tansley 1953). In New Zealand where conditions appear to be ideal for its growth, gorse is found also in other habitats such as gravel and marl pits, abandoned quarries, mismanaged and abandoned farms and burnt natural vegetation.

Gorse avoids very alkaline soils but will invade disturbed non-calcareous loams (Tansley 1953). However, it has been found growing on relatively high pH soils. For example, Grubb *et al.* (1969) found that in 10-12 years gorse plants reduced soil pH from 5.6 to 3.5-4.5

in the top 1 cm mineral layer and from 6-7 to 5 at 10 cm depth. Because of its tolerance of soil acidity (Anon 1958; Tansley 1953; Pate 1961; Egunjobi 1967) it grows very well in soils of low fertility but nevertheless shows a considerable response to fertilizers (Egunjobi 1967; Knight 1968; Thompson 1974).

Under favourable environmental conditions, Egunjobi (1967, 1969) estimated the amount of nitrogen accumulation under gorse at 100-200 kg/ha/year during the first 4 or 5 years in a secondary succession following a fire. As the plants thinned out the amount of nitrogen fixed declined. Studies on productivity by the same author showed that when gorse was dominant the rate of dry matter production was 15,000 kg/ha/year and dropped to 2000-3000 kg/ha/year when the succession was dominated by non-nitrogen fixing species. Egunjobi suggested that in a secondary succession from gorse to a climax community, the gorse phase is likely to be the most productive. Regular fires would influence the comeback of gorse once the self-thinning process started.

2.3.5 Land Development from Gorse

Gorse, as an introduced weed, invades medium to high fertility rainfall areas where the climax vegetation is forest. In many areas, especially in hill country, gorse is the number one pasture problem. In Wanganui, for example, farmers spend almost as much on chemical control as on fertilizers (Walton 1972). Gorse spreads by seed and persists through regrowth from dormant shoots on aerial stems and the root crown after cutting, burning or ineffective chemical treatment (Egunjobi 1967; Matthews 1975, 1976). In the development of gorse infested land it is necessary both to control the existing infestation and to prevent reinfestation. Successful initial control is achieved by such methods as burning, biological control, mechanical and herbicide treatments. Experience has shown, however, that no single method is effective and two or more methods are normally combined. In addition, to the control treatments themselves, budgeting for the development of gorse country must include provision for adequate fencing, top-dressing, oversowing (see section 2.3.5.4) and increased stock numbers.

2.3.5.1 Herbicides

Many herbicides have been employed for gorse control and herbicide experimental work has been reviewed by Matthews (1951, 1975, 1976), Little (1960, 1965), Mason (1973), Rolston (1974), Sineiro-Garcia (1974) and Walton (1972). The commonly employed herbicides are esters of 2,4,5-T and 2,4,5-T/picloram and 2,4,5-T/dicamba mixtures. 2,4,5-T alone or in combination with picloram are the most effective when employed under optimum growth conditions during late spring and summer. Under adverse conditions, the rate of application required must be increased two- or three-fold.

Very large gorse plants are more difficult to kill than smaller plants and follow-up sprays are generally necessary. With large plants it may be more effective to cut or burn them first and then spray the regrowth. Herbicides are thus used in obtaining a clean burn to facilitate easier control of stump regrowth and access to grazing animals. If the chemical treatment is used to assist burning adequate herbicide is employed to desiccate rather than kill the gorse and the most efficient material is 2,4,5-T plus diquat applied 2-3 months ahead of burning.

2.3.5.2 Biological Control

Biological control refers to the control of plants or animals by the introduction of organisms which attack them. Some of the insects that attack gorse in New Zealand are the accidentally introduced cotton cushion scale (*Icerya purchasi* Mask), the deliberately introduced gorse seed weevil (*Apion ulicis* Forst.) and the native longhorn beetle *Oemona hirta* F. The *I. purchasi* locally killed out a large area of gorse before being itself destroyed by the ladybird *Rodolia cardinalis* Muls. and the larvae of the fly *Cryptochaetum iceryae* Will. (Little 1960; Miller 1970). *O. hirta* larvae are fairly common in the stems of old gorse plants and cause some plants to collapse but have only a minor overall controlling effect (Little 1960; Miller 1970).

A. ulicis was introduced into New Zealand in 1931 in an attempt to check the spread of gorse by destroying the developing seed (Moss 1959). When the weevil was introduced gorse was important as a hedging plant and in certain areas young gorse was used for stock fattening. For this reason and to avoid the danger of erosion, which it was thought might follow the destruction of gorse on steep slopes, a seed destroying insect was chosen in preference to a general defoliator, or to stem or root feeding insects (Hoy 1964; Miller 1970).

The female weevil lays her eggs in the young pod and, when the grubs hatch, they feed upon the developing seeds but do not destroy them all (Hoy 1964; Moss 1959; Small 1968). Destruction of 20-40% of the seed crop in summer has been reported in Wanganui district (Moss 1959) and Ivens (personal communication) has observed up to 68% infested pods near Palmerston North. During winter however the weevil is inactive and much gorse seed escapes damage. Regular fires have also been found to reduce the weevil population (Moss 1959).

Now that gorse hedges are less important, more attention is being given to the possibility of introducing insects capable of inflicting direct damage to the foliage and or the stem and roots. If the results of host specificity trials currently in progress are satisfactory, it is anticipated that field releases of *Apion scutellarii* (a gall-forming weevil) and *Depressaria umbellana* (a moth with larvae which feed on the shoots) will be made in 1979-80 (Ivens, personal communication).

2.3.5.3 Mechanical control and burning

Control based on a combination of mechanical methods and burning is effective and cheaper than the use of the chemicals alone. Clearing is followed by oversowing with certified seed and top-dressing. On large blocks fencing and the provision of water is necessary and follow-up treatments include spot-spraying and management designed to discourage the establishment of seedlings (Duncan 1953; Currie 1959; Allo 1959; Little 1960; Bell 1961; Small 1968; Batten & McDonnell 1969; Bascand 1973; Anon 1974a; Matthews 1975, 1976). The precise combination of methods used depends upon the nature of the topography.

The initial burning may be with or without cutting, crushing or the use of a desiccant spray. The effectiveness of burning standing gorse depends on the age of the stand, the time of burning and the climatic conditions. To carry a hot fire the gorse block must be at least four years old. When burnt at the optimum time, February or March, on a day with high temperature, low humidity and a light breeze, a fierce fire is inevitable (Brodie 1950; Bell 1961). Back fires are thought to cause more damage to the bushes than head-fires (Miller *et al* . 1955, Ahlgren and Ahlgren 1960; Daubenmire 1968). The degree of kill of bushes will depend on the degree to which the fire kills the basal stem and root crown which is protected by the soil and litter. Whittaker (1961) working with *Calluna* heath, found that temperatures between 340-440°C at ground level did not prevent stump regrowth or germination of seed. In New Zealand, Miller *et al* . (1955) recorded between 200-250°C at 0.5 cm depth in dry litter but did not prevent regeneration. Gorse burning is thought to kill much seed in the litter layer and to stimulate germination of shallowly buried seed but little quantitative data exists (Moss 1959; Rolston and Sineiro-Garcia 1974). Normally oversowing is done immediately after burning although occasionally it is postponed until after a second burn carried out to remove dead sticks (Duncan 1953). Unless improved pasture species are sown, the production after burning is normally poor (Matthews 1976).

As an alternative, gorse may be cut in winter/spring and burnt the following autumn. This method is used where gorse is too young to carry a good fire but, with time to dry and for grass to accumulate and provide additional fuel, a hot clean burn can be obtained. The ash then provides a good seedbed and the low root food reserves during the winter/spring period lead to reduced regrowth after burning in autumn (Brodie 1950; Yeates 1951). This technique is superior because it leaves a cleaner seedbed, less chemical is used and regrowth from stumps or seedlings is not as troublesome (Duncan 1953; Matthews 1976).

On land accessible to machinery, development is easier where gorse is young, rotary slashers and choppers may be used with or without burning (Parker 1964; Batten and McDonnell 1969). Gorse may be grubbed after cutting and burning and oversown to pasture with or without cultivation (Feist 1956; Moss 1959). Successful results have been reported after burning, bulldozing, deep ploughing or giant discing and sowing to brassicas for one or two years before the pasture species are sown (Feist 1956; Small 1968; Matthews 1975).

2.3.5.4 Other Aspects of Land Development

Fencing, topdressing and control of livestock numbers are important aspects in the development of gorse country and many failures are attributed to neglect of these factors (Levy 1970).

Fencing should be according to aspect (Suckling 1954, 1959, 1966, 1975; Lambert 1976). This type of fencing is needed for control of grazing in relation to scrub weed control.

Application of fertilizer, normally superphosphate, is essential to the success of oversowing (Cullen 1966a, Cullen *et al.* 1966; Dunbar 1970) although it also appears to boost the growth of gorse seedlings (Egunjobi 1967, Thompson 1974). The rates of the various phosphate fertilizers used range from 375-750 kg/ha (Duncan 1953; Feist 1956; Currie 1959; Parker 1964; Anon 1974a).

The size of the block to be developed should be directly related to the number of stock available for controlled grazing. The mob-stocking rate normally ranges from 200-750 sheep/ha (Duncan 1953; Feist 1956; Currie 1959; Suckling 1966, 1975; Anon 1974a; Matthews 1975). The maximum number of animals to be used is determined by the peak growth of the pasture species and the gorse regrowth during spring.

2.3.6 Early Pasture Management in Relation to Gorse Control

Observations on established gorse plants have shown that treatments which remove the apical buds stimulate regrowth from dormant buds on the lower stems and root crown. Unless follow up measures are taken control treatments may thus lead to the development of multistemmed plants which are harder to control than the original single-stemmed plants (Matthews 1976). For permanent control, therefore, destruction of the initial plants must be followed by changes of the habitat to prevent re-establishment of the infestation from regrowth. The changes may be brought about by the manipulation of plant competition through grazing management, supplemented by other practices such as cutting and the use of chemicals.

2.3.6.1 Plant Competition

An important aspect of management is the encouragement of competition against gorse by stimulating the desired pasture species at the expense of the gorse regrowth. This objective is attained in part, at least, by using quick growing and aggressive pasture species supplied with adequate levels of fertilizers. A dense, vigorous sward is thus formed which will smother young gorse regrowth and prevent germination and seedling development. One problem with gorse is that it also responds to fertilizer applications (Feist 1956; Egunjobi 1967; Wilson 1968; Knight 1968; Thompson 1974). The only weak point of the gorse seedling is that its early growth rate is slow (Rolston and

Sineiro-Garcia 1974; Ivens 1977) so that in the first season it may be smothered by a vigorous pasture, especially by white clover (Thompson 1974). Thompson observed that the clover altered the habitat to favour the development of a stem rot fungus (*Rhizoctonia* sp.) which destroyed many gorse seedlings. Thompson also noted that the response to phosphate was high, with less response to nitrogen, lime or potash. Nitrogen application inhibited the nodulation of seedlings and reduced the size and number of nodules on mature plants. Knight (1968) found that the addition of trace elements such as B and Mo to phosphate greatly stimulated gorse regrowth.

Thompson (l.c.) also reported on the inter-relationships between gorse, pasture and fertilizer in a low fertility situation. Where nitrogen was deficient in the spring, a high rate of phosphorus (54 kg.ha) was unable to maintain pasture competition at a high enough level to suppress further invasion by gorse seedlings. This is of interest as it suggests a reason for the persistent re-invasion by gorse in low fertility sites. Again as the pasture vigour declined in late spring due to low soil moisture, there was little competition to gorse seedlings from the pasture species.

Due to the slow growth rate of gorse during the juvenile stage, when the paddock is spelled for a long period the seedlings become etiolated because they are growing at light intensities below the compensation point and the number of shoots and spines are reduced (Hutchinson 1967; Rolston and Sineiro-Garcia 1974). Hutchinson attributes the persistence of gorse seedlings under low light intensity to a low metabolic rate as a result of low respiration, a feature typical of woody species (Went 1957; Grime 1966). The chances of gorse persisting in the seedling stage would seem to be greatest when the pasture species deteriorate in the absence of grazing. The seedlings then resume their normal growth and are unaffected by subsequent pasture competition.

2.3.6.2 Grazing Management

While competition from pasture species is important, in preventing gorse seedling establishment, control by the grazing animal is more so. The pasture requires a quick grazing with a high concentration of stock during the first few months after germination to encourage tillering of grasses, and prevent slow growing species from being overshaded. The grazing also controls regrowth, consolidates the soil and encourages the development of a good ryegrass-clover sward (Feist 1956;

Duncan 1953; Small 1968; Lynch 1973; White 1973a; Leach *et al.* 1976).

Although the grazing systems on hill country vary greatly, some system of rotational mob-stocking is necessary for effective control of gorse regrowth (White 1973a; Anon 1974a, Rennie 1976). The pasture must be grazed heavily for a short time and spelled for a period determined by the season and climate. Care must be taken to avoid overgrazing, however, which can have disastrous effects. Such management allows the pasture species to develop a greater leaf area, to intercept more light and, when they have developed a substantial root system to draw moisture from a deeper layer of the soil in summer (Jantii and Kramer 1956; Brougham 1970). Hard and frequent defoliation is undesirable, especially for erect-growing species, as it leads to the removal of the vegetative buds (Brougham 1960, 1970), delays regrowth (Campbell 1969) and lowers the shoot:root ratio (Brougham 1970). Treading effects have been extensively studied by Edmond and his collaborators as reviewed by Brown and Evans (1973) and ryegrass and clovers have been found to be quite tolerant.

Successful management hinges on the fact that grass and clovers are better adapted to close and heavy grazing than are young gorse seedlings (Thompson 1974). Rolston and Sineiro-Garcia (1974), however, reported that seedlings reacted to defoliation by producing shoots with a prostrate habit and that seedlings were only killed if cut below the cotyledons. They attributed much of the effect of grazing animals to treading, pulling and subsequent stress from moisture deficiency in spring and summer. Although early mob-stocking may lead to the uprooting of some pasture plants, the benefits of reduced competition and rapid spread of bottom pasture species, compensate for any losses (Herriott 1958).

The different grazing behaviour of different types of stock may also be utilized. Suckling (1964) using varying stocking rates of sheep with and without cattle, under a set stocking system found that the inclusion of cattle with the ewes led to a marked improvement in weed control. Similarly, on the Coromandel range near Paeroa, virgin bush has been controlled by using sheep, cattle and goats under a rotational grazing system (Thorp 1975). One interesting aspect of gorse control has been reported by Wilson (1968) in Tasmania. He observed that wethers soon become accustomed to gorse if high stocking rates are used under the guidance of older experienced wethers. He also noted that application of superphosphate improved the palatability of gorse as wethers did not graze where fertilizer could not be applied.

Once well established, gorse shoots are protected from grazing by their sharp stiff spines and continue to grow steadily. When this stage is reached, livestock can have little effect on the bushes and other control methods should be employed.

Under set-stocking systems, animals graze the pasture almost continuously and the more erect species are more affected by grazing than the prostrate ones, while the more palatable clovers tend to be grazed out (Smethan 1973b; Smith and Dawson 1976). Thus weeds are less subject to competition for light and the pasture plants are not given the chance to express their full potential for regrowth. This system is not recommended during the early stages of pasture development but has given promise in more developed hill pastures as reported by Suckling (1959, 1964, 1966, 1975). His findings led him to recommend set-stocking during the lambing to weaning period followed by mob-stocking in summer and autumn, then set-stocking again from mid-May onwards to avoid pugging in winter.

2.3.6.3 Mechanical Control

Mowing is a common practice on tractor country with the primary aim of encouraging better pasture utilization rather than to control weeds (Lynch 1973). In this type of land, Allo (1959) reported a successful control of gorse infested pasture by mowing for a crop of hay or silage. In hill country, however, many slopes are too steep for mowing.

On suitable ground, rotary mowers and choppers are used on a variety of scrub weeds as long as the stems are not too thick (Bell 1961; Parker 1964; Batten and McDonnell 1969). For controlling gorse, these machines may be more suitable than chemicals, cultivation or burning because their use causes little pasture damage. Repeated slashing close to the ground will eliminate most of the gorse regrowth when coupled with grazing management to chew off young regrowth shoots and seedlings (Parker 1964).

On hill country where ground machinery cannot be operated, cutting by brush cutters for example, may be used on scattered bushes too big to be affected by grazing animals. Herbicide treatment may be needed later to deal with regrowth.

2.3.6.4 Chemical Control

The use of selective herbicides which in New Zealand means compounds to which clover plants are tolerant is impracticable as an overall treatment for the control of gorse once a good stand of clovers has been established. Herbicides effective against gorse are very destructive to clovers and therefore detrimental to the pasture.

Regrowth that cannot be eliminated by grazing or mechanical control however, can be killed with 2,4,5-T applied as a spot treatment. The most susceptible stage is from the seedling stage up to a height of 1-1.5 m (Moss 1960; Anon 1974a; Matthews 1976; Rennie 1976). Oversowing with clover should follow as soon as possible after phytotoxic residues have disappeared so that other weeds cannot occupy the space (Henderson and Popay 1976).

2.4 "GRASSLANDS NUI" PERENNIAL RYEGRASS

"Mangere" the fore-runner of "Nui", was developed through selection of perennial ryegrass under lax grazing to begin with and later under intensive dairying on the property of Mr T. Ellett in Mangere district, south Auckland (Cumberland and Honore 1970). For over 40 years, Mr Ellett has been using this ecotype with great success and claims "Mangere" to be more suitable for permanent pastures than such cultivars as "Grasslands Ariki" and "Grasslands Ruanui". This claim has been confirmed by Cumberland and Honore (1970) in the Auckland area and by McLeod (1974) in the South Island near Timaru. In both areas "Mangere" was superior in terms of seasonal and annual production, in persistence under dry conditions during summer and autumn under intensive grazing management and in resistance to weed invasion.

"Grasslands Nui" which has been bred as a selection from "Mangere" by Armstrong (1978) is superior to "Mangere" as well as "Ruanui" and "Ariki". It is a faster establisher, and because of its quicker growth must be managed carefully to ensure that the slower establishing clovers are not overshaded (Armstrong 1978; Baars *et al* . 1976; Ritchie *et al* 1975-76). The superiority of Nui is possibly due to its morphology. It is semi-erect and more open in growth habit than Ruanui or Ariki, also more leafy and develops more tillers. The leaves are approximately 20% wider than those of Ruanui and Ariki.

Like "Mangere" (Rumball 1969; Ellett 1974; McLeod 1974), Nui is more persistent under severe grazing especially under dry summer and autumn conditions in comparison with Ariki and Ruanui. It also responds more to irrigation (Sheath *et al.* 1976; Armstrong 1978, Baars *et al.* 1976). Its superiority is due to its ability to produce a greater number of tillers or tiller buds which remain viable and grow rapidly whenever moisture becomes available (Armstrong 1978; Sheath *et al.* 1976). Nui has greater seasonal and total production due to its better growth during summer and autumn when the other cultivars are dormant or dying back (Sheath *et al.* 1976; Armstrong 1978; Baars *et al.* 1976).

The dry matter production of Nui during the first year is normally low but increases in later years (Baars *et al.* 1976, Armstrong 1978). With suitable management, the increased vigour does not affect the productivity of clovers in the sward but reduces the growth of weeds and other grasses. Harris *et al.* (1977) found that Nui or clover mono-cultures, or a mixutre of the two reduced the dry matter of weeds during the establishment year under grazing from 5,300 to 350,1,610 and 430 kg/ha, respectively. The fact that Nui pastures have a good ryegrass/ clover balance, should also mean that they have a lower bloat potential.

As with Ruanui and Ariki, the maximum production from Nui is obtained under medium to high fertility conditions. While apparently less palatable than annual ryegrasses, Nui is equally acceptable to stock as other perennial ryegrasses (Armstrong 1978). However, Nui tends to be intermediate between Ruanui and Ariki in resistance to rust attack (Armstrong and Rumball 1975) and further selections for rust resistance are being made. The effect of rust is to lower productivity and acceptability to grazing animals. A further effect is to weaken the grass component of the sward with resulting clover dominance or weed infestation (Lancashire and Latch 1970). Kain *et al.* (1977) report that Nui is more susceptible to stem weevil than Ruanui or Ariki.

2.5 EXPERIMENTAL STUDIES OF COMPETITION

Most pastures comprise a combination of sown pasture and naturalized species, the growth of which is influenced by competition for such factors as light, water and essential nutrients. Competition commonly involves a combination of two or more factors, in which case analysis of the precise nature of the interaction is difficult.

The nature of competition within plant communities has been analysed by de Wit (1960), Harper (1961, 1964) and Donald (1963). de Wit's approach is based on the concept of competition for 'space' which by definition includes all factors and resources. He does not separate and identify the role of individual factors. Donald (1963) emphasizes the importance of identifying the factors being competed for.

Donald (1958) developed a technique to study competition between above-ground and underground factors. The design allowed *Lolium perenne* L. and *Phalaris tuberosa* L. to be grown in pots with below and above ground divisions allowing either competition or no competition for light, nutrients or both. The results of the above experiment led to the modified technique adopted by Snaydon (1971), King (1971) and Eagles (1972). In these studies, competition for both nutrients and light was clearly demonstrated, although competition for light was found to be small.

Stern and Donald (1962) studied competition for light between subterranean clover and *Lolium rigidum* by preventing competition for water or nutrients. The plants were grown in slot-like containers with a surface area of 40 cm by 2.5 cm. It was possible to make up swards of different types by clamping similar or different units together side by side so that light was the only factor involved in competition. A modification of this technique has been used by Hall (1971) to study competition for potassium between *Setaria* and *Desmodium*. Alternate rows of grass and legume in separate units could not compete for nutrients, whereas with the same arrangement in units of twice the width competition for nutrients occurred.

The basis of the studies by de Wit and his colleagues (de Wit 1960, 1961, 1970; de Wit and van den Bergh 1965; de Wit, Tow and Ennik 1966; van den Bergh 1968) is the replacement series experiment in which two species are grown together in different proportions, and compared with monocultures of each species. Differences in growth of the species in the various proportions give a measure of the susceptibility of each species to competition as well as of its ability to compete. Interpretation of the experiments was restricted to determining the existance of competition or interference. The competitive power of each species, which is called the relative crowding coefficient (k) indicates the degree of competition. A detailed account of this is given in section 3. However,Hall (1974a,b) has proposed a method of analysis for identifying the causative factors involved. The model is suited for use both in pot and field experiments involving studies both of annuals and the establishment phase of perennial pasture plants.

3. EXPERIMENTAL MATERIALS AND METHODS

The experimental work was designed to provide information on the effects of defoliation and fertilizer treatments on the growth of gorse and "Grasslands Nui" perennial ryegrass seedlings combined in replacement series experiments. The plants were grown with adequate soil moisture under natural light conditions in a glasshouse at Massey University. Two trials were conducted. Trial 1 was carried out over a period of 22 weeks during spring and summer (27/9/76-1/3/77) to assess the effects of varying degrees of defoliation under conditions of near optimum soil fertility. Trial 2 was conducted over 18 weeks during autumn and winter (4/4/77 - 10/8/77) to evaluate the response of the two species to various fertilizer treatments.

3.1 PRELIMINARY WORK

3.1.1 Seed Collection

Gorse seeds for trial 1 were extracted from litter collected under a dense gorse stand. To facilitate the process, the litter was soaked for 24 hours in water to allow the heavy gorse seeds and soil particles to sink to the bottom, while most of the humus, thorns and twigs floated, and were skimmed off. The seeds, soil particles and remaining trash were washed under high water pressure through 2 mm Endicott sieves which retained most of the gorse seed. The separated seeds with a small amount of trash were dried and then cleaned in a Dakota seed blower. Seeds for trial 2 were collected from ripe pods, which, after threshing, were also separated from chaff in the seed blower.

3.1.2 Seed Treatment

To ensure maximum germination the hardseededness of the gorse seed was overcome by scarification. The clean seed was scarified with concentrated sulphuric acid for 30 minutes as detailed by Butler (1976) and dried at room temperature on paper towels. The dried, treated seed could be stored successfully for several weeks.

"Grasslands Nui" perennial ryegrass, supplied by DSIR, Palmerston North had a 97% germination (W. Harris 1976 pers. comm.) and the gorse seed used for trial 1 gave 85% germination after 19 days. The germination percentage of the freshly collected seed used in trial 2 was 66 after 21 days. The lower germination was partly due to rotting of soft seed and partly to a higher proportion of hard seeds. Of the seed collected from litter, 11% remained hard after scarifying and 4% rotted. Similar figures for the seed from pods were 22 and 12% in germination tests carried out at 20°C for 18 hours in the light alternating with 15°C for 6 hours in the dark.

Before sowing the seeds were pregerminated under the same temperature regime and were inoculated as the radicles emerged, being sown immediately afterwards. The rhizobium strains used were 5295 and 5042 which were provided by the DSIR, Palmerston North, by courtesy of Dr. R.M. Greenwood.

3.1.3 Soil Type and Box Size

The soil used in both trials was Tokomaru silt loam which belongs to the central yellow-grey earths soil group. It was collected from a construction site on a former Massey dairy farm. It is an alluvial soil with an upper layer 15.2 - 20.3 cm deep of a dark-brownish-grey, heavy silt loam over a mottled clay loam (New Zealand Soil Bureau, 1954). Mole drains are effective in this soil type and last for many years but, even with drainage, these soils tend to be wet in winter (During, 1972). The soil was expected to be of low fertility as it included some subsoil and had not been top-dressed for the last ten years (P. Gregg, pers. comm). For trial 2 it was important to use soil of low fertility in order to show a response to fertilizers and it was thought advisable to use the same soil for trial 1 with the addition of adequate fertilizers. The soil quick test carried out by Ruakura Agricultural Research Centre, Hamilton indicated that K and Mg were adequate (values of 12 and 40 respectively), Ca low (11) and P deficient (13). The pH was 5.4.

For trial 1, the soil was thoroughly mixed in a concrete mixer and any clods broken up before filling the boxes. For trial 2, in addition to the mixing, the soil was passed through a 2 mm sieve to remove stones and clay lumps which were not broken up by the mixer.

The plants were grown in wooden boxes 30 cm square and 20 cm deep filled with soil to a depth of 18 cm.

3.2 TRIAL 1

3.2.1 Fertilizer Application

Due to the low soil fertility, two days before sowing, each box was supplied with a base dressing of potassium chloride, magnesium sulphate, calcium-ammonium nitrate, superphosphate and calcium sulphate to give the nutrient levels shown in Table 1. In addition, after two cuts, one gram of urea was applied to each box in order to maintain an adequate level of nitrogen.

Table 1. Fertilizer Application

Fertilizer used (g/box)	Elements (g/box)					
	K	Mg	S	P	Ca	N
Potassium chloride -5.2	2.60					
Magnesium sulphate -4.3		0.43				
Superphosphate - 5.2			0.62	0.52		
Calcium-ammonium nitrate - 6.9					1.04	1.80
Calcium sulphate - 3.0			0.30		0.74	
Total Elements (g/box)	2.60	0.43	0.92	0.52	1.78	1.80
Total Elements (kg/ha)	288.9	47.8	102.2	57.7	193.3	200.0

3.2.2 Experimental Design and Sowing Technique

To determine the competitive balance between the two species, the design described by de Wit (1960) was used. A randomised complete block arrangement of 60 boxes was employed involving five planting ratios (R) and three cutting heights (H) all replicated four times. Each replicate occupied two trolleys in the glasshouse and the layout of the treatments is shown in Figure 3.

The replacement series was made up of monocultures of each species and three mixtures in the proportions shown below. The plant frequency (designated Z in de Wit's work) was 48 per box (i.e. 533 plants/m^2). The relative plant frequencies were:

Fig. 3. Experimental layout of trial 1.

11 N1·0 HC	6 G·25N·75 NC	1 G1·0 HC
12 G·75N·25 LC	7 G·75N·25 LC	2 N1·0 LC
13 G·25N·75 LC	8 N1·0 NC	3 G·75N·25 NC
14 G1·0 NC	9 G·50N·50 NC	4 G·50N·50 LC
15 G·50N·50 HC	10 G1·0 LC	5 G·25N·75 HC

REP. 1

46 N1·0 NC	51 G·25N·75 NC	56 G·75N·25 NC
47 G·25N·75 LC	52 N1·0 LC	57 G·25N·75 HC
48 G·75N·25 HC	53 G1·0 NC	58 G1·0 HC
49 G1·0 LC	54 G·50N·50 NC	59 N1·0 HC
50 G·50N·50 LC	55 G·75N·25 LC	60 G·50N·50 HC

REP. 4

26 N1·0 LC	21 N1·0 NC	16 G·50N·50 HC
27 G1·0 LC	22 G·25N·75 HC	17 G·25N·75 LC
28 G·50N·50 LC	23 G·75N·25 HC	18 N1·0 HC
29 G·75N·25 NC	24 G·50N·50 NC	19 G1·0 NC
30 G·25N·75 NC	25 G1·0 HC	20 G·75N·25 LC

REP. 2

31 G1·0 LC	36 N1·0 LC	41 G·75N·25 NC
32 G·25N·75 LC	37 G·75N·25 LC	42 N1·0 HC
33 G·50N·50 NC	38 G·25N·75 LC	43 G·50N·50 NC
34 G·75N·25 HC	39 G1·0 HC	44 G·50N·50 HC
35 N1·0 NC	40 G·25N·75 HC	45 G1·0 NC

REP. 3

Gorse (Z_G)	Nui (Z_N)	Symbol
1.0 (48)	--	G.1.0
0.75(36)	0.25 (12)	G.75N.25
0.50(24)	0.50 (24)	G.50N.50
0.25(12)	0.75 (36)	G.25N.75
--	1.0 (48)	N.1.0

On 27 - 28 September 1976 one gorse and two or more Nui seeds were sown at each sowing position at 15 mm depth. The Nui seedlings were thinned to one per planting position later. The exact sowing positions were located with the aid of a frame fitted with cross strings and made to fit on top of each box (Plate 1). The 0.50:0.50 mixture was sown by alternating gorse and Nui in each row. The 0.75:0.25 mixture was obtained by alternating complete rows of the more numerous species with rows on which the two species alternated. Each of the less numerous species was thus surrounded by 8, of the more numerous (5 in the edge rows) (Figure 4).

After sowing, the glasshouse temperature was maintained at 20±5°C and water given frequently. Any weeds appearing were removed by hand.

The cutting heights were low cut (2 cm above soil level), high cut (4 cm) and the uncut control and are designated LC, HC and NC respectively.

3.2.3 Measurements/Sampling Procedures

The assessments made were the dry matter yield of the shoot and root of each species per box, the nodule numbers per gorse seedling and the tiller/side shoot numbers.

3.2.3.1 Defoliation Treatments

Ten weeks after sowing (7.12.76) all treatments except the control were defoliated with hand shears at a height of 2 cm above soil level. This was high enough to leave the basal buds of the gorse seedlings undamaged. The primary aim of this pre-treatment was to observe the sprouting potential of gorse seedlings. Subsequent cuts were made on 3.1.77, 4.2.77 and 1.3.77 i.e. every four weeks for LC and HC. These cuts mark the end of harvest periods 1, 2 and 3 and 14, 18

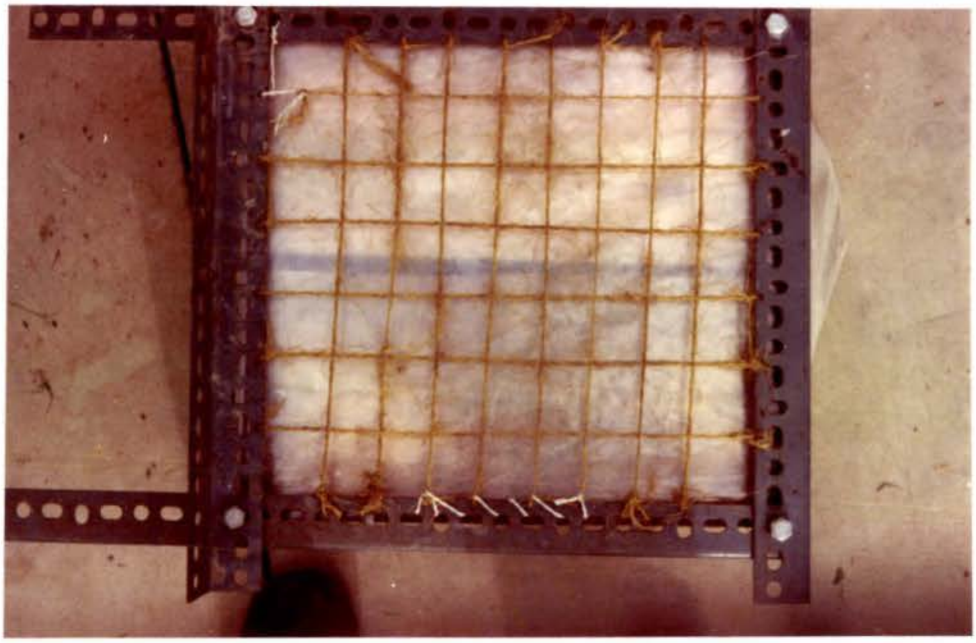
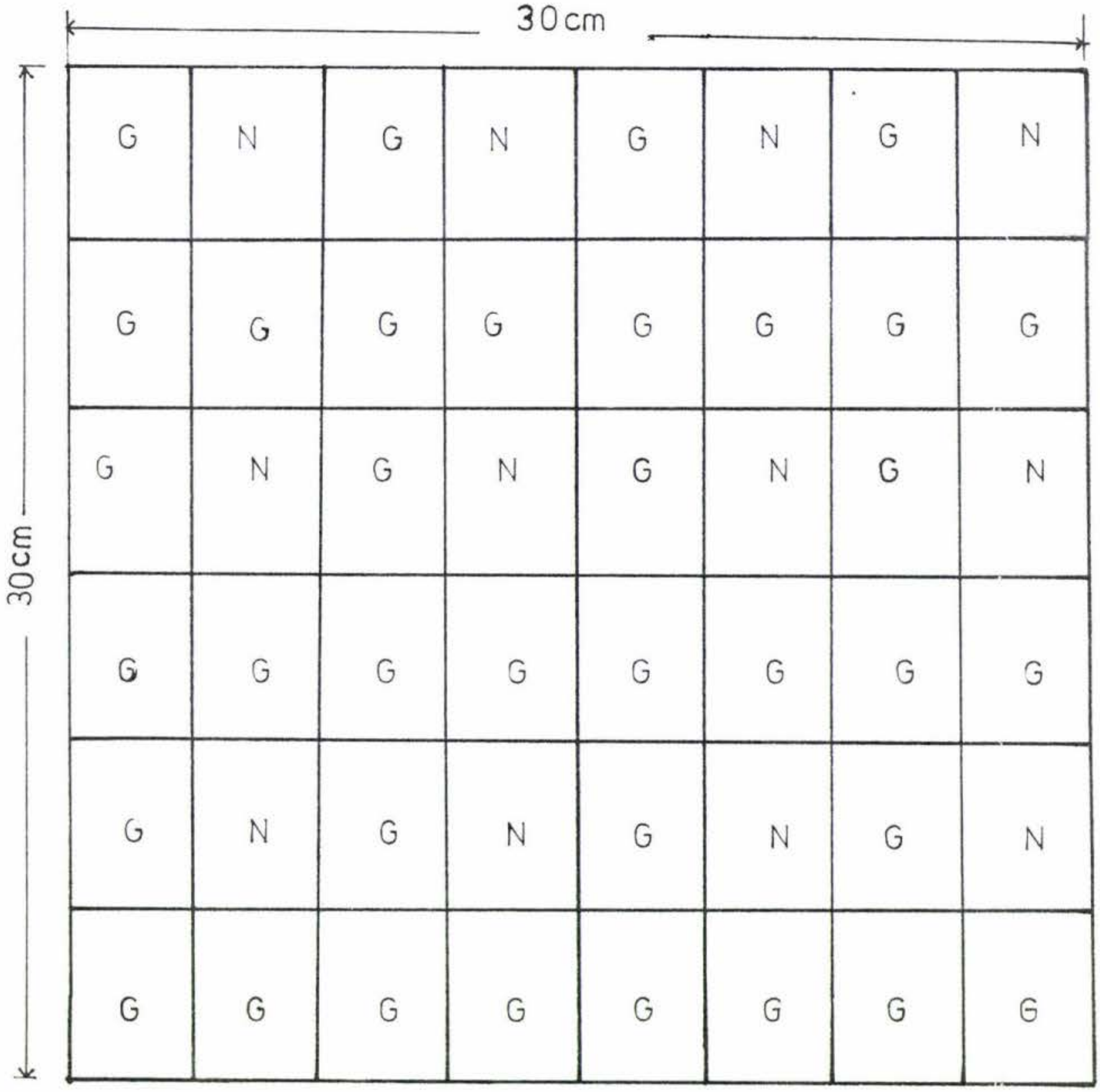


Plate 1. Frame used in the sowing operation

Fig. 4. Sowing pattern of G.75N.25 mixture. By interchanging the species G.25N.75 can be sown.



and 22 weeks respectively after sowing. The dry matter data from the pre-treatment cut was not analysed separately but was added to the dry matter of harvest period 1. The cut shoots were separated into Nui and gorse before drying at $80^{\circ}C$ for about 14 hours.

At the third harvest, there were two stages of cutting for LC and HC. The first cut was made at the respective cutting heights and the second at ground level. The dry matter obtained below the respective cutting height, referred to as stubble, was then added to the shoot dry matter from the three cuts together to make up the total shoot dry matter for the whole growing period. The control plants were cut only at the soil surface at the final harvest.

3.2.3.2 Root Dry Matter and Gorse Nodules

After the final harvest, the root dry matter was assessed by washing the soil mass from each box over Endicott sieves with 2 mm apertures until all the soil was removed (Plate 2). The root system of the two species were separated and nodules from 10 gorse seedlings were counted before drying at $80^{\circ}C$ for about 14 hours and weighing.

3.2.3.3 Tillers/Side Shoots

Tiller counts from Nui and gorse side shoots were counted from 10 plants per box before the two final cuts. The working figures were converted to total tillers/side shoots/box.

3.3 TRIAL 2

This trial commenced immediately after the completion of the first trial, using the same boxes, and soil type. The same seedling number per box and dormancy breaking treatment of gorse seed was also employed. The experiment differed in the experimental treatments designed to study the response of the two species to fertilizer treatment.

3.3.1 Experimental Design and Treatments

The experiment was laid out in a randomized block design involving 96 boxes. There were four replicates, three replacement ratios

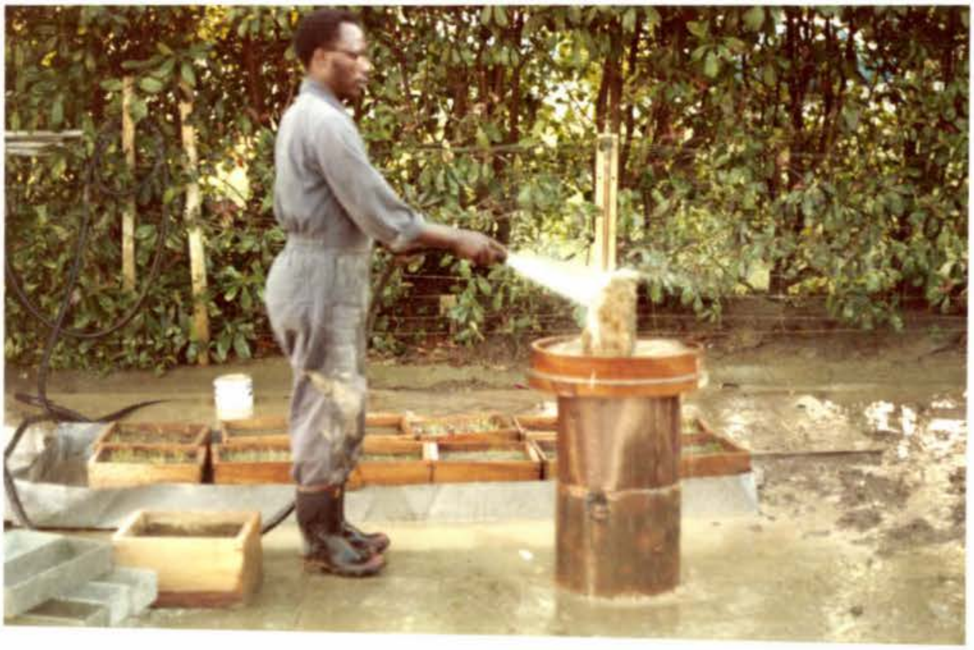


Plate 2. Washing technique of soil for the extraction of the root system

involving a monoculture of each species and a G.75N.25 mixutre and eight fertilizer treatments. The fertilizers uses were: urea (N), superphosphate (P) and potassium chloride (K). The three fertilizers were each used alone (N, P and K), combined in pairs (NP, NK and PK), all three together (NPK) and none (control). The layout of the trial is shown in Figure 5.

The amounts of each fertilizer and the necessary elements are shown in Table 2 together with the calcium sulphate added as a source of sulphur (S) and calcium (Ca) for those treatments without superphosphate. This was necessary because the superphosphate contained 10% S in the form

Table 2. Amount of Fertilizers and Elements used.

Fertilizer		Amount (g/box)	Element (kg/ha)
Potassium chloride	(K)	1.0	55.6
Urea	(N)	1.0	50.0
Superphosphate	(P)	7.9	70.0
	(S)	7.9	87.8
	(Ca)	7.9	175.6
Calcium sulphate	(S)	4.2	87.8
	(Ca)	4.2	116.6

of calcium sulphate, 20% Ca and impurities of various minor elements (During 1972). The fertilizer application was made immediately after sowing which was done between 4th and 7th April 1977. The sowing pattern was as in trial 1 and Nui seedlings were thinned to one per sowing position on 15th April, 1977. Water was applied as necessary to maintain an adequate moisture level and weeds were removed by hand.

3.3.2 Sampling Procedure

On the 10th August 1977, 18 weeks after sowing, the experiment was concluded. The data collected included the dry matter of the shoots cut at ground level, the dry matter of the roots after washing out of the soil, the number of nodules on the roots of gorse seedlings and the numbers of Nui tillers per box. The procedures adopted were as detailed in trial 1.

Fig. 5. Experimental layout for trial 2.

Key: 1.....96 Box numbers — N, K, P,(C) Fertilizers (Control)
M — Mixture of G.75N.25 (followed by box number)
N — Nui (N1.)(followed by box Number)
C — Corse (C1.0) " " " "

G19 NK	G13 P	M7 P	G1 PK
M20 N	M14 PK	G8 NP	M2 NK
N21 K	N15 PK	N9 NP	N3 NK
G22 N	M16 K	G10 NPK	N4 P
M23 NP	G17 K	M11 NPK	M5 C
N24 C	N18 NPK	N12 N	G6 C

REP.1

G73 N	G79 K	G85 P	N91 P
M74 NPK	N80 NPK	N86 K	G92 NPK
N75 NP	M81 C	M87 NK	M93 K
G76 C	G82 NP	N88 N	M94 PK
M77 NP	N83 NK	G89 PK	G95 NK
N78 C	M84 N	M90 P	N96 PK

REP.4

G43 N	N37 PK	M31 PK	G25 NPK
N44 K	M38 NPK	G32 PK	M26 NP
M45 K	G39 P	N33 P	N27 NK
N46 NP	N40 N	G34 NP	N28 NPK
M47 C	M41 NK	N35 C	G29 NK
G48 K	G42 C	M36 P	M30 N

REP. 2

N49 NP	N55 NPK	G61 K	N67 K
M50 P	G56 NP	M62 NPK	M68 K
G51 N	M57 NK	N63 P	G69 C
N52 PK	58 N	G64 PK	G70 P
G53 NK	N59 C	N65 N	N71 NK
M54 P K	G60 NPK	M66 NP	M72 C

REP.3

3.4 STATISTICAL PROCEDURE

To test the differences between treatments in the two trials, analyses of variance were carried out on the untransformed data for dry matter yield, shoot:root ratio, number of tillers/side shoots and root nodules. In all analyses of variance, the conventional notation for levels of significance will be used; i.e. difference not significant at P = 0.05 by ns, significant at $P < 0.05$ by * and significant at $P < 0.01$ by **. Where the analysis showed a significant difference, the value of the least significant difference (LSD 0.05) was calculated. In addition, the coefficients of variation (cv) were computed and expressed in percentages.

The separate data of the two species were used to fit parameters to the two species competition model of de Wit (1960, 1961, 1970) and his colleagues (de Wit and van den Bergh 1965; de Wit *et al.* 1966; van den Bergh 1968) summarized by Hall (1974a, 1974b). By comparing the growth of a species in a mixture with its growth in a pure stand the degree of competition between the two species can be described mathematically. The competitive power is measured by the relative crowding coefficient. According to de Wit, the relative crowding coefficient (k) for species a grown in association with species b is k_{ab} and the crowding coefficient for species b grown in association with species a is k_{ba}. The relative crowding coefficient for each species is calculated from the following equations:

$$k_{ab} = \frac{O_{ab} \; Z_b}{(M_a - O_{ab}) \; Z_b}$$

$$k_{ba} = \frac{O_{ba} \; Z_a}{(M_b - O_{ba}) \; Z_a}$$

where M_a and M_b are the monoculture yields of species a and b respectively, O_{ab} and O_{ba} are the yields of species a and b in mixtures and Z_a and Z_b are the relative frequencies of the species. Recently, a computer programme was developed by Thomas (1970) to calculate the relative crowding coefficients according to the least squares method. For th e purpose of this experiment, the computer programme was written in basic and run on the PDP 11/45 computer at DSIR, Palmerston North. In these computations k is assumed to be frequency indpendent.

The de Wit model makes it possible to study both "space" and "different space" and therefore competitive and non-competitive interference. According to de Wit (1960), the term "space" means growth factors generally, including water, light, nutrients, etc. Two species occupying the same space are in direct competetion. When two species occupy "different space", non-competitive interference may be taking place in addition to competitive interference. This can occur when the two plants have different growth periods, or where the rooting depth or external source of nutrients is different. Non-competitive interference is common in mixtures of a legume with a non-leguminous species.

From the theory of de Wit, two species growing in a mixture the product of whose relative crowding coefficients for any yield parameter equals 1, compete for the "sampe space" and are mutually exclusive. When the product of the relative crowding coefficients is greater than 1 the two plants interact to their mutual benefit, i.e. they compete for different space. Conversely, when the product of the relative crowding coefficients is less than 1, an inhibitory mechanism such as a toxic exudate is assumed to be operating.

Curves based on yields in relation to the plant ratios were derived from 4 and 3 parameter models. The 4 parameter model was obtained from independent estimates of gorse and Nui in a particular series following the procedures described by Thomas (1970). The equations are:

$$\text{Yield of gorse} = \frac{k_{GN}\, Z_G\, M_G}{k_{GN} + Z_N}$$

$$\text{Yield of Nui} = \frac{k_{NG}\, Z_N\, M_N}{k_{NG} + Z_G}$$

where M_G and M_N are the monoculture yields of gorse and Nui respectively, Z_G and Z_N represent the relative planting frequencies of the species in mixture and the constants k_{GN} and k_{NG} are the relative crowding coefficients which represent the competitive power in mixture of gorse to Nui and Nui to gorse respectively.

The 3-parameter model was fitted with the constraint that $k_{NG} = \frac{1}{k_{GN}}$ with respect to the equations given above. This model is based on the assumption that the two species were competing for the same space, i.e. $k_{GN} \times k_{NG} = 1$ (de Wit 1960). If the between models F test shows a significant difference, it indicates that the 4p model is more appropriate i.e. $k_{GN} \times k_{NG}$ is significantly greater or less than 1. This implies that mixing of the species increased or reduced yields relative to their respective monocultures.

The dry matter yield data obtained from trial 2 could not be fitted to the de Wit competition model because the computer programme supplied by DSIR could not deal with the situation where the mixture G.75N.25 was not balanced by the G.25N.75 mixture. It is hoped in time that it will be possible to modify the existing computer programme to handle the data from trial 2 and that a more complete analysis of the competitive interactions in this trial will then become possible.

4. RESULTS

4.1 TRIAL 1.

4.1.1 Establishment of Gorse and Nui

The pregerminated gorse and Nui seeds emerged satisfactorily in less than a week. Nui seedlings were faster in growth rate than gorse seedlings. While the gorse seedlings were at the cotyledon stage, some of the Nui seedlings were producing tillers.

More than half of the Nui seedlings had tillers four weeks after sowing and more tillers were produced in mixtures than in monocultures. Initially, the tillers grew horizontally to occupy the whole soil surface area in all boxes and then adopted an upright growth habit. An examination of all tillers after four weeks showed only two which had rooted. The horizontal growth of the grass tillers was more pronounced in the mixtures containing 50% or fewer grass plants. Regardless of the initial number of Nui seedlings, six weeks after sowing, weeds were no longer a problem as all the soil surface was covered.

Six weeks after sowing, the majority of gorse seedlings (82%) were past the cotyledon stage and had 6-10 simple leaves. Although the seedlings were healthy, the initial growth rate was slow. Stem elongation became obvious 8-10 weeks after sowing, by which time the seedlings averaged 4 cm in height in monocultures and more than this in mixtures. Gorse seedlings in the mixtures were etiolated and produced no side shoots. At the end of the experiment, each gorse seedling had a well defined tap-root which branched near the top, the branches growing deeply into the soil.

Both gorse and Nui seedlings were attacked by pests. Gorse seedlings were attacked by an unidentified defoliating insect, three weeks after sowing. Attempts to find the insect were unsuccessful but the problem was short-lived as no further damage occured after the fourth week. During the 17th week, Nui seedlings in the control boxes were attacked by aphids. These were controlled with a 0.05% solution of dichlorvos (Vapona).

4.1.2 Effects of Defoliation and Plant Ratios

The individual box figures for the dry matter yields of the two species for trial 1 are presented in Appendix 1. The yields of the defoliated treatments are shown for the three harvest periods together with the cumulative yields for periods 1-2 and 1-3. At the end of the trial, the total shoot dry matter yield for the cut treatments was made up of the total for harvest periods 1-3 plus the stubble weight and for the uncut controls was the total growth over the trial period. Nui tillers and gorse side shoots were also counted before the second and third cuts and the detailed counts are given in Appendix 2. The full nodule counts for gorse seedlings made at the end of the trial are given in Appendix 3. The data thus recorded formed the basis for the statistical analyses of the effects of defoliation, of varying plant ratio and of the interactions on gorse and Nui seedlings.

4.1.2.1 Gorse Seedlings

The shoot dry matter figures for gorse seedlings over harvest periods 1, 2 and 3 and the cumulative yield figures over periods 1-2 and 1-3 are presented in Table 3. Analysis of variance indicated that there were significant differences in yield between cutting heights(H) and plant ratios (R) over all growth periods. In the first harvest period the low cut plants outyielded the high cut, but for subsequent harvests the yields were higher with the high cut. Over the whole growth period severe defoliation at 2 cm depressed the total dry matter yield more than the cut at 4 cm. This difference between cutting heights also applied to the root dry weights shown in Table 4 and to the total plant weights (root + shoot). Table 4 also shows that uncut control plants yielded at least 3 times the dry matter of the cut plants. Over all yield periods, Tables 3 and 4 show that the yields of shoots, roots and whole plants were greatly reduced when grown in combination with Nui. Even with one Nui to every three gorse the yield was reduced by at least two-thirds and with higher proportions of grass was reduced still further (Plates 3-6).

Plates 3-6 The effect of Nui seedlings reduced the total dry matter production of gorse from 100% in G1.0 to 24, 8 and 4% in G.25N.25, G.50N.50 and G.25N.75 respectively in the uncut controls.

Plate 3. Gorse alone - shoot and root

Plate 4. G.75N.25 - gorse shoot and root on left and Nui shoot and root on right.

Plate 5. G.50N.50 - Nui shoot and root on left and gorse shoot and root on right

Plate 6. G.25N.75 - Nui shoot and root on left and gorse shoot and root on right

Table 3. Gorse. Mean shoot dry matter yields (g/box) over three separate harvest periods and cumulative yields as affected by plant ratio and cutting height.

Harvest Periods	Date	Weeks from Sowing	Cutting Height (H)	Plant Ratios (R) G1.0	G.75N.25	G.50N.50	G.25.N.75	Mean	CV %	LSD 0.05 R	H	R x H
1	3/1/77	14	Low cut	7.90	2.55	1.23	0.60	3.07				
			High cut	5.40	2.40	1.08	0.58	2.37		**	**	*
			Mean	6.65	2.48	1.16	0.59	2.72	29.2	0.83	0.58	
2	4/2/77	18	Low cut	7.10	1.43	0.60	0.35	2.37				
			High cut	13.18	1.43	0.73	0.25	3.90			**	**
			Mean	10.14	1.43	0.67	0.30	3.14	20.5	0.67	0.47	
3	1/3/77	22	Low cut	5.55	1.00	0.65	0.45	1.91				
			High cut	7.28	1.70	1.23	0.35	2.64		**	**	*
			Mean	6.42	1.35	0.94	0.40	2.28	27.7	0.66	0.47	
1-2	3/1-4/2/77	18	Low cut	15.0	3.98	1.83	0.95	5.44				
			High cut	18.58	3.83	1.80	0.83	6.20		**	*	**
			Mean	16.79	3.91	1.82	0.89	5.62	16.3	0.99	0.70	
1-3	3/1-1/3/77	22	Low cut	20.55	4.98	2.48	1.40	7.35		**	**	**
			High cut	25.85	5.53	3.03	1.18	8.90		**	**	**
			Mean	23.20	5.26	2.76	1.29	8.13	15.2	1.28	0.90	

Table 4. Gorse. The effects of cutting and plant ratio on dry matter yields of shoot, root and the whole plant (g/box) over the full growing period of 22 weeks.

Plant Part	Cutting Height (H)	Plant Ratios (R) G1.0	G.75N.25	G.50N.50	G.25 N.75	Mean	CV %	LSD 0.05 R	H	R x H
Shoot	Low cut	28.48	8.10	3.78	2.43	10.70				
	High cut	43.15	9.70	5.20	3.75	15.45				
	Control	125.03	31.13	10.55	4.90	42.90		**	**	**
	Mean	65.55	16.31	6.50	3.69	23.02	31.3	5.98	5.18	
Root	Low cut	6.33	2.10	0.93	0.58	2.49				
	High cut	9.23	2.28	1.43	0.45	3.35				
	Control	34.43	6.93	2.93	1.48	11.44		**	**	**
	Mean	16.66	3.77	1.76	0.84	5.76	22.0	1.05	0.91	
Root	Low cut	34.80	10.20	4.70	3.00	13.18				
+	High cut	52.38	11.98	6.60	4.20	18.79				
Shoot	Control	159.45	38.05	13.48	6.43	54.35		**	**	**
	Mean	82.22	20.08	8.26	4.54	28.78	18.5	6.62	5.74	

The interaction between plant ratios and cutting treatments were also significant for all yield components and periods. These significant interactions are due mainly to the greater effect of plant ratio on the uncut gorse plants than on the cut ones.

The shoot, root and total plant dry matter yield per seedling is shown in Table 5. The uncut control was significantly greater than defoliated treatments and G1.0 and G.75N.25 were significantly

Table 5. Gorse: The effect of cutting and plant ratio on dry matter yield of shoot, root and the whole plant (g/plant) over the full growing period of 22 weeks.

Plant Part	Cutting Height	Plant Ratios G1.0	G.75N.25	G.50N.50	G.25N.75	Mean	CV %	LSD 0.05 R	H	RxH
Shoot	Low cut	0.60	0.23	0.16	0.20	0.30				
	High cut	0.90	0.27	0.22	0.31	0.42				
	Control	2.61	0.87	0.44	0.41	1.08		**	**	**
	Mean	1.37	0.46	0.27	0.31	0.60	28.9	0.15	0.13	
Root	Low cut	0.13	0.06	0.04	0.05	0.07				
	High cut	0.19	0.07	0.06	0.04	0.09				
	Control	0.72	0.19	0.12	0.13	0.29		**	**	**
	Mean	0.35	0.11	0.07	0.07	0.15	21.7	0.03	0.02	
Root	Low cut	0.73	0.29	0.20	0.25	0.36				
+	High cut	1.09	0.33	0.27	0.35	0.51				
Shoot	Control	3.33	0.98	0.56	0.54	1.37		**	**	**
	Mean	1.71	0.56	0.34	0.38	0.75	27.1	0.18	0.16	

greater than G.50N.50 and G.25N.75 for all plant components. The interactions are due to the greater reduction in weight of gorse seedlings by mixing with Nui in the uncut controls than in the defoliated treatments.

The relationship between shoot and root was calculated by dividing the total shoot dry matter yield by the root dry matter. As shown in Table 6 the shoot:root ratio was significantly reduced by both cutting treatments and plant ratio.

Gorse is a typical legume in producing root nodules, the number of which are presumably related to its nitrogen fixing potential.

Table 6. Gorse. The effects of plant ratio and cutting height on the shoot:root ratio.

Cutting Height	Plant Ratios					CV	LSD 0.05		
	G1.0	G.75N.25	G50N.50	G.25N.75	Mean	%	R	H	R x H
Low cut	3.70	3.76	4.51	5.50	4.36				
High cut	3.89	4.20	5.10	5.68	4.72				
Control	3.61	3.34	4.25	3.62	3.70		**	**	ns
Mean	3.73	3.76	4.62	4.93	4.26	23.9	0.73	0.85	

As presented in Table 7, it is seen that although the counts were very variable, defoliation significantly reduced the number of nodules per plant.

Table 7. Gorse. The effects of plant ratio and cutting height on nodulation (nodules/plant)

Cutting Height	Plant Ratios					CV	LSD 0.05		
	G1.0	G.75N.25	G.50N.50	G.25N.75	Mean	%	R	H	R x H
Low cut	16.8	5.6	5.5	4.8	8.2				
High cut	27.8	7.6	5.1	4.2	11.2				
Control	38.5	18.5	13.4	7.0	19.4		**	**	*
Mean	27.7	10.6	8.0	5.3	12.9	43.3	4.6	4.0	

Plate 7 illustrates the strong nodule formation of uncut gorse seedlings. The majority of nodules were large and pinkish in colour when cut open in comparison with the fewer and smaller nodules from defoliated plants, especially when growing in mixtures. Plant ratio also had a highly significant effect ($P < 0.01$) and the number of nodules per plant decreased with increasing proportion of Nui seedlings. The interaction significant at $P < 0.05$ was due to the fact that in the mixtures similar numbers of nodules were produced with both cutting treatments whereas gorse alone produced fewer nodules with the low than with the high cut.

Plate 7. Nodule production of gorse seedling grown in monoculture without cutting

Table 8. Gorse. The effects of defoliation and plant ratio on the number of side shoots per plant.

Sample Periods	Dates	Weeks from sowing	Cutting Height	Plant Ratios: G1.0	G75.N.25	G.50N.50	G.25N.75	Mean	CV %	LSD 0.05: R	H	R x H
1	3/2/77	18	Low cut	5.7	3.6	2.5	2.9	3.6				
			High cut	4.3	3.2	2.2	2.4	3.0		**	**	**
			Control	1.7	1.0	1.0	1.0	1.2	15.4	0.4	0.3	
			Mean	3.9	2.6	1.9	2.1					
2	28/2/77	22	Low cut	9.2	6.8	4.8	5.5	6.6				
			High cut	8.5	6.0	4.4	4.3	5.8				
			Control	1.1	1.0	1.0	1.0	1.0		**	**	**
			Mean	6.2	4.6	3.4	3.6		14.9	0.6	0.5	

Removing the shoot apex results in the growth of varying numbers of side shoots and Table 8 shows that the cutting heights, plant ratios and the R x H interactions were all highly significant ($P < 0.01$) for both sampling periods. In defoliated treatments more side shoots were produced in monocultures than in mixtures with Nui seedlings. The R x H interaction may be due to the greater effect of defoliation on gorse in monocultures than in the mixtures.

4.1.2.2 "Grasslands Nui" Perennial Ryegrass

The effect of defoliation on Nui was quite different to that on gorse seedlings. As shown in Table 9 there were no significant differences between cutting heights in dry matter yield over any of the harvest periods and the yield increments decreased with time. However, as shown by the final plant weights given in Table 10, the dry matter yields of both shoots and roots were significantly higher in the uncut controls in either of the cutting treatments.

Plant ratio had relatively little effect on shoot dry matter (Table 9). There was a significant difference only at the first harvest between the Nui monocultures and the mixtures with gorse. The differences in the final total weights of shoots and roots were larger and highly significant. With the shoot weights the differences between ratios were similar at the varying cutting heights. With the root weights there was a particularly large difference between ratios at the lowest cutting height but the interactions were not significant.

Table 9. Nui. Mean shoot dry matter yields (g/box) over three separate harvest periods and cumulative yields as affected by plant ratio and cutting height.

Harvest Periods	Dates	Weeks from Sowing	Cutting Height	Plant Ratios					CV	LSD 0.05		
				N1.0	N.75G.25	N.50N.50	N.25G.75	Mean	%	R	H	R x H
1	3/1/77	14	Low cut	31.8	26.2	30.3	24.4	28.2				
			High cut	32.3	26.2	24.8	24.8	27.0		*	ns	ns
			Mean	32.0	26.2	27.5	24.6	27.6	18.1	5.2		
2	4/2/77	18	Low cut	8.1	7.4	8.8	8.0	8.1				
			High cut	6.9	8.8	7.8	7.6	7.8				
			Mean	7.5	8.1	8.3	7.8	8.0	31.0	ns	ns	ns
3	1/3/77	22	Low cut	4.5	3.5	3.6	2.8	3.6				
			High cut	3.7	4.3	5.0	3.6	4.1				
			Mean	4.1	3.9	4.3	3.2	3.9	20.7	ns	ns	ns
1-2	3/1-4/2/77	18	Low cut	39.9	33.6	39.0	32.4	36.2				
			High cut	39.2	35.0	32.6	32.4	34.8				
			Mean	39.3	34.3	35.8	32.4	35.5	17.4	ns	ns	ns
1-3	3/1-1/3/77	22	Low cut	44.4	37.1	42.6	35.2	39.8				
			High cut	42.9	39.2	37.6	36.0	38.9				
			[illegible]	[illegible]	[illegible]	[illegible]						

Table 10. Nui. The effects of cutting and plant on dry matter yields of shoot, root and the whole plant (g/box) over the full growing period of 22 weeks

Plant Part	Cutting Height	Plant Ratios N1.0	N.75.G.25	N.50G.50	N.25G.75	Mean	CV %	LSD 0.05 R	H	RxH
Shoots	Low cut	50.2	44.2	47.7	39.5	45.4				
	High cut	54.6	49.8	49.3	42.3	49.0				
	Control	81.8	82.0	75.5	70.6	77.5		**	**	ns
	Mean	62.2	58.7	54.2	50.8	57.3	11.5	5.5	4.8	
Roots	Low cut	35.1	22.3	19.8	15.1	20.5				
	High cut	24.9	26.9	28.7	19.7	25.0				
	Control	57.5	62.5	74.8	51.6	61.6		*	**	ns
	Mean	35.8	37.2	41.1	28.8	35.7	24.6	7.3	6.3	
Root + Shoot	Low cut	75.3	66.5	67.5	54.6	66.0				
	High cut	79.5	76.7	78.0	61.9	74.0		**	**	ns
	Control	139.3	144.5	150.3	122.2	139.0				
	Mean	98.0	95.9	98.6	79.5	93.0	7.0	8.1	7.0	

Table 11 shows the effect of the treatments on the shoot:root ratio of Nui. The ratio was significantly higher with the cut treatments than

Table 11. Nui. The effects of plant ratio and cutting height on the shoot:root ratio.

Cutting Height	Plant Ratios G.75N.25	G.50N.50	G25N.75	N1.0	Mean	CV %	LSD 0.05 R	H	R x H
Low cut	2.09	2.06	2.44	2.70	2.32				
High cut	2.21	1.86	1.73	2.51	2.08				
Control	1.45	1.31	1.10	1.40	1.32		**	**	ns
Mean	1.92	1.74	1.76	2.20	1.90	21.1	0.33	0.29	

with the uncut control. Plant ratio had an effect and there was no interaction between cutting heights and plant ratios.

The effect of defoliation and plant ratio on the tiller formation of Nui for the two sampling periods is shown in Tables 12 and 13 for tillers/box and tillers/plant respectively. Cutting height had a significant effect ($P < 0.01$) for both sampling periods, the uncut plants producing more tillers than the defoliated ones. As would be expected plant ratio had a greater effect. N.25 had half the number of tillers per box of N1.0 although there were only one quarter the number of plants. Table 13 shows that the higher number was due to the greater tiller production per Nui seedling in N.25, being almost twice as much as N1.0.

4.1.2.3 Amount of Gorse in Mixtures

Table 14 shows the amounts of gorse dry matter recorded over the various harvest periods expressed as percentages of the total dry matter. The differences between the cutting treatments were non-significant but the proportions of gorse increased with time and the increase was higher for HC than the LC treatment. The proportions of gorse based on the final yields of shoots + roots are given in Table 15. The shoot proportion was considerably higher in the uncut than the cut boxes i.e. the uncut grass was inferior to the cut treatments in suppressing gorse seedlings. There were also highly significant differences ($P < 0.01$) between plant ratios in all yield periods. In all cases, the proportion of dry matter was considerably lower than the original proportion of plants in the mixtures. The significant interactions are a result of the greater differences between cut and uncut boxes containing a high proportion of gorse plants than in those with smaller gorse proportions.

Table 12. Nui. The effects of defoliation and plant ratio on the numbers of tillers produced per box

Sampling Periods	Dates (weeks from sowing)	Cutting Height	Plant Ratios N1.0	N.75G.25	N.50G.50	N.25G.75	Mean	CV %	LSD 0.05 R	H	R x H
1	3/2/77	Low cut	551	472	418	295	434				
	(18)	High cut	539	521	393	281	433				
		Control	578	557	427	332	474		**	**	**
		Mean	556	512	413	303	447	5.5	20	18	
2	28/2/77	Low cut	588	499	433	286	451				
	(22)	High cut	548	467	375	265	414				
		Control	700	611	413	337	515		**	**	ns
		Mean	612	526	407	296	460	17.3	66	57	

Table 13. Nui. The effects of defoliation and plant ratio on the number of tillers produced per plant

Sampling Periods	Dates (weeks from sowing)	Cutting Height	Plant Ratios N1.0	N.75G.25	N.50G.50	N.25G.75	Mean	CV %	LSD 0.05 R	H	R x H
1	3/2/77	Low cut	11.5	13.1	17.4	24.6	16.7				
	(18)	High cut	11.2	14.5	16.4	23.4	16.4				
		Control	12.1	15.5	17.8	27.7	18.3		**	ns	ns
		Mean	11.6	14.4	17.2	25.2	17.1	15.7	2.2		
2	28/2/77	Low cut	12.3	13.9	18.1	23.8	17.0				
	(22)	High cut	10.9	13.0	15.6	22.1	15.4				
		Control	14.6	17.0	17.2	30.2	19.7		**	**	ns
		Mean	12.6	14.6	17.0	25.3	17.3	15.1	2.2	1.9	

Table 14. Gorse. The effects of cutting and plant ratio on the proportion of gorse in mixtures expressed as a percentage of the total shoot dry matter of both species.

Harvest Periods	Dates	Weeks from Sowing	Cutting Height	Plant Ratios				CV %	LSD 0.05		
				G.75N.25	G50N.50	G.25N.75	Mean		R	H	R x H
1	3/1/77	14	Low cut	10.6	4.1	2.4	5.7				
			High cut	9.7	4.5	2.3	5.5		**	ns	ns
			Mean	10.1	4.3	2.3	5.6	28.0	1.7		
2	4/2/77	18	Low cut	18.2	6.9	7.1	10.7				
			High cut	19.4	13.5	3.3	12.1		**	ns	ns
			Mean	18.8	10.2	5.2	11.4	53.8	6.5		
3	1/3/77	22	Low cut	35.7	18.1	16.6	23.4				
			High cut	49.0	26.1	5.3	28.0		**	ns	ns
			Mean	42.3	22.1	17.7	25.7	34.1	9.4		
1-2	3/1/77-4/2/77	18	Low cut	12.4	4.7	3.0	6.7				
			High cut	11.8	5.7	2.5	6.7		**	ns	ns
			Mean	12.1	5.2	2.7	6.7	21.2	1.5		
1-3	3/1/77-1/3/77	22	Low cut	14.3	5.8	4.0	8.1				
			High cut	15.5	8.4	3.2	9.0		**	ns	ns
			Mean	14.9	7.1	3.6	8.6	21.2	1.9		

Table 15. Gorse. The effects of cutting and plant ratio on the proportion of gorse in mixtures expressed as percentages of final shoot and root dry matter totals for both species

Plant Part	Cutting Height	Plant Ratios				CV	LSD 0.05		
		G75N.25	G.50N.50	G.25N.75	Mean	%	R	H	RxH
Shoot	Low cut	20.7	8.0	5.6	11.4				
	High cut	23.0	10.7	7.1	13.6				
	Control	44.1	13.9	6.3	21.4		**	**	**
	Mean	29.3	10.9	6.3	15.4	29.2		3.8	3.8
Root	Low cut	14.3	4.7	2.5	7.2				
	High cut	12.6	4.9	1.7	6.4				
	Control	14.2	4.1	2.4	6.9		**	ns	ns
	Mean	13.7	4.5	2.2	6.8	41.8	2.4		
Shoot + Root	Low cut	19.0	7.0	4.5	10.2				
	High cut	19.5	8.6	5.2	11.1				
	Control	31.5	8.7	4.6	14.9		**	**	**
	Mean	23.3	8.1	4.8	12.1	26.2	2.7	2.7	

4.1.3 Competitive Indices

Gorse and Nui dry matter yields and side shoots/tiller numbers were fitted to the two species competition model of de Wit (1960) following procedures described by Thomas (1970). The relative crowding coefficient calculated for each species gave a measure of its competitive power in association with the other species. The curves shown in Figures 6-10 were derived from 4p and 3p models and the data used to fit the curves is given in Appendix 4.

Tables 16-20 give the monoculture yields calculated from the fitted curves together with the relative crowding coefficients for the two species and the products of the crowding coefficients. The tables also show the significance tests for 'between species' and 'between models' variance ratios. As pointed out by Thomas (1970), if the between species F ratio is not significant then the between model F ratio can be interpreted as an indication of a fundamental difference between the two species. If the between models F ratio is not significant, the hypothesis that the species are crowding for the same space may be accepted. A significant between models F ratio indicates that the species do not compete for the same

Figure 6. Replacement diagrams based on three harvests of shoot dry matter (g/box) of Nui and gorse seedlings for low cut (a) & high cut (b)

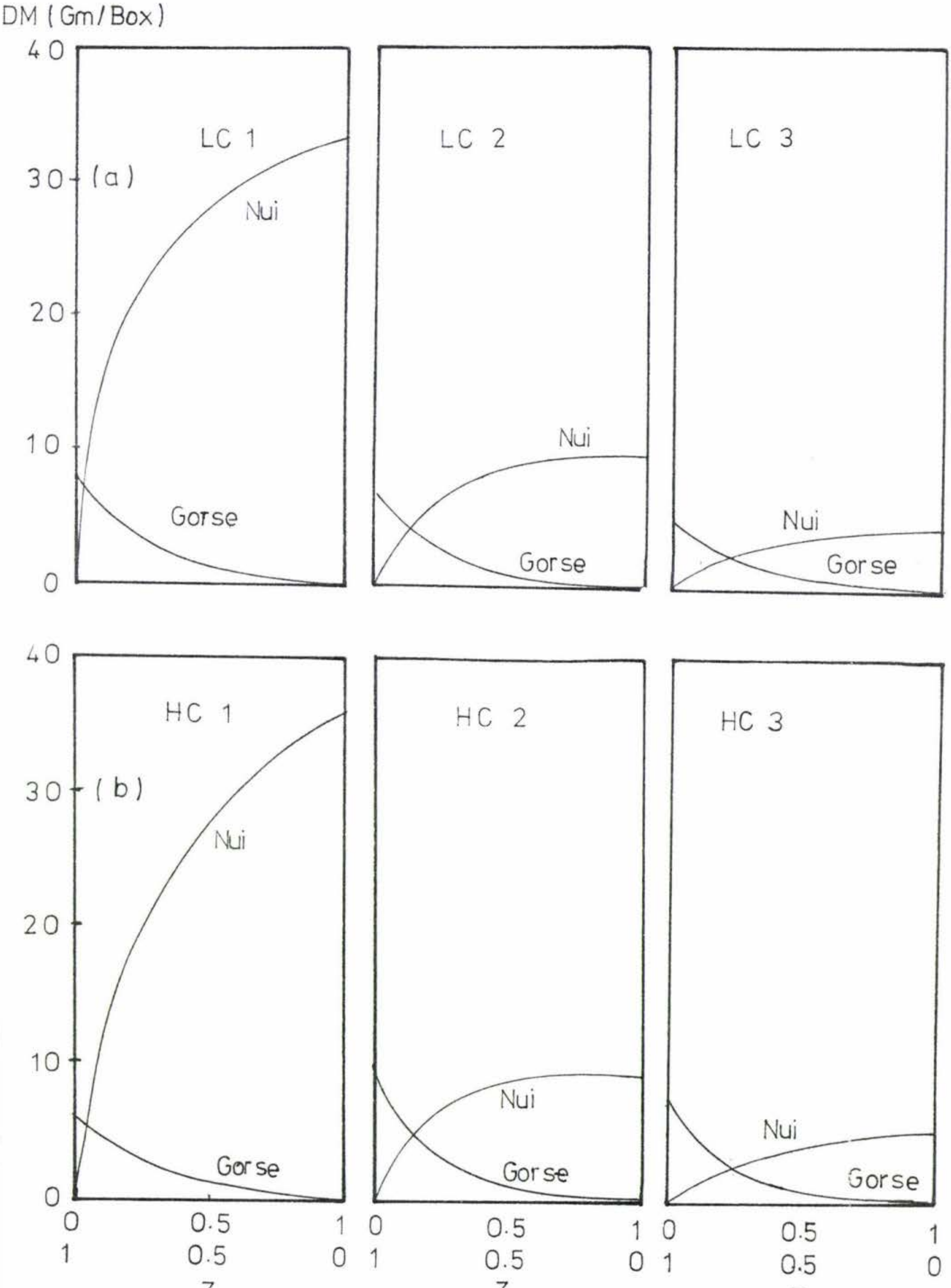


Figure 7. Replacement diagrams based on shoot yields of cumulative yields 1-2 and 1-3 for low cut (a), high cut (b) & uncut control (c).

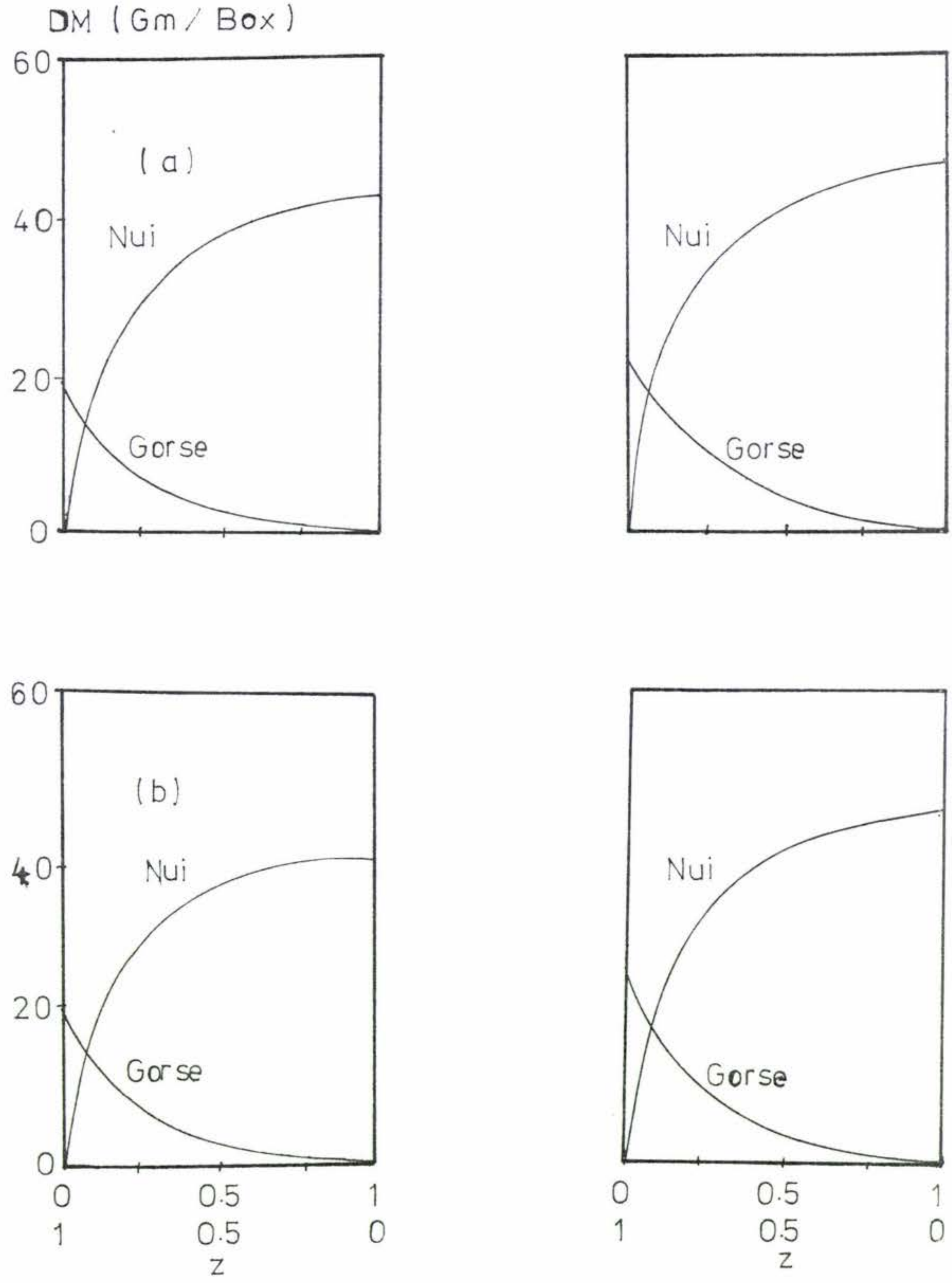


Figure 7. (contd.)

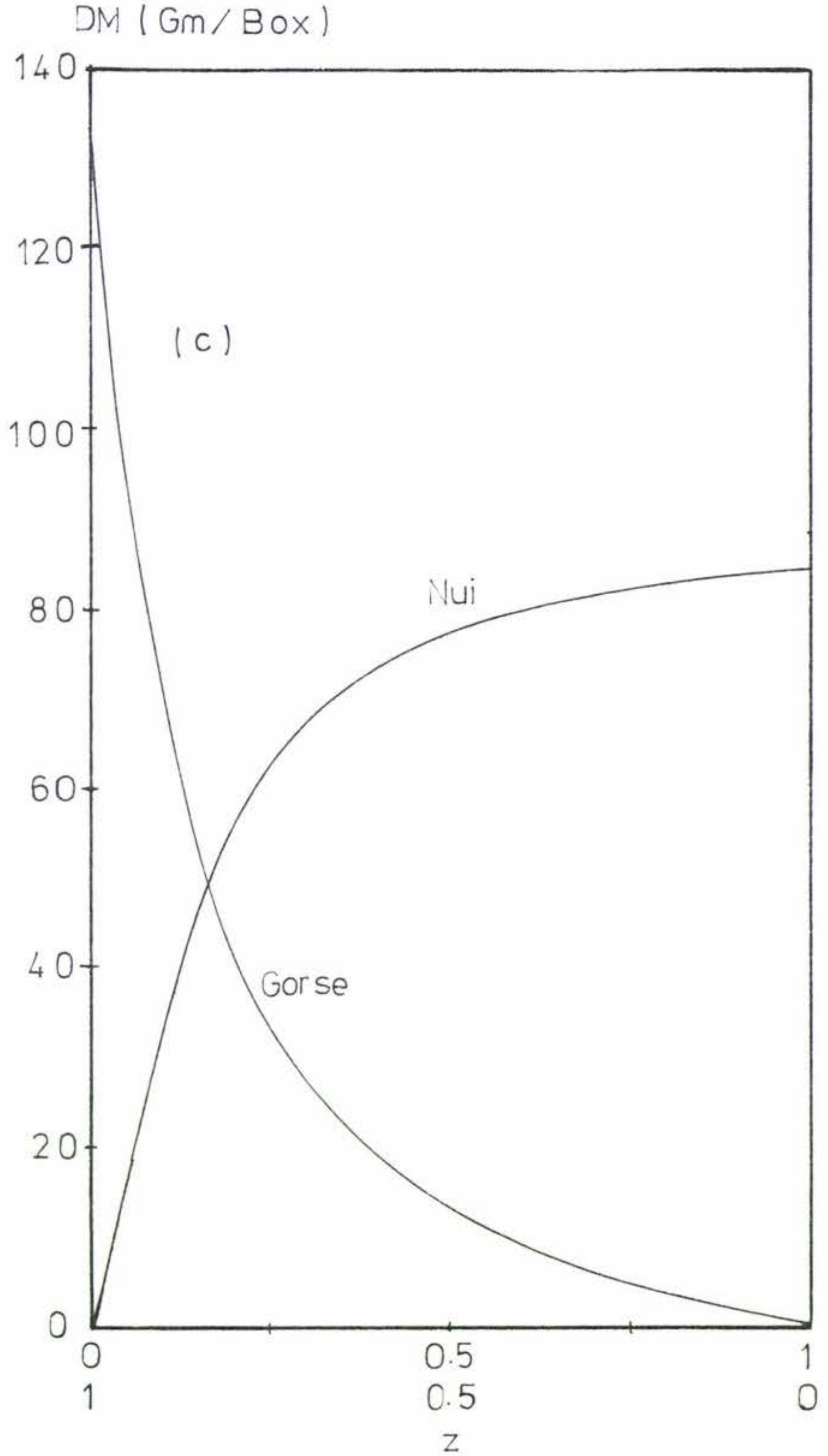


Figure 8. Replacement diagrams based on root dry matter (g/box) of Nui and gorse for low cut (a), high cut (b) and uncut control (c)

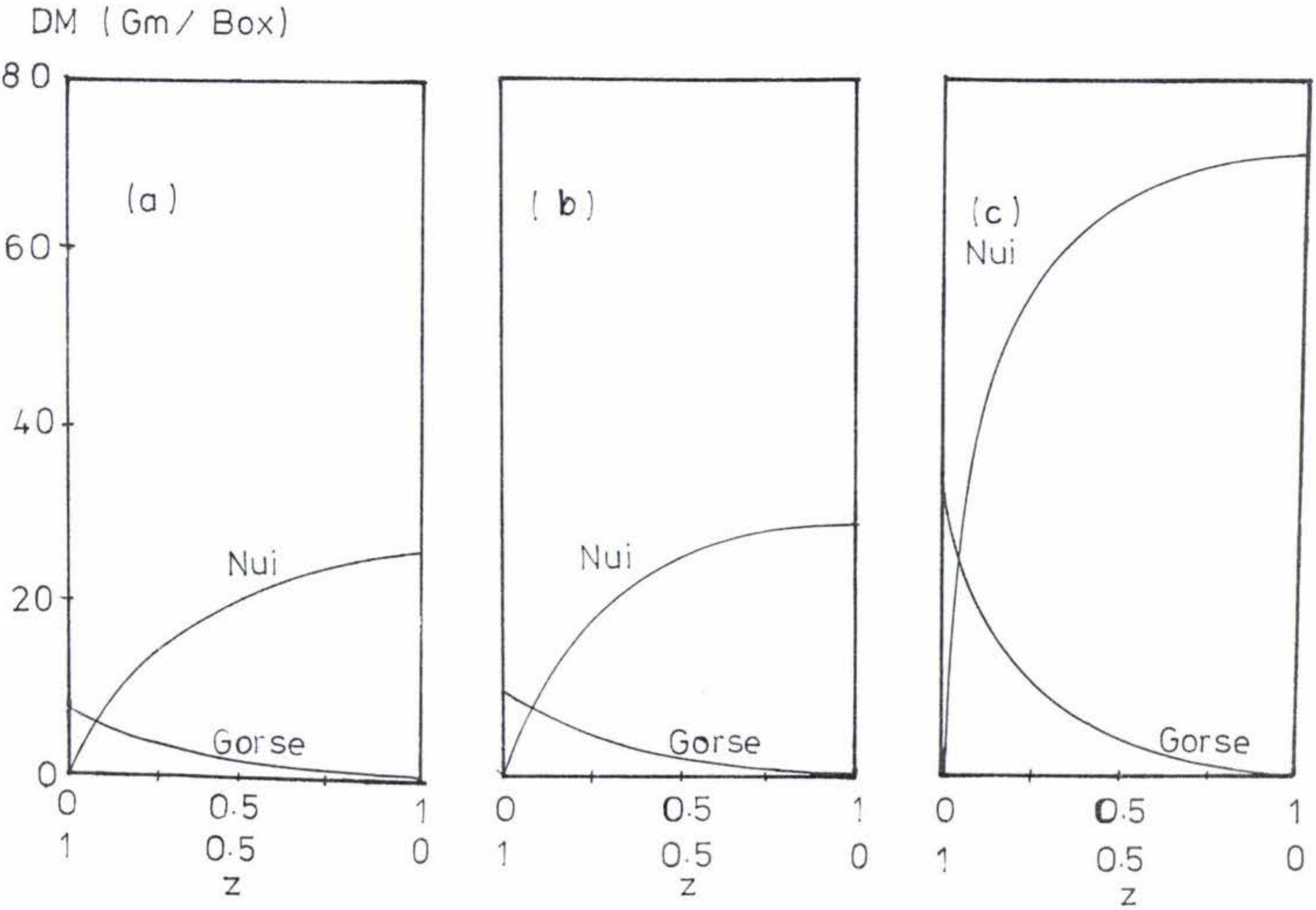
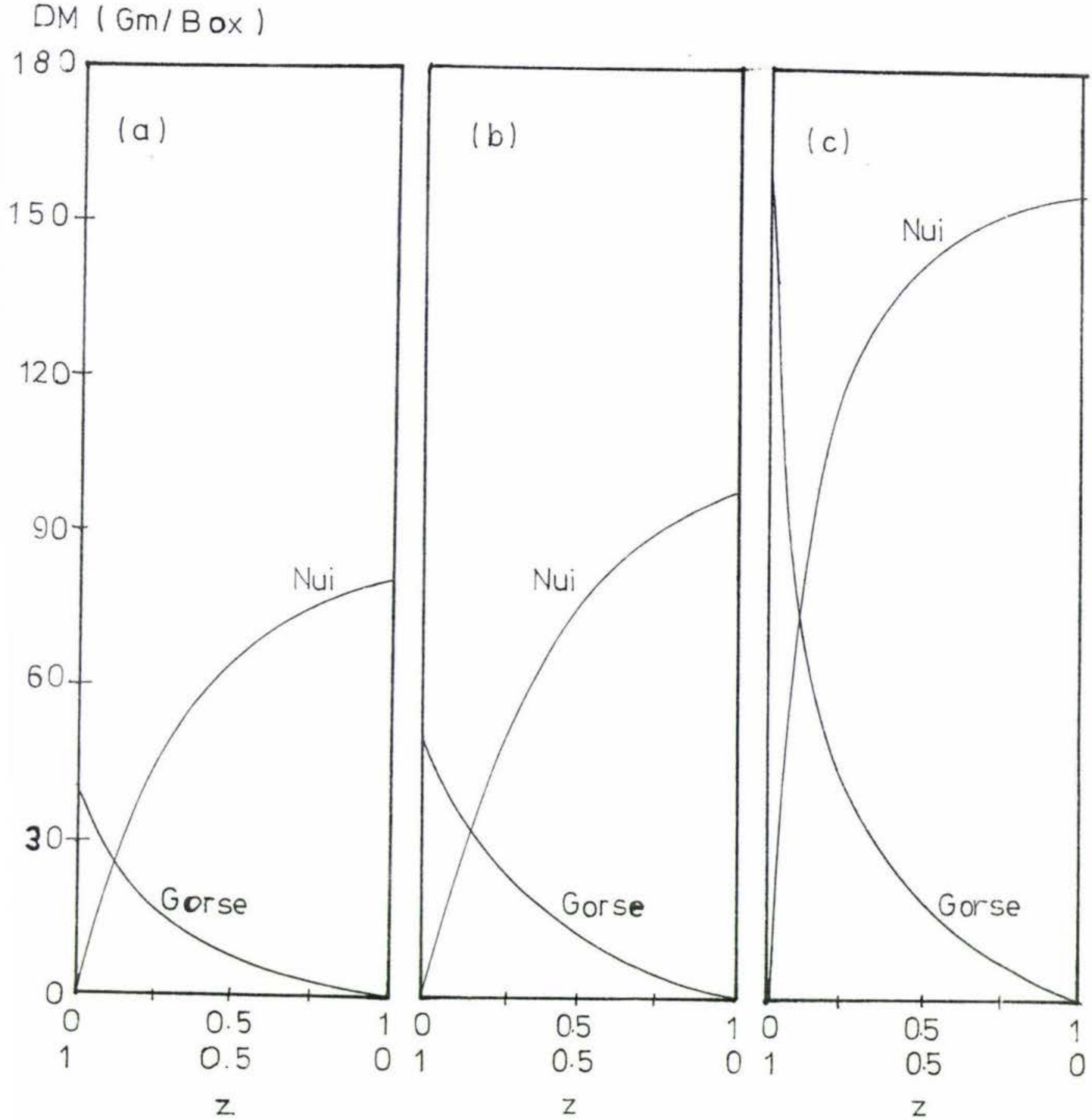


Figure 9. Replacement diagrams based on total plant dry matter yields (g/box) of Nui and gorse for low cut (a), high cut (b) and control (c).



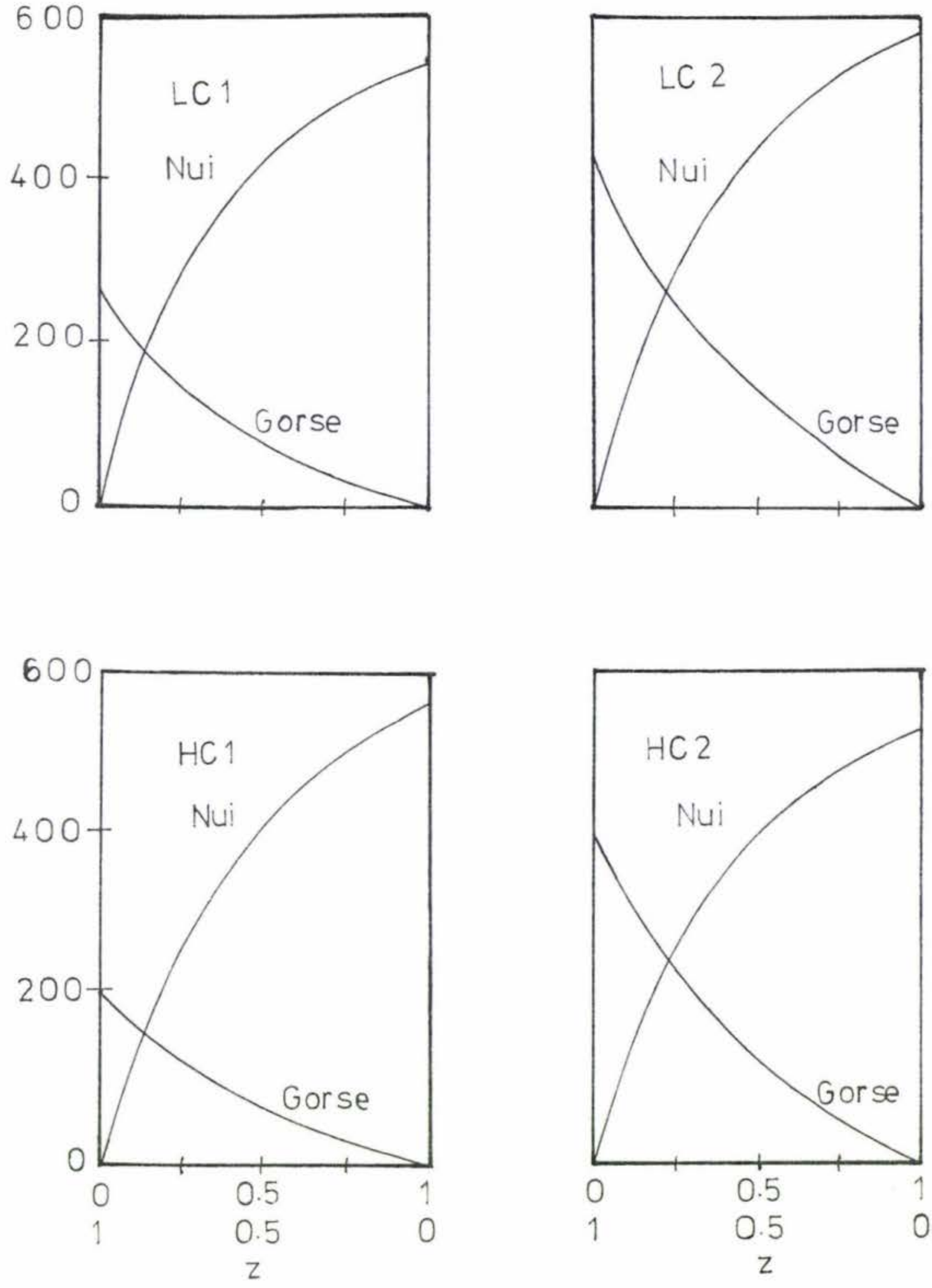


Figure 10. Replacement diagrams based on side shoots/tillers/box of gorse/Nui for low cut (LC1 & LC2) and high cut (HC1 & HC2).

space, again indicating a fundamental difference.

In all the tables the dominance of Nui is clearly demonstrated by its k_{NG} value which is consistently above 1.0. By contrast the relative crowding coefficient of gorse (k_{GN}) is consistently less than 1.0 and mostly between 0.1 and 0.3

4.1.3.1 Shoot Dry Matter Yield

The dry matter yields of the two species for harvest periods 1 to 3 for the cut treatments are presented in the replacement diagrams (Figures 6a and b). Gorse was considerably reduced in mixtures with Nui relative to its growth in monoculture. However, the gorse yields declined less over successive harvest periods than did the yields of Nui so that over the last harvest period, the gorse outyielded the grass.

The calculated monoculture yields given in Table 16 show the same yield relationships and the relative crowding coefficients for the two species show that k_{GN} varies from 0.06 - 0.32 while k_{NG} varies from 4.21 to 23.03. The product $k_{GN} \times k_{NG}$ is in the range 1.19-3.96 and shows no consistent change with successive harvests. In three out of the six sets of yield data the between models F ratio is non-significant.

Figure 17 a and b and Table 17 show the results of similar calculations on the data for cumulative yields of the two cutting treatments. The relative crowding coefficients for gorse and Nui are within the ranges indicated above, as are their products. For the two high cut harvest periods the between models F ratio is non-significant, but with the low cut harvests this test cannot be made.

The single harvest figures of the uncut controls are presented in the replacement diagram (Figure 7c) and Table 17. Gorse in mixtures was considerably reduced relative to its growth in monoculture. Gorse monoculture outyielded Nui by about 50%, while in the G.75N.25 mixture the gorse yield was only about 40% that of Nui.

4.1.3.2 Root Dry Matter

The root dry matter yields of the two species shown in the replacement diagrams (Figure 8) and Table 18, indicate that both species in monocultures produced less dry matter in the cut treatments than in the uncut controls. In the monocultures gorse produced less dry matter than Nui and the root growth of gorse was more affected by cutting than that of Nui. The gorse root dry matter yield was

Table 16. Fitted monoculture yields and relative crowding coefficients for the two cutting heights and three yield periods

Cutting Height	Harvest Dates	Parameters of model used	Monoculture Yields M_G	M_N	Relative Crowding Coefficients k_{GN}	k_{NG}	$k_{GN} \times k_{NG}$	F Ratio 14:14 df Between species variance	1.28 Between Models
Low cut	3/1/77	4p	7.8	31.0	0.22	12.36	2.75	2.56*	
		3p	8.3	34.8	0.20	4.98			
	4/2/77	4p	6.6	9.2	0.16	23.03	3.96	1.65 ns	1.26 ns
		3p	7.0	10.3	0.15	6.80			
	1/3/77	4p	5.0	4.3	0.25	6.14	1.54	3.88 **	
		3p	5.2	4.6	0.24				
High cut	3/1/77	4p	5.4	30.5	0.32	11.35	3.68	1.18 ns	8.81 **
		3p	6.1	36.2	0.26	3.80			
	4/2/77	4p	13.1	9.7	0.06	19.37	1.19	1.61 ns	0.01 ns
		3p	13.1	9.8	0.06	16.23			
	1/3/77	4p	7.3	4.6	0.17	17.59	3.01	1.55 ns	1.77 ns
		3p	7.6	5.1	0.16	6.26			

Table 17. Calculated monoculture yields and relative crowding coefficients for cumulative yields of the two cutting heights and the uncut controls

Cutting Height	Harvest Dates	Parameters of model used	Monoculture Yields M_G	Monoculture Yields M_N	Crowding Coefficients k_{GN}	Crowding Coefficients k_{NG}	Crowding Coefficients $k_{GN} x k_{NG}$	F Ratios 14:14 df between species variance	F Ratios 1:28 df between models
Low cut	3/1 - 4/2/77	4p	14.2	39.1	0.19	16.91	3.14	2.70*	
		3p	15.0	43.7	0.17	5.87			
	3/1 - 1/3/77	4p	19.2	43.3	0.19	14.69	2.85	3.22*	
		3p	20.2	48.2	0.18	5.61			
High cut	3/1 - 4/2/77	4p	17.9	38.3	0.13	15.04	1.92	1.42 ns	1.12 ns
		3p	18.3	40.5	0.12	8.12			
	3/1 -	4p	25.0	42.5	0.14	15.81	2.17	1.29 ns	2.01 ns
		3p	25.7	45.4	0.13	7.63			
Control	1/3/77	4p	126.7	83.3	0.12	16.39	1.93	5.03**	
		3p	129.6	87.7	0.11	8.79			

approximately ½, 1/3 and ¼ of that of Nui in the uncut, high cut and low cut treatments respectively. The relative crowding coefficients

Table 18. Calculated monoculture root dry matter yields and relative crowding coefficients for the two cutting heights and the uncut controls after 22 weeks.

Cutting Height	Parameter of Model used	Monoculture Yields		Relative Crowding Coefficients			F Ratios	
		M_G	M_N	k_{GN}	k_{NG}	$K_{GN} \times k_{NG}$	14:14 df between species variance	1:28 df between models
Low cut	4p	5.9	25,6	0.29	4.56	1.33	2.35ns	0.36ns
	3p	6.1	26.7	0.28	3.59			
High cut	4p	9.0	27.8	0.19	15.11	2.85	2.59*	
	3p	9.4	30.7	0.17	5.74			
Control	4p	33.3	69.3	0.12	18.75	2.26	1.37 ns	0.73 ns
	3p	34.0	73.8	0.12	8.54			

for the two species and the $k_{GN} \times k_{NG}$ products are all of the same order as with the shoot dry matter figures already discussed. The F ratio for between species variance was significant only in the case of the high cut treatment.

4.1.3.3 Total Plant Dry Matter

Figure 9 shows the dry matter yields as totals of shoots plus roots over the entire experimental period. The total dry matter production for the two cut treatments is seen to be less than with the uncut treatments. In the uncut controls both species produced the same dry matter yield while in the cut treatments Nui outyielded gorse. However, the gorse in mixtures was depressed more in the uncut controls than in the cut treatments. The relative crowding coefficients are shown in Table 19 and the values for gorse were higher in the two cut treatments than in the uncut control. By contrast the relative crowding coefficient for Nui seedlings was higher in the control than in the defoliated treatments. The products $k_{GN} \times k_{NG}$ were also higher in the cut treatments and the between species F ratio was significant with these treatments.

Table 19. Calculated monoculture yields of total plant dry matter (g/box) and relative crowding coefficients for the two cutting heights and the uncut controls

Cutting Height	Parameters of Models used	Monoculture Yields		Relative Crowding Coefficients			F Ratios	
		M_G	M_N	k_{GN}	k_{NG}	$k_{GN} \times k_{NG}$	14:14df between species variance	1:28df between models
Low cut	4p	31.8	74.2	0.27	8.76	2.39	7.02**	
	3p	34.0	83.3	0.24	4.11			
High cut	4p	46.7	81.6	0.33	10.95	3.66	18.08**	
	3p	51.5	97.2	0.28	3.59			
Control	4p	159.5	150.6	0.12	17.21	2.02	2.42 ns	0.96 ns
	3p	162.9	159.1	0.11	8.77			

4.1.3.4 Side Shoots/Tillers

Gorse and ryegrass have completely different growth patterns and as might be expected, Figure 10 shows that with cutting, fewer gorse side shoots are produced than tillers of Nui. Gorse shoots were increased by more severe or repeated cutting while there was little difference in tiller numbers of Nui between cutting heights or number of cuts. With ryegrass the uncut control produced the highest number of tillers but gorse seedlings did not produce side shoots without cutting. The greater ability of ryegrass to produce tillers is reflected in the higher values of the relative crowding coefficient (Table 20) but the difference between the species is less than in the coefficients based on dry matter yields. With gorse k_{GN} increased with repeated cutting in the low cut treatment while with Nui, k_{NG} decreased with repeated cutting at both cutting heights. The products of the relative crowding coefficients were close to 1.0 at both cutting

Table 20. Calculated monoculture tiller/side shoot numbers and relative crowding coefficients for the two cutting heights. Curves for the uncut controls were not calculated

Cutting Height	Sampling Dates	Parameter of Model used	Monoculture Yields		Relative Crowding Coefficients			F Ratio	
			M_G	M_N	k_{GN}	k_{NG}	$k_{GN} \times k_{NG}$	14:14 df between species variance	1:28 df between models
Low cut	3/2/77	4p	259.5	545.3	0.40	3.60	1.44	1.75 ns	2.64 ns
		3p	271.4	580.6	0.37	2.72			
	28/2/77	4p	422.8	593.8	0.50	2.85	1.42	1.12 ns	2.95 ns
		3p	444.2	633.4	0.45	2.21			
High cut	3/2/77	4p	205.1	558.0	0.44	3.05	1.34	1.49 ns	2.32 ns
		3p	213.7	587.8	0.41	2.45			
	28/2/77	4p	403.1	532.6	0.43	2.90	1.23	2.54*	
		3p	415.4	552.3	0.40	2.49			
Control	3/2/77-	-	81.6	578.0	-	-	-	-	-
	28/2/77	-	52.8	700.1	-	-	-	-	-

heights but the between species F ratio was significant for sampling period 2 of the high cut.

4.2 TRIAL 2

4.2.1 Seedling Development

In the second trial the growth of both species was slower in the absence of fertilizers than in the first trial. The stems of gorse seedlings did not start to elongate until more than 14 weeks after sowing. The growth pattern of Nui seedlings was similar to that in trial 1. However, by the time the experiment was concluded the grass seedlings in the unfertilized boxes had made relatively little growth (Plates 8 and 9).

The gorse seedlings were affected by a fungus disease in one box 10 weeks from sowing but the disease was controlled with benlate spray. Two weeks later, Nui seedlings in monocultures treated with P, NP, PK and NPK were developing a yellow colour. The persistence of this problem until the end of the trial was thought to be due to the depletion of N as a result of initial more vigorous growth in those boxes fertilized with P.

4.2.2 Effects of Fertilizers on Gorse and Nui Seedlings

The raw data for gorse and Nui seedlings in terms of shoot and root dry matter production, together with the gorse nodule counts and the Nui tiller numbers are given in Appendix 5. The data plus the shoot:root ratios and proportions of gorse in mixtures were the basis of the statistical calculations and summaries presented in tables 21-25.

The yield figures summarized in figure 11 show that both Nui and gorse seedlings were more productive in monoculture than in mixtures and that as in the first trial, the grass seedlings made considerably more growth than the gorse. It is also clear that with gorse the shoot dry matter was higher than the root dry matter, while with Nui a greater weight of root was produced than shoot. Of the fertilizers used, P, NP, PK and NPK significantly increased growth of both species in comparison with the control or the K, N and NK treatments. A detailed account of each species follows.

Plate 8. Growth in unfertilized controls.
Left - gorse monoculture middle -G.75N.25 mixture
Right - Nui monoculture

Plate 9. Growth with complete fertilizer treatment (NPK)
Left - Nui monoculture Middle - G.75N.25 mixture
Right - gorse monoculture

Figure 11. The effects of fertilizers and plant ratio on shoot and root dry weights of gorse and Nui seedlings (g/box).

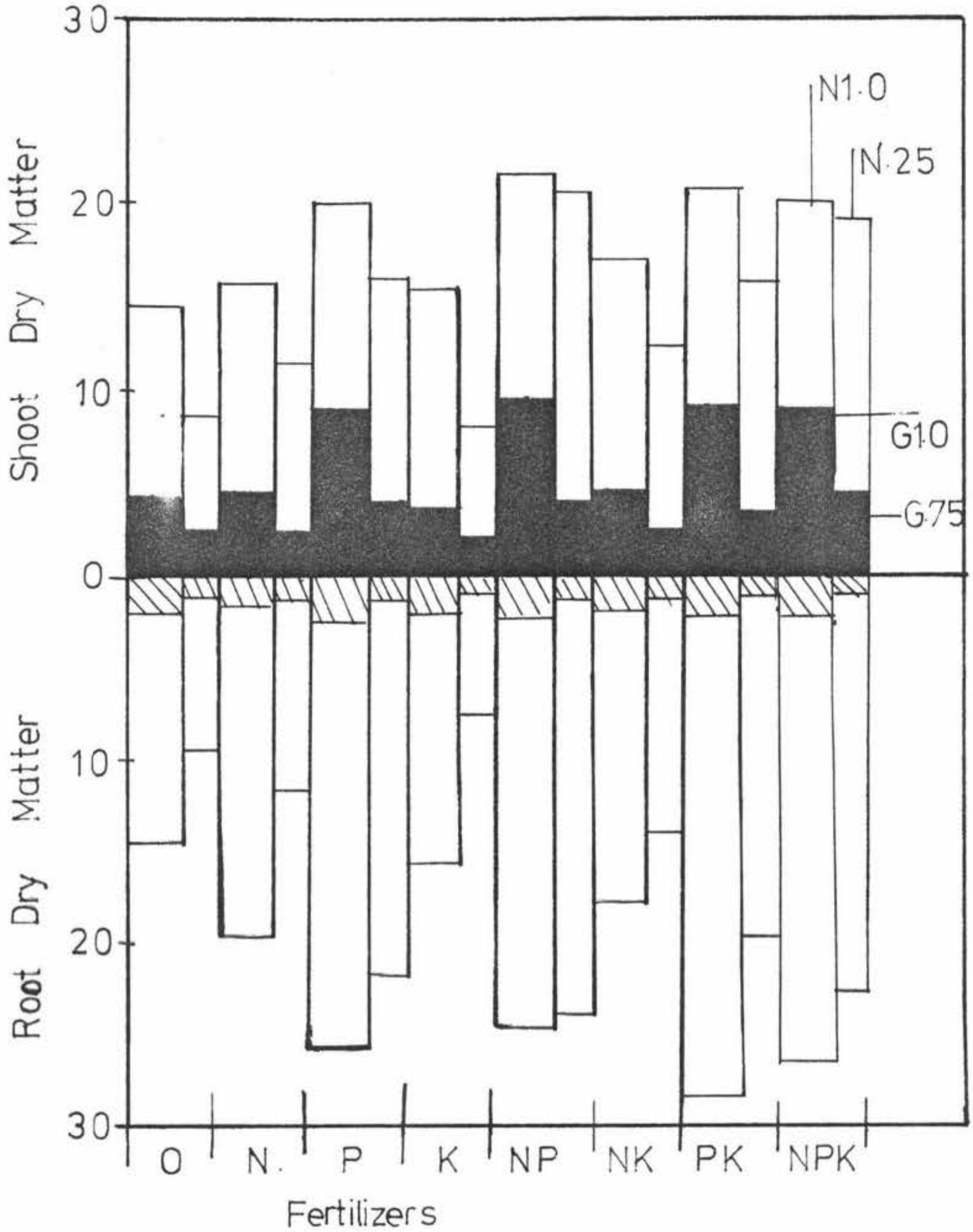


Table 21. Gorse. Mean dry matter yield (g/box) of shoot, root and total plant in monocultures and mixtures and shoot:root ratios when harvested 18 weeks after sowing

Fertilizer	Shoot DM			Root DM			Root + Shoot DM			Shoot:Root Ratio		
	Plant Ratios			Plant Ratios			Plant Ratios			Plant Ratios		
	G1.0	G.75N.25	Mean	G1.0	G.75N.25	Mean	G1.0	G.75N.25	Mean	G1.0	G.75N.25	Mean
Control	4.13	2.25	3.19	2.00	1.10	1.55	6.13	3.35	4.74	2.05	2.05	2.05
N	4.28	2.33	3.30	1.83	1.40	1.61	6.10	3.73	4.91	2.44	1.72	2.08
P	8.90	4.15	6.53	2.55	1.20	1.88	11.45	5.35	8.40	3.48	3.58	3.53
K	3.85	1.98	2.91	1.80	1.13	1.46	5.65	3.10	4.38	2.13	1.81	1.97
NP	9.30	4.05	6.68	2.25	1.15	1.70	11.55	5.20	8.36	4.15	3.57	3.86
NK	4.28	2.35	3.31	2.00	1.38	1.69	6.28	3.73	5.00	2.12	1.78	1.95
PK	9.05	3.55	6.43	2.15	1.13	1.64	11.20	4.93	8.06	4.36	3.38	3.87
NPK	9.15	4.18	6.81	2.38	1.05	1.71	11.53	5.53	8.53	3.89	4.24	4.29
Mean	6.62	3.17	4.89	2.12	1.19	1.65	8.73	4.36	6.55	3.14	2.76	2.95
CV%	16.8			19.2			15.3			16.3		
LSD 0.05 R	** 0.42			** 0.16			** 0.51			** 0.24		
LSD 0.05 F	** 0.83			ns			** 1.01			** 0.49		
R x F	**			*			**			ns		

4.2.2.1 Gorse Seedlings

Table 21 presents the gorse shoot, root and total plant dry matter weights and also the shoot:root ratios. It shows that significant differences between the plant ratios and fertilizer treatments occurred with all these measurements except for the roots in the case of fertilizers. There were also significant interactions except in the case of shoot:root ratios.

The shoot dry matter yield showed a large response significant at $P < 0.01$ to P alone or in combination with N, K or NK. Addition of N, K or NK without P, however, had no significant effect. The suppression of gorse seedlings by Nui in the ratio of one Nui to every three gorse was highly significant ($P < 0.01$). The average gorse yield in mixtures was less than half of that in monoculture. The significance ($P < 0.05$) of the plant ratio, fertilizer interaction was mainly due to the lower response to P in the mixtures than with gorse alone.

Table 22. Gorse. The effects of fertilizers and plant ratios on nodulation (nodules/plant)

Plant	Fertilizers									CV	LSD 0.05		
Ratios	Control	N	P	K	NP	NK	PK	NPK	Mean	%	R	F	RxF
G1.0	14.7	15.4	36.7	16.3	27.9	16.3	24.9	26.2	22.3				
G.75N25	11.8	11.0	15.7	10.6	14.8	12.2	16.9	17.3	13.8		**	**	**
Mean	13.3	13.2	26.2	13.3	21.3	14.3	20.9	21.8	18.0	18.2	1.6	3.3	

Fertilizer treatment had no significant effect on the root dry matter production of gorse. As with the shoots, the root dry matter of gorse in the mixtures was considerably less than in the monoculture ($P < 0.01$). The root growth in the mixtures was greatest in the boxes treated with N and NK and the interaction between plant ratio and fertilizers was significant at $P < 0.05$.

The effects of fertilizers on total plant dry matter followed closely the effects on the shoots and all P fertilizer treatments gave yields significantly greater than the controls or treatment with N, K and NK. Again, the total yield of gorse in monocultures was about double that in the mixtures containing one ryegrass to each three gorse seedlings. The R x F interaction observed ($P < 0.01$) was again largely due to the lower response to P in the mixtures than in monoculture.

The differences in shoot:root ratio were also significant ($P < 0.01$) both for plant ratio and fertilizer treatment but there was no significant interaction. The ratio was highest for treatments containing P showing that in the presence of this fertilizer there is less need for gorse plants to develop a large root. With the exception of the NPK treatment, the shoot:root ratio in the monocultures was higher than in the mixtures.

Table 22 shows the effects of fertilizers on gorse nodulation and it is clear that all treatments including P stimulated nodule production. Treatment with P alone resulted in the production of significantly more nodules than in the combination with N, K or NK. The lowest degree of nodulation occurred with the controls or treatments with N or K. The reduction in nodule numbers compared with monocultures was of the same order as the reduction in root growth. The R x F interaction for nodule numbers was significant at $P < 0.01$.

The proportion of gorse shoots, roots and total plant weights in the mixtures expressed as percentages of the total dry weights of gorse plus ryegrass is given in Table 23. It will be seen that the roots of gorse formed a very much lower proportion of the total than did the shoots. It is also clear that while fertilizer treatments had no significant effect on shoot proportions, there were significant differences in the proportions of root, the values being particularly low where fertilizers containing P were applied.

Table 23. Gorse. The yields of shoot, root and total plant in mixtures expressed as a percentage of total dry matter per box.

Plant Part	Fertilizers									CV %	LSD 0.05
	Control	N	P	K	NP	NK	PK	NPK	Mean		
Shoot	32.0	22.5	26.4	25.8	21.9	20.3	25.4	24.7	24.9	34.6	ns
Root	14.5	13.1	5.4	15.8	4.8	10.1	5.9	4.7	9.3	41.7	**5.7
Shoot + Root	22.8	17.6	14.2	20.8	12.2	14.6	14.3	13.5	16.3	32.3	ns

Table 24. Nui. Mean dry matter yield (g/box) of shoot, root and total plant in monocultures and mixtures and the shoot:root ratios when harvested 18 weeks after sowing

Fertilizers	Shoot			Root			Root + Shoot			Shoot:Root Ratio		
	Plant Ratios			Plant Ratios			Plant Ratios			Plant Ratios		
	N1.0	G.75N.25	Mean	N1.0	G.75N.25	Mean	N1.0	G.75N.25	Mean	N1.0	G.75N.25	Mean
Control	14.6	8.5	11.5	14.4	9.4	11.9	29.0	17.8	23.4	1.03	0.92	0.98
N	15.6	11.3	13.2	19.5	11.5	15.5	34.6	22.8	28.7	0.79	0.97	0.88
P	20.0	15.9	18.0	25.4	21.7	23.5	45.4	35.6	41.5	0.79	0.73	0.76
K	15.3	8.0	11.6	15.7	7.6	11.7	30.9	15.6	23.3	0.96	1.12	1.04
NP	21.3	20.5	20.9	24.6	23.9	22.3	46.0	44.4	45.2	0.87	0.84	0.86
NK	17.1	12.2	14.6	17.7	14.1	15.9	34.8	26.3	30.5	0.97	0.86	0.92
PK	20.6	15.8	18.2	28.2	19.4	23.8	48.9	35.1	42.0	0.73	0.81	0.77
NPK	19.9	19.2	19.5	26.3	22.7	24.5	48.8	41.8	44.0	0.77	0.83	0.80
mean	18.0	13.9	16.0	21.5	16.3	18.9	39.5	30.2	34.8	0.86	0.88	0.87
CV%			22.4			18.9			11.4			18.3
LSD 0.05 R		**	1.8		**	2.0		**	2.5		ns	
LSD 0.05 F		**	3.6		**	3.6		**	5.1		**	0.16
R x F		ns			ns			ns			ns	

4.2.2.2 "Grasslands Nui" Perennial Ryegrass Seedling

The mean shoot, root and total plant dry weights of Nui and the shoot:root ratios are given in Table 24. It will be seen that the differences between fertilizer treatments and plant ratios were highly significant, but that there was no R x F interaction.

All fertilizer treatments containing P increased the dry matter of shoots and roots though the increase was proportionately less than in the case of gorse. The root weights were higher than the weights of shoots with all treatments except the unfertilized controls and application of K alone. Although N without P did not significantly increase the weights of shoot or root alone there was a significant increase in the total root + shoot weights both with N and NK. Thus the shoot:root ratio in most cases was less than 1.0. The root dry matter weights were considerably increased by all treatments containing P and this led to lower shoot:root ratios with these treatments. In the mixtures, the dry weights of ryegrass were reduced in proportion to the plant number but there were no differences in the shoot:root ratio.

The numbers of tillers produced by Nui seedlings were recorded 4 weeks after sowing and at later intervals. The response to fertilizers after 18 weeks is shown in Table 25. With all treatments receiving P, the numbers were significantly higher than the control or

Table 25. Nui. The effects of fertilizers and plant ratios on tiller production 18 weeks after sowing (no/box).

Plant	Fertilizers									CV	LSD 0.05		
Ratios	Control	N	P	K	NP	NK	PK	NPK	Mean	%	R	F	RxF
N1.0	306	320	356	272	394	318	428	440	355				
N.25G.75	158	165	221	160	255	189	216	253	202		**	**	ns
Mean	232	243	289	216	325	254	322	347	278	15.1	21	42	

the N, K and NK treatments ($P < 0.01$) and the complete fertilizer, NPK, resulted in the production of more tillers than P alone. In the mixtures the tiller numbers were considerably less than in the monocultures. However, the numbers of tillers per plant were higher in the mixtures. There was no interaction between fertilizers and plant ratio.

5 DISCUSSION

The operation of preparing a seedbed for pasture establishment provides appropriate conditions for the breaking of dormancy, the germination and establishment of the weed seed population in the soil. Thus pasture species introduced after desiccation of the resident vegetation may be subject to competition both from regrowth of the resident species and from other weeds which may not have been evident initially. In this situation the competitive interactions between the pasture seedlings and two or more weed species may be very complex. It is difficult to deduce which species is dominant at any one time and how seriously pasture establishment will be affected by weeds. In the present studies to confine the competitive interaction to the two test species, it was important to minimize the effects from weeds and other variable factors.

In the early stages of the experiments weed seeds in the soil germinated and emerged with the sown species. These weeds were removed by hand as they emerged so that their influence was minimal. Of the other factors, water was maintained at an adequate level throughout the experiments. At the beginning of trial 1, a generous fertilizer treatment was applied and in trial 2, fertilizer levels were adjusted in accordance with the experimental treatments. Light varied with the seasons and may have been a limiting factor for growth especially in trial 2 which was conducted during autumn and winter.

The results of the two trials will be discussed in relation to the early growth and development of the two species and the effects of defoliation and fertilizers when the species were growing either in mixtures or monocultures.

5.1 EARLY GROWTH AND DEVELOPMENT

After emergence, the growth rate of the gorse seedlings was very slow compared with Nui seedlings in both trials. Because of their rapid growth rate the Nui seedlings were the more aggressive especially with the growth of tillers which rapidly covered the soil surface and caused shading. The monoculture of Nui was more efficient than the gorse monoculture or the G.75 N.25 mixture in producing a dense ground cover which prevented the establishment of weed seedlings. At the same time gorse seedlings in mixtures were shaded by the grass while they were at the cotyledon stage. Due to this initial advantage, Nui seedlings gradually became increasingly dominant. A similar relationship has been demonstrated with persicaria *(Polygonum persicaria)* growing in association with barley, where the faster initial growth of the barley enabled it to suppress the persicaria (Aspinall and Milthorpe 1959). Similarly, Harris *et al.* (1977) showed that under field conditions in New Zealand, ryegrass reduced the growth of annual weeds to 5% of their potential because of its higher growth rate. In Australia, Michael (1970) reports that St. John's wort (*Hypericum perforatum* var. *angustifolium* D.C.), serrated tussock *(Nassella trichotoma)*, skeleton weed *(Chondrilla juncea)*, lantana (*Lantana camara* sens. lat.) and many other weeds can be suppressed by pasture grasses and legumes.

In the shade produced by the Nui shoot system the gorse seedlings did not respond to the shading effect by rapid growth towards the light. The slow growth rate of gorse seedlings in the early stages is thought to be an adaptation of woodland species resulting from a slow metabolic rate. Grime (1966) demonstrated the slow respiratory rate of woodland species with a number of tree seedlings. With gorse seedlings the response to shading was limited to an inhibition of cell extension due to the reduced metabolism (Grime 1965). Thus the gorse seedlings in mixtures remained under low light intensity conditions until a higher growth rate started three months after sowing. Gorse seedlings in mixtures later became very etiolated as they grew to reach the top of the Nui shoot system. Uncut gorse seedlings by themselves were considerably more robust and slightly taller than in mixtures. The growth patterns observed were typical of those reported by Rolston and Sineiro-Garcia (1974) who found that shaded and unshaded seedlings of similar age did not differ significantly in height. The increase in gorse growth rate after three months in trial 1 may have been due to the seedlings passing from the juvenile to the young adult stage. In the young adult stage Millener (1961) suggests that gorse seedlings are less susceptible to inhibition by low light intensity than in the juvenile stage.

In trial 1, no gorse died as a result of shading by Nui seedlings in the mixtures. However, in trial 2, some gorse plants in mixtures appeared to die from a fungus disease which was probably encouraged by shading from the grass. Similar cases of death of gorse seedlings have been reported by Hutchinson (1967) and Thompson (1974). Experimental evidence with tree seedlings by Grime and Jeffrey (1965) and Grime (1966) suggest that shade tolerant species are less susceptible to infection than shade intolerant seedlings both above and below the compensation point of light.

The slow growth rate observed for gorse seedlings in spite of the relatively large seed size is contrary to the theory that large seeds have an advantage in terms of emergence and seedling vigour in comparison with smaller seeds (Black 1959). Black found that stands of subterranean clover derived from large seeds in mixtures of plants from both large and small seeds had larger cotyledons and maintained their superiority over plants from the small seeds for 11-12 weeks after sowing. At this stage 97% of the incident light was being intercepted by plants derived from large seeds and less than 3% by the suppressed plants from small seeds. The advantages of large seeds are more apparent with annual species than with perennial tree seeds. The main advantage of large seeds in tree species is that the seedlings appear to survive better in the shade, presumably because of the larger supply of food reserves (Salisbury 1942). Hutchinson (1967) has reported that gorse seedlings persist longer in the dark than other species with smaller seeds. However, Bieniek and Millington (1968) reported a 50% death rate for gorse seedlings when a low light intensity was coupled with a short-day length.

The growth rate of gorse seedlings in the present work was slower in autumn and winter than in spring and summer which is in agreement with observations by Millener (1961), and Hutchinson (1967). Among others, Ivens (1977) observed that under glasshouse conditions, seeds sown in winter took about 12 weeks to reach the 6-10 leaf stage, the period being reduced to 6 weeks when seed was sown in the summer.

Formation of thorns was observed about 14 weeks after sowing in trial 1 but there was no sign of thorn formation 18 weeks from sowing in trial 2. It was also observed in trial 1, that thorn formation was slightly delayed in mixtures as a result of shading by the grass seedlings. The findings in these trials support other observations that both shading (Rolston and Sineiro-Garcia 1974) and short-day length (Millener 1961; Bieniek and Millington 1967, 1968; Duncan 1971) delay the formation of thorns. The delay in thorn formation would be expected to result in seedlings remaining soft and readily grazed by animals for longer periods. Thus it would be expected that it would be easier to control gorse seedlings after sowing pastures in autumn than in spring, as the seedlings do not become thorny until the following spring or summer. Gorse seedlings germinating in the spring develop thorns during summer or autumn when newly establishing pasture species may be less competitive due to dry soil conditions.

In the absence of cutting, suppression of the growth of gorse seedlings by Nui continued until the grass reached maturity or until the gorse seedlings broke through the Nui shoot canopy. The moment this occurred, competition for light became much less important and the gorse seedlings started to produce side shoots and thorns from the upper buds at a rapid rate. Thereafter the shoot system of the gorse started to shade the ryegrass which is what happens in the field when gorse infested pastures are allowed to revert. Similar growth patterns have been reported by Aspinall and Milthorpe (1959) with a persicaria-barley association. The proportion of depressed persicaria in the mixture increased as the more competitive barley matured. A similar explanation has been advanced by Clatworthy (1960) to explain the persistence of the less vigorous but late maturing *Trifolium fragiferum* when associated with *T. repens*.

Because of the fact that gorse cannot be controlled by pasture competition alone, defoliation or cutting of some sort is also necessary to reinforce the effects of competition. Lynch (1973) warns that unless the stocking pressure is raised above the equivalent of about 8 sheep per hectare, reversion to gorse is inevitable. Such reversion occurred on a large scale in New Zealand in the 1930s following the abandonment of large areas of marginal hill country.

At the beginning of trial 1 and during the whole growing period for Trial 2, it is probable that competition for light was the main factor limiting the growth of gorse. This is in accordance with the findings of Donald (1951, 1963) and Blackman and Black (1959) that if water and nutrients are adequate, light will become the limiting factor controlling the growth of *Helianthus annuus*.

5.2 EFFECTS OF DEFOLIATION

5.2.1 Shoot Dry Matter

The shoot dry matter weights for the three harvest periods in the cutting trial, and the cumulative yields for gorse and Nui are shown in Tables 3 and 9 respectively. Nui seedlings reacted in a totally different manner from gorse to the competitive situation as influenced by defoliation and plant ratio. Although gorse was suppressed by cutting, especially in the mixtures, the ratio of gorse increased with time due to a greater decrease in the growth of Nui (Table 14).

At the first harvest, the dry matter yield of gorse was higher in the low cut treatment but for the subsequent harvests the yields were higher with higher cutting. At the low cutting height the higher yield resulted from increased growth after the initial cut at 2 cm during the tenth week after sowing. With the high cut treatment on the other hand most gorse shoots were still below the 4 cm cutting height and the majority of the shoots were not cut. The greater dry weight increase after the first harvest with the higher compared with the lower cutting height demonstrates the importance of the residual photosynthetic surface area. In the gorse monoculture the dry weight increase in harvest period 2 with the high cut treatment was almost double that of the low cut treatment. However, in mixtures with ryegrass the residual leaf area was less important, presumably because of shading by the grass immediately after defoliation. The decrease of gorse in the final harvest period could be explained by the combined effects of shading and intensity of defoliation.

The total shoot dry weight of uncut gorse was considerably higher than the total production in the defoliated treatments and in the uncut controls the effects of shading were greater with the mixtures than with the gorse monoculture (Tables 4 and 5).

Gorse seedlings normally have an erect habit of growth and in the defoliated plants, the majority of the photosynthetic tissues were removed at each successive cutting. Recovery from cutting was slow but no gorse seedlings died because many buds capable of regenerating were situated below the cutting height. In mixtures, defoliation was of benefit to the gorse due to the removal of the shade produced by the grass leaves. The greater shading in the uncut controls was presumably the reason for the greater reduction of gorse growth in mixtures. Shading may be more important than defoliation in suppressing gorse during the early stages of development. If the gorse seedling grows above the canopy of pasture plants, however, competition from the pasture species cannot prevent the continued growth of the gorse. Rolston and Sineiro-Garcia (1974) also found that defoliation at varying heights reduced the dry weights of gorse. Thompson (1974) obtained greater suppression of gorse when he introduced pasture species which provided increased competition through shading after defoliation.

The results suggest that the effects of varying intensity of defoliation are related to the residual leaf area. This emphasizes the important role of the stubble in determining the rate and degree of recovery of gorse after cutting and in this respect gorse does not differ from plants such as lucerne (Langer & Steinke 1965; Langer & Keoghan 1970), subterranean clover (Davidson & Donald 1958) and *Dactylis glomerata* L. (Davidson & Milthorpe 1966). More severely defoliated plants have been found to start regrowth more slowly after cutting because of the reduced food reserves which, as shown by Davidson & Milthorpe (1966) and Brown *et al.* (1968), may be present in the stems, leaves and roots of pasture plants.

The growth of Nui between cuts decreased with time and no differences were observed between cutting heights or between plant ratios except in harvest period 1 (Table 9). The total shoot growth on the other hand differed significantly between plant ratios and cutting heights as shown in Table 10. It was only at the lowest ratio of one Nui plant to three gorse however, that the total shoot growth of Nui was significantly reduced. The decreased growth of Nui between cuts with time resulted in lower total shoot weights of all defoliated treatments compared with the uncut controls. This was probably due to reduced nutrient uptake as a result of defoliation.

The cutting method used in trial 1 involved raising the tillers to a vertical position and cutting them to an even height. This method may have caused more severe defoliation than either mowing or grazing where tillers growing at an angle would be cut a greater distance from the base. The effects of defoliation are to reduce the amount of photosynthetic tissue for light interception (Brougham 1956, 1957), to reduce the reserves of carbohydrate, proteins and other materials available for growth or for respiration when photosynthesis is restricted (Davidson and Milthorpe 1966). Defoliation also results in large decreases in the rates of root extension and uptake of nutrients (Davidson and Milthorpe 1966).

The long period of growth which took place in trial 1 without replenishing the nutrients, together with the removal of nutrients by defoliation and the restricted root volume in the boxes may have resulted in the exhaustion of the supply of available nutrients. Under these conditions Nui was more competitive during the early stages of growth, as has also been shown in studies on ryegrass by Harris (1971, 1973) and Remison and Snaydon (1978). Defoliation during the period when reproductive tillers were developing 14-18 weeks after sowing must have had a greater effect on the competitive ability of Nui than earlier defoliation. This would be in accordance with reports by Rhodes (1968a, 1968b) and Whittington and O'Brien (1968) that the production of reproductive tillers in various grasses coincides with a decline in competitive ability, probably because the growth of roots and the uptake of nutrients declines (Troughton 1957).

5.2.2 Root Dry Matter

In addition to its functions of anchorage and absorption of water and nutrients the root system is also important in providing the food materials needed for growth after cutting before sufficient photosynthetic surface has developed.

In the present work defoliation has been found to reduce root growth, more so with gorse than Nui seedlings (Tables 4 and 9). Repeated cutting weakened gorse and led to a loss in shoot weight and eventually also in the root weight. Roots in the defoliated treatments were short and poorly developed and there was little nodule development. By contrast, the roots in the uncut control monoculture were numerous, the primary root well developed and numerous pink healthy nodules were present. The effects of hard defoliation on the growth of roots has also been demonstrated by Rolston and Sineiro-Garcia (1974) for gorse seedlings and by Brougham (1956), Davidson and Donald (1958) and Langer and Steinke (1965) for pasture legumes and grasses. Langer and Keoghan (1970) have also shown that removal of half or all the residual leaf area of lucerne resulted in a decline in root weight and a low or negative growth of the entire plant.

With a smaller root system it is probable that defoliation would reduce the drought resistance of gorse and that pasture species would also be less competitive for the same reason (Brougham 1970). Measures taken to control gorse seedlings should therefore include removal of as much of the shoot system as possible in order to weaken the root system. This could be expected to delay recovery and the plants would be further retarded by being shaded by the pasture species. Under field conditions a considerable degree of shading would be expected once the pasture was established because ryegrass recovers quickly after cutting, except when it is beginning to flower as was the case in the present experiment. At other seasons, many basal leaves and the growing points of the tillers are unaffected by cutting and regrowth is immediate.

The low root dry matter weights of gorse in mixtures may have been due to the greater growth of Nui roots especially in the G.25N.75 and G.50N.50 mixtures where root growth was greater than in the monocultures. It was apparent when washing out the root systems that the Nui roots were evenly spread. The greater growth of Nui both above and below soil level suggests that the gorse plants were subjected to competition both from the roots and shoots.

5.2.3 Total Plant Dry Matter

The overall effects of cutting height and plant ratio are most clearly shown by the total plant dry weights given in Tables 4, 5 and 9. The effects were broadly similar to those shown by the shoot and root weights already discussed. Because of the slow growth of gorse during the juvenile stage, it was suppressed in mixture with Nui especially in the uncut boxes. The total weight of individual seedlings was reduced from 3.33 g in the monoculture to 0.98, 0.56 and 0.54 g in G.75N.25, G.50N.50 and G.25N.75 respectively. The greater growth in the uncut controls shows that during the early development stage, gorse growing in association with Nui was more affected than at later stages due to competition for light as a result of shading. It is clear that although competition from pasture species reduces the growth of gorse,this factor alone cannot control gorse because once the plants grow above the level of the pasture sward they branch out, become dense and thorny and eventually dominate the pasture. More effective control measures can be based on the maintenance of a competitive pasture together with severe defoliation at intervals by rotational mob-stocking which has additional pulling and treading effects. Advantage may also be taken of the different grazing behaviour of different types of stock. Suckling (1964) using sheep and cattle and Thorp (1975) using sheep, cattle and goats in rotation reported better control of brush species than from a single type of stock. If the combination of pasture competition and defoliation by grazing proves inadequate it may become necessary to use mechanical control and herbicides in addition.

5.2.4 Shoot:Root Ratio

In the present trials, the shoot:root ratios for both gorse and Nui seedlings were greater than 1.0 and, with cutting, the values were significantly increased as shown in Tables 6 and 11. With gorse, the ratio was higher in mixtures than in monocultures, but with Nui this situation was reversed. It is likely that the root development of gorse seedlings in mixtures was restricted by intense competition from the Nui shoot and root systems. The Nui seedlings utilised the great majority of the soil volume in mixtures as a result of their rapid growth and the gorse roots were crowded out. The increase of shoot:root ratio with defoliation has also been reported by Rolston and Sineiro-Garcia (1974) in gorse cuttings.

The relatively greater depression of the root growth of gorse than of Nui by cutting or competition means that gorse affected by defoliation is more liable to suffer from drought or pulling and treading by grazing animals than ryegrass. Pulling and treading would be likely to be of importance because, with defoliation the gorse root system was poorly developed and mostly concentrated near the soil surface.

5.2.5 Nodule Counts

In spite of the variability of the gorse root nodule data, cutting or growing in mixture with ryegrass were shown to cause a significant reduction in nodulation. Not only were the numbers of nodules reduced with decreasing gorse density but with increasing density of ryegrass plants the number of nodules per individual gorse plant was also reduced. This was presumably due to reduction in the root system of gorse as a result of shading but defoliation also reduced nodulation in gorse plants growing alone. The greater reduction of nodule number in the uncut compared with the defoliated mixtures, may indicate that shading is more important than defoliation. Pritchett and Nelson (1951) obtained similar results by shading lucerne seedlings.

5.2.6 Side Shoots/Tillers

Defoliation stimulated gorse side shoot production. As shown im Table 8, the low cut stimulated a greater amount of branching but the shoots tended to be weak and small and consequently led to low dry matter production. At both cutting heights the side shoots were distributed over the entire length of the residual stems, possibly associated with the fact that cutting removed all leaves and left only base stem. The large number of potential sites available to produce side shoots with both cutting heights is shown by the increase in shoot numbers between the two sampling periods. However, as would be expected, the larger the number of Nui seedlings present in the mixtures, the smaller was the side shoot number. Similar effects have been reported by Rolston and Sineiro-Garcia (1974) who found that both light and defoliation were important for the production of side shoots in gorse. Under hard defoliation, their gorse cuttings reacted by producing shoots with a prostrate habit, a feature which was not confirmed in this trial, probably because of closer crowding of the plants.

Uncut Nui plants produced more tillers than in the cut treatments. At the low cutting height the number of tillers was maintained between cuts, while with the high cut trreatment there was a slight drop in tiller number over the two sampling periods (Tables 12 & 13).

As previously mentioned the technique whereby tillers were lifted upright for cutting probably increased the severity of defoliation and may have caused the death of reproductive tillers being formed at the time. The small number of tillers especially at the higher cutting level was probably a competitive effect due to shading at the base of the weakened plants preventing tiller formation.

Many workers, including Brougham (1957) and Davies (1974) found that defoliation of pasture grasses affects the rate of tiller production more than any other factor, either causing an increase or a drecrease depending on the conditions. In the field, close defoliation has been reported to increase tiller density in sheep pastures, while lax grazing management of dairy pastures results in fewer tillers per unit area (Mitchell and Glenday 1958). In the present work it is difficult to interpret the high tiller numbers in the uncut control boxes where a high level of intraspecific competition for light must have been operating.

Nui in association with gorse produced more tillers than in monoculture. The large number of tillers per plant demonstrates the ability of Nui to spread rapidly into spaces not occupied by gorse. The spread of Nui tillers was apparently unaffected by the gorse seedlings so that the grass behaved very much like a single species sown at varying densities as studied by Yoda *et al.* (1963) and Kays and Harper (1974). In Kays and Harper's work perennial ryegrass was sown at densities of 320, 1,000, 3,200 and 10,000/m^2 and a similar differential multiplication of tillers was found, the plants at the lowest density producing more tillers (23 per plant) than those at the highest density (2 per plant).

The shading effect of the Nui tillers on gorse seedlings in the present trial was demonstrated by the absence of side shoots in the uncut control boxes and by the reduced shoot growth in both the cut and uncut mixtures. Similar effects have been noted by Narrington-Davies (1968) and Crocker and Martin (1964) in associations of the aggressive perennial ryegrass with other pasture grasses. In both series of trials, the suppressed species in the mixture suffered from a reduced capacity to exploit water and nutrients (Donald 1958).

5.2.7 Competitive Indices

Nui seedlings grew faster than gorse from the earliest stages of growth (see Table 16) and the grass shoot system was already shading the gorse seedlings before defoliation started. Thus in the mixtures the grass soon became dominant as a result of its faster growth and earlier shade-producing ability. The higher yield of Nui in the mixtures compared with the monocultures suggests that nitrogen fixed by rhizobia in the gorse root nodules was being made available to the Nui in addition to the original store of nitrogen in the soil. As has been shown by de Wit *et al.* (1966), grasses and legumes are mutually exclusive in the absence of rhizobia, i.e. the product of their relative crowding coefficients does not differ significantly from 1.0. The results suggest that the Nui obtained a more plentiful supply of nitrogen in the mixtures, presumably as a result of rhizobial activity in the gorse root nodules.

In the monocultures, the dominance of gorse in harvest period 3 at the low cutting height and in harvest periods 2 and 3 at the higher cutting height was due to an increased photosynthetic surface area resulting from side shoot production. The relative crowding coefficients did not present any consistent change. In mixtures, on the other hand, the gorse seedlings were shaded by the grass from the second week after defoliation onwards due to the rapid extension of the grass leaves after cutting. The significant between species F ratio at the lower cutting height in harvest period 3 suggests that, gorse suffered both from the effects of shading and defoliation. On the other hand Nui suffered more than gorse from the effects of defoliation which impaired its ability to extract soil N as indicated by low shoot dry weights in mixtures compared with the monoculture.

The root dry matter production of both species decreased with increasing intensity of defoliation as shown in Table 18. The relative crowding coefficient based on root growth for Nui increased and that of gorse decreased with increasing intensity of defoliation. The figures may be interpreted as suggesting that the root system of Nui was depressed primarily by defoliation due to the reduced root growth and nutrient uptake associated with the onset of flower development. By contrast gorse suffered more from shading. With both species, however, severe defoliation restricted root growth more than shoot growth, resulting in an increased shoot:root ratio and a shallower rooting system. Similar effects resulting from defoliation have been reported by Jantii and Kramer (1956), Brougham (1970) and Langer and Keoghan (1970) for pasture species. The present results suggest that the size of the root system is the most important factor involved in competition.

The overall effect of defoliation is best demonstrated by the total plant weight figures given in Table 19. The weights of Nui were higher in some of the mixtures than in monocultures both with the uncut controls and with the defoliated treatments. This suggests that the grass benefited from nitrogen fixed in the root nodules of gorse as discussed earlier in the section on shoot dry weights.

The product of the relative crowding coefficients based on tiller and side shoot numbers showed a tendency to decrease with time (Table 20) suggesting that with repeated cutting, Nui was becoming less vigorous in comparison with gorse. The strongly competitive nature of Nui was shown by the high $k_N G$ value but this decreased with repeated cutting. With gorse the increase of k_{NG} with time shows that repeated defoliation increased the numbers of side shoots, presumably by improving the light conditions, though the shoots remained small and weak. The reduced production of side shoots in mixtures again points to the importance of shading by a dense competitive pasture in suppressing gorse under field conditions.

The effects of competition and defoliation reported in this trial are likely to be modified in the field. In the trial Nui became less productive with time because of the limited soil volume in the boxes and this may have been the main reason why it entered the reproductive phase early. Under field conditions it is probable that 4-weekly defoliation at the heights recommended for ryegrass/clover pastures by Brougham (1970) would be more favourable to Nui especially if the grazing animal is involved. In this case the grass is also favoured by the associated nutrient cycling. The treading and pulling effects of grazing animals similarly have more adverse effects on gorse than on Nui. The present results also suggest that the use of nitrogenous fertilizers would favour Nui at the expense of gorse.

The relative crowding coefficients give an indication of the intensity of competition taking place. The relative crowding coefficient was consistently lower than 1.0 for gorse and higher than 1.0 for Nui. The products k_{GN} x k_{NG} were generally above 1.0 which can be interpreted as indicating that the two species competed for different space and tended to interact to their mutual benefit. The stimulation of grass by gorse nodules is unlikely to help in suppressing gorse. Under field conditions, in the absence of clovers (Sears 1953), it would be better to supply fertilizer as a source of N.

Over all the 21 parameters analysed, in 10 cases there were significant differences either between the species or models. As Thomas (1970) points out, a significant between species F ratio can be interpreted as an indication of a fundamental difference between species. A significant between models F ratio can also be regarded as indicating that the species do not compete for the same space. Thus the differences between species and models in the present work provide an additional suggestion that gorse and Nui compete for different space.

Referring to the total plant dry weights shown in Table 19, the most probable explanation is that defoliation regimes resulted in greater competitive interference between species than in the uncut controls. The findings of King (1971), Snaydon (1972) and Eagles (1972) suggest that in the early stages of growth competition between roots is more important than between shoots and, as moisture was not limiting in the present trials, it is likely that nutrients were the main limiting factor involved in competition. It can be assumed that soil nutrients would be potentially available to both species but that, depending on the competitive uptake abilities, their rates of root elongation and the number, size and efficiency of their roots, different quantities of nutrients would be taken up by the two species. For this reason the use of a fast growing grass like Nui ryegrass can act to suppress weed species in the early phases of pasture establishment.

5.3 EFFECTS OF FERTILIZERS

5.3.1 Dry Matter Yield

In the second trial the growth of gorse was again less than that of Nui as shown in Tables 21 and 24 and Figure 11. The growth rate of both species was slower than in trial 1 probably because of the shorter day length as discussed in section 5.1. In the unfertilized controls the growth rate was particularly low. The effects of the various nutrients were as follows:

5.3.1.1 Nitrogen

Gorse showed no response to the level of nitrogen applied either in shoot or root growth. A similar lack of response has been reported by Thompson (1974) both for seedlings and mature plants. Application of nitrogen appeared to reduce nodulation and presumably also reduced nitrogen fixation. Similar behaviour has been reported for clover by Walker *et al.* (1956) who found that with increasing levels of nitrogen fertilizer, clover took up more of the applied nitrogen and fixed less.

In contrast the dry weights of Nui increased both in monocultures and mixtures. Work on nitrogenous fertilizers reviewed by During (1972) has shown that in the presence of this element, grasses are more competitive than associated legumes. According to Nye (1968) the intensity of competition increases as the degree of overlap of the root feeding zones increases. The extent of the area from which the roots can absorb nutrients is influenced by the mobility of the nutrient ions and by the rate of extension of the roots. For a mobile nutrient like nitrogen, Nye found that the feeding volume is quite extensive and overlap may occur quickly.

5.3.1.2 Potassium

Neither species responded to application of potassium either by increased height or dry matter production and it must be concluded that the level of this element in the soil was adequate (see section 3.1.3). The lack of response to K by gorse has also been reported by Thompson (1974). In the presence of adequate nitrogen, grasses are reported to be stronger competitors for K than legumes (Blaser and Brady 1950; During 1972) and it seems probable that the poor response of Nui in the present trial may have been due to a shortage of Nitrogen.

5.3.1.3 NK.

The addition of K to N did not increase the effect of the latter. The growth of gorse with this combination was not significantly greater than the control while the increase in the growth of Nui was not significantly different from that produced by N alone.

5.3.1.4 P-based Fertilizers

The soil used was deficient in P (see section 3.1.3) and there was a strong response to all the P-based fertilizers applied by both shoot and root growth of gorse and ryegrass. Similar responses with gorse have been reported by Feist (1956), Egunjobi (1967), Knight (1968), Wilson (1968) and Thompson (1974). Large amounts of superphosphate are normally applied in the development of pasture after clearing gorse infested hill country in order to encourage the clovers. This fertilizer treatment is also likely to encourage the growth of gorse seedlings but encourages ryegrass to a greater extent (White 1973b; Matthews 1975, 1976). In the present experiment the lower response to P by gorse in mixtures could be due to the competitive aspects related to nutrient uptake and shading.

Work on competition for nutrients, such as that reported by Donald (1963), has shown that grasses are stronger competitors than clovers for P and other nutrients. It is because of this competition, that, sufficient P had to be supplied to meet the demands of the grass before the needs of gorse could be satisfied. Consideration of the mean dry weights of individual Nui seedlings in mixtures, suggests that the plants were able to take up larger amounts of the available nutrients than those plants in monoculture. This could provide an explanation of why the growth of Nui in monocultures was depressed four weeks before the trial was terminated.

The nature of interspecific root competition has been discussed by Nye (1968). Observations under field conditions have shown that the feeding zone for soil P is relatively small as this nutrient is less mobile than nitrogen. Thus the overlapping of feeding zones may not take place very quickly. The fact that in mixtures gorse roots were reduced in the presence of P-based fertilizers, supports the suggestion that gorse root growth was depressed by the shading effect of the Nui shoot system so that its nutrient uptake was impaired.

In experiments where the effects of competition above and below ground have been separated it has been found that the effects of root competition are greater in young plants than competition between shoots (Donald 1958; Rhodes 1968b; Snaydon 1971; Remison and Snaydon 1978). In the present work where moisture was not limiting, root competition must have been mainly for nutrients. As shown in Table 23, the gorse root dry matter production expressed as a proportion of the total of both species in mixtures was only 6% in P-treated boxes when compared with 15% in the unfertilized controls. Similar figures for gorse shoots were 25% with P and 32% without. Addition of P fertilizer to the mixtures had no significant effect on the proportions of the shoot weights of the two species (see Table 23).

The adaptability of gorse to low soil fertility has been indicated here by its greater root proportion in unfertilized soil when compared with that in soil treated with P-based fertilizers. This explains the ease with which gorse becomes established in low fertility areas where the pasture species are relatively uncompetitive. Ryegrass, however, is strongly competitive under field conditions where the soil fertility is high (Harris 1971).

The shoot:root ratio was higher for gorse seedlings than for Nui and with gorse the ratio was higher in monocultures than in mixtures. The lower ratio with gorse in mixtures where Nui produced relatively little shoot dry matter indicates that the grass did not cause enough shading to depress gorse root growth. At the same time, the low root yields of Nui in these treatments suggest that there was relatively little root competition. However, the large amounts of Nui root dry matter in mixtures where P-based fertilizers were used (shown by the lower shoot:root ratios) suggests that gorse root growth was depressed as a result of a shading effect by the grass shoot system.

5.3.2 Nodule Numbers

In the absence of ryegrass gorse seedlings produced more nodules than in mixtures (Table 22). The higher the level of Nui shoot dry matter production in mixtures the lower the number of nodules produced. Of all the fertilizers used, the lowest number of nodules were produced with N, K and NK which did not differ significantly from the control.

P-based fertilizers gave the greatest response of total plant dry matter and in monoculture resulted in production of most nodules. In mixtures, however, nodule production was less than with other fertilizers because shading by the grass reduced the size of the gorse root system. Thompson (1974) also found that application of nitrogen completely inhibited nodulation of gorse seedlings and greatly reduced the size and number of nodules in mature gorse.

Nitrogen fixation by the rhizobia associated with gorse seems to be vigorous. Working on a gorse site near Wellington, Egunjobi (1969) estimated that nitrogen was accumulated at a rate of 100-200 kg/ha/annum during the first years of rapid dry matter accumulation. Because of its nitrogen fixing ability it is not surprising to find gorse thriving well in low fertility conditions (Anon 1958; Pate 1961; Grubb *et al.* 1969). However, cases have been reported where the growth of gorse was reduced due to a failure of nodulation (Miles 1974).

5.3.3 Tillers

As shown in Table 25, larger total numbers of grass tillers per box were produced in monoculture than in mixtures, however, despite the reduced numbers of grass plants the number of tillers per plant were increased and individual tillers were larger because of reduced intra-specific competition.

In trial 2 the effects of fertilizers on tiller production were similar to those on total plant dry weight. The observations are in agreement with those reported by Remison & Snaydon (1978) who also found increased numbers of ryegrass tillers where NPK fertilizer was applied.

6. CONCLUSION

Under low fertility conditions, pastures lack vigour and tend to develop bare patches where weeds can gain an entry. On the other hand gorse can thrive under conditions of low fertility and is then at its most competitive as pasture plants make little growth and sufficient grazing pressure cannot be maintained to keep it under control.

The most practicable methods of preventing reinvasion by seedlings when establishing pasture on areas cleared of gorse is to make the maximum use of the competitive powers of the pasture plants themselves together with grazing management. This can be achieved by using a high seeding rate of certified seed which is free from impurities, has good germination and a rapid growth rate. The species sown should also be aggressive under suitable levels of nutrients and soil moisture. Of the above factors, moisture is the most difficult to manipulate. However, autumn may be a better time for sowing than s pring as moisture conditions are normally favourable and the growth of gorse seedlings will be retarded as a result of the short-day length and shading by the pasture species. The seedlings thus remain susceptible to defoliation by stock until the following spring or summer when they start forming thorns.

A highly competitive pasture requires a high level of soil nutrients to make the vigorous growth which will smother young gorse seedlings and prevent germination. Gorse, however, also responds to improved soil conditions so that control measures must be based on the differing growth patterns of the gorse and the pasture plants. Gorse seedlings have a low growth rate during the early stages of growth and a dense pasture cover at this time offers both shoot and root competition. The denser shoot system of pasture grasses retards gorse growth primarily because it inhibits root development. Furthermore, the shading effect delays the formation of side shoots and spines and also of the nodules which are essential for the successful establishment of the seedling.

Shading by itself does not kill gorse seedlings because they can withstand low light intensity and eventually overtop the pasture when the grass growth weakens as a result of reduced soil moisture or some other factor. Because the seedlings cannot be adequately controlled by pasture competition alone, its effects must be supplemented by controlled grazing in the form of rotational mob-stocking. A dense and vigorous pasture allows a higher stocking rate which in turn increases the fertility cycle and further impairs the growth of gorse seedlings. With adequate spellings, which have to be determined according to the local season and climate, a dense sward should develop, causing the gorse seedlings to etiolate. Under these conditions, the plants are more readily destroyed or damaged by the effects of grazing animals than non-etiolated seedlings. The effect of grazing animals results from defoliation combined with trampling, pulling and subsequent moisture stress in late spring and summer in consequence of a reduced and shallow root system.

Although mob-stocking is the accepted method for controlling gorse seedlings under conditions favourable for pasture growth, under certain circumstances, it may delay regrowth of the pasture and reduce its competitive ability. This may occur for example when reproductive tillers are forming and the buds may be grazed out. However, when the pasture grasses are well developed and defoliation is followed by rapid regrowth, more frequent and closer grazing may be appropriate. Better control will then be achieved because grasses are better adapted to close, heavy grazing than are young gorse seedlings.

Seedlings and young shoots of gorse are soft, palatable and nutritious before they become thorny. The critical period appears to be in spring or early summer when the soft growth hardens. The aim should therefore be to obtain control before the summer as gorse seedlings or regrowth can grow better than pasture during periods of moisture shortage and so escape the effects of grazing. It is therefore important to apply a high pressure on the animals so as to achieve control of gorse before thorns develop. If the effect of grazing is insufficient and the gorse plants become fully hardened, other control methods such as cutting or spraying should be employed. Cutting by itself rarely kills gorse plants but may be useful to stimulate regrowth which is more susceptible to the effects of herbicides or soft enough to be browsed by livestock.

7. APPENDICES

APPENDIX 1(a) Dry matter yield for harvest periods 1 to 3

Cutting Height	Yield Period	Replicates	Plant Ratios G1.0	-	G.75	N.25	G.50	N.50	G.25	N.75	-	N1.0
Low cut	1	I	10.3	-	2.4	22.4	1.5	28.3	0.6	31.3	-	34.4
		II	8.0	-	2.7	21.6	1.3	32.3	0.5	23.0	-	30.9
		III	5.5	-	2.2	28.1	1.1	32.6	0.8	22.5	-	37.0
		IV	7.8	-	2.9	25.5	1.0	27.8	0.5	28.1	-	24.8
	2	I	6.4	-	1.2	6.6	0.5	8.6	0.3	5.5	-	8.7
		II	6.8	-	1.3	8.3	0.5	8.8	0.6	3.4	-	2.5
		III	7.4	-	1.4	10.0	0.7	10.2	0.4	9.2	-	10.1
		IV	7.8	-	1.8	7.2	0.7	7.5	0.1	11.4	-	11.1
	3	I	5.2	-	1.0	2.6	0.9	3.8	0.3	3.5	-	4.1
		II	5.8	-	1.5	3.6	0.6	3.2	0.6	1.6	-	4.5
		III	5.2	-	0.9	3.1	0.6	3.6	0.3	4.1	-	4.5
		IV	6.0	-	0.6	1.8	0.5	3.8	0.6	4.6	-	4.9
High cut	1	I	6.0	-	2.2	22.9	1.1	21.4	0.6	20.8	-	32.0
		II	6.5	-	3.4	26.9	1.1	29.9	0.7	41.3	-	30.2
		III	4.8	-	2.4	23.0	1.2	21.6	0.5	23.1	-	35.2
		IV	4.3	-	1.6	26.5	0.9	26.4	0.5	19.6	-	31.8
	2	I	11.5	-	1.1	5.3	0.5	6.7	0.2	4.9	-	4.1
		II	14.0	-	1.3	6.6	0.8	2.9	0.4	8.7	-	4.5
		III	15.0	-	1.0	9.9	0.9	6.3	0.1	13.3	-	6.6
		IV	12.2	-	2.3	8.5	0.7	15.3	0.3	8.1	-	12.3
	3	I	6.0	-	2.1	3.2	1.3	5.9	0.4	2.8	-	3.2
		II	8.8	-	2.1	3.5	1.6	4.1	0.3	4.0	-	3.0
		III	5.7	-	1.1	4.0	1.2	4.1	0.3	5.4	-	3.7
		IV	8.6	-	1.5	3.5	0.8	5.7	0.4	4.9	-	4.8
Control	3	I	124.8	-	24.8	74.8	9.6	65.9	5.3	58.4	-	68.9
		II	147.7	-	27.3	62.1	7.3	79.3	3.8	90.2	-	86.6
		III	95.5	-	39.8	74.4	18.2	81.1	6.3	90.7	-	91.7
		IV	132.1	-	32.6	71.1	7.1	75.7	4.2	88.7	-	79.8

APPENDIX 1(b) Cumulative vield periods 1-2 and 1-3

Cutting Height	Yield Period	Replicates	Plant Ratios G1.0	- G.75	N.25	G.50	N.50	G.25	N.75	- N1.0
Low cut	1-2	I	16.7	- 3.6	29.0	2.0	36.9	0.9	36.8	- 43.1
		II	14.8	- 4.0	29.9	2.8	41.1	1.1	26.4	- 33.4
		III	12.9	- 3.6	38.1	1.8	42.8	1.2	31.7	- 47.1
		IV	15.6	- 4.7	32.7	1.7	35.3	0.6	39.5	- 35.9
	1-3	I	21.9	- 4.6	31.6	2.9	40.7	1.2	40.3	- 47.2
	1	II	20.6	- 5.5	33.5	2.4	44.3	1.7	28.0	- 37.9
		III	18.1	- 4.5	41.2	2.4	46.4	1.5	35.8	- 51.6
		IV	21.6	- 5.3	34.5	2.2	39.1	1.2	44.1	- 40.8
High cut	1-2	I	17.5	- 3.3	28.2	1.6	28.1	0.8	25.7	- 36.1
		II	20.5	- 4.7	33.5	1.9	32.8	1.1	50.0	- 34.7
		III	19.8	- 3.4	32.9	2.1	27.9	0.6	36.4	- 41.8
		IV	16.5	- 3.9	35.0	1.6	41.7	0.8	27.7	- 44.1
	1-3	I	23.5	- 5.4	314	2.9	34.0	1.2	28.5	- 39.3
		II	29.3	- 6.8	37.0	3.5	36.9	1.4	54.0	- 37.7
		III	25.5	- 4.5	36.9	3.3	32.0	0.9	41.8	- 45.5
		IV	25.1	- 5.4	38.5	2.4	47.4	1.2	32.6	- 48.9

APPENDIX 1(c) Total shoot dry matter (Cumulative yield period 1-3 + stubble)

Low cut	I	29.8	- 7.8	34.6	3.9	46.3	1.9	45.8	- 51.5
	II	26.7	- 8.9	39.6	3.9	50.2	3.9	40.7	- 43.5
	III	25.3	- 7.2	45.0	3.6	51.2	2.3	41.6	- 60.0
	IV	32.1	- 8.5	38.8	3.7	43.1	1.6	48.5	- 45.9
High cut	I	37.4	- 9.3	36.9	5.1	43.6	2.0	41.4	- 49.6
	II	50.5	- 11.0	44.9	5.6	50.9	8.9	59.3	- 52.7
	III	44.7	- 8.4	44.1	5.4	43.5	1.7	54.4	- 56.7
	IV	40.0	- 10.1	43.2	4.6	59.1	2.4	44.2	- 59.2

APPENDIX 1(d) Root Dry Matter

Cutting Height	Replicates	Plant Ratios G1.0	-	G.75	N.25	G.50	N.50	G.25	N.75	-	N1.0
Low cut	I	7.4	-	2.5	12.0	0.8	17.8	0.7	22.6	-	21.2
	II	6.6	-	2.7	19.3	1.4	25.3	0.8	27.6	-	26.8
	III	5.9	-	1.8	16.7	0.7	20.9	0.5	21.7	-	34.6
	IV	5.4	-	1.4	12.2	0.8	15.0	0.3	17.2	-	17.7
High cut	I	8.6	-	2.4	21.5	2.2	25.5	0.4	25.5	-	23.8
	II	9.4	-	2.8	27.2	2.1	35.3	0.6	31.1	-	28.1
	III	10.1	-	2.1	20.5	0.7	25.6	0.4	28.1	-	22.9
	IV	8.8	-	1.8	9.6	0.7	28.4	0.4	22.6	-	24.8
Control	I	38.2	-	5.2	61.9	3.1	74.9	1.6	51.8	-	47.0
	II	37.5	-	6.9	39.7	2.9	68.9	1.3	61.8	-	61.4
	III	31.0	-	7.2	60.8	3.7	108.7	1.7	74.2	-	73.8
	IV	31.0	-	8.4	43.8	2.0	46.5	1.5	62.1	-	47.9

APPENDIX 1(e) Plant (Shoot + Root) Dry Matter

Low cut	I	37.2	-	10.3	46.6	4.7	64.1	2.6	68.4	-	72.7
	II	33.3	-	11.6	58.9	5.3	75.5	4.7	68.3	-	70.3
	III	31.2	-	9.0	61.7	4.3	72.1	2.8	63.7	-	94.6
	IV	37.5	-	9.9	51.0	4.5	58.1	1.9	65.7	-	63.6
High cut	I	46.0	-	11.7	58.4	7.3	69.1	2.4	66.9	-	73.4
	II	59.9	-	13.8	72.1	7.7	86.2	9.5	90.4	-	80.8
	III	54.8	-	10.5	64.1	6.1	69.1	2.1	82.6	-	79.6
	IV	48.8	-	11.9	52.8	5.3	87.5	2.8	66.8	-	84.0
Control	I	163.0	-	30.0	136.9	12.7	140.8	6.9	110.2	-	115.9
	II	185.2	-	34.2	101.8	10.2	148.2	5.1	152.0	-	148.0
	III	126.5	-	47.0	135.2	21.9	189.8	8.0	164.9	-	165.5
	IV	163.1	-	41.0	114.9	9.1	122.2	5.7	150.8	-	127.7

APPENDIX 2. The effects of cutting height and plant ratios on Nui tillers and gorse side shoots per box for the two sampling periods

Cutting Height	Sampling Period	Replicates	G1.0	-	G.75	N.25	G.50	N.50	G.25	N.75	-	N1.0
Low cut	1	I	258.0	-	115.2	224.4	57.6	364.8	36.0	604.8	-	528.0
		II	264.0	-	129.6	358.8	62.4	453.6	31.2	464.4	-	422.4
		III	312.0	-	126.0	292.8	62.4	434.4	44.4	417.6	-	571.2
		IV	235.2	-	140.4	304.8	52.8	420.0	25.2	399.6	-	681.6
	2	I	499.2	-	248.4	246.0	100.8	350.4	76.8	669.6	-	489.6
		II	456.0	-	252.0	321.6	134.4	571.2	67.2	450.0	-	513.6
		III	388.8	-	223.2	278.4	120.0	444.0	70.8	522.0	-	667.2
		IV	417.6	-	252.0	296.4	100.8	367.2	50.8	354.8	-	681.6
High cut	1	I	254.4	-	122.4	289.2	55.2	316.8	28.8	450.0	-	480.0
		II	216.6	-	129.6	290.4	55.2	340.8	34.8	622.8	-	508.8
		III	172.8	-	82.8	306.0	43.2	393.6	24.0	561.6	-	595.2
		IV	187.2	-	118.8	237.6	57.6	520.8	26.0	450.0	-	571.2
	2	I	432.0	-	205.2	272.4	124.8	338.4	46.8	435.6	-	594.4
		II	484.8	-	248.4	290.4	132.0	388.8	67.2	540.0	-	532.8
		III	398.4	-	190.8	290.4	91.2	355.2	38.4	489.6	-	547.2
		IV	312.0	-	216.0	206.4	93.6	417.6	54.0	403.2	-	518.4
Control	1	I	96.0	-	36.0	289.2	24.0	393.6	12.0	442.8	-	499.2
		II	62.4	-	36.0	278.4	24.0	456.0	12.0	500.4	-	614.4
		III	81.6	-	36.0	398.4	24.0	439.2	12.0	626.4	-	585.6
		IV	81.6	-	36.0	362.4	24.0	420.0	12.0	658.8	-	614.4
	2	I	62.4	-	36.0	342.0	24.0	367.2	12.0	565.2	-	528.0
		II	48.0	-	36.0	304.8	24.0	434.4	12.0	669.6	-	916.8
		III	48.0	-	36.0	396.0	24.0	470.4	12.0	637.2	-	710.4
		IV	48.0	-	36.0	405.6	24.0	381.6	14.4	572.4	-	643.2

APPENDIX 3. Gorse Nodules (numbers/plant)

Cutting Height	Replicates	Relative Plant Frequencies G1.0	G.75	G.50	G.25
	I	19.7	6.6	6.4	4.8
Low cut	II	16.8	4.8	3.6	5.9
	III	14.4	6.6	6.6	4.3
	IV	16.4	4.6	5.4	4.0
High cut	I	23.6	6.1	6.4	5.6
	II	31.0	6.1	6.7	3.7
	III	24.4	10.6	4.3	2.3
	IV	32.2	7.4	3.0	5.1
Control	I	21.1	9.5	9.5	9.2
	II	47.2	20.7	8.1	5.0
	III	43.4	7.5	19.3	5.5
	IV	42.2	36.3	16.8	8.5

APPENDIX 4. Fitted monoculture and mixture dry matter yields for:

(a) harvest periods 1-3 and cumulative yield periods 1-2 and 1-3 for the cut treatments and control (Fig. 6-7).

Cutting Height	Weeks from Sowing	Dates of Harvest	Harvest Periods	Parameter or Model	Relative Plant Frequencies							
					G1.0	G.75N.25		G.50N.50		G.25N.75		N1.0
Low cut	14		1	4p	7.8	3.1	25.0	1.4	28.7	0.5	30.2	31.0
				3p	8.3	3.1	21.7	1.4	29.0	0.5	32.6	34.8
	18		2	4p	6.6	2.1	8.2	0.9	8.8	0.3	9.1	9.2
				3p	7.0	2.1	7.2	0.9	0.9	0.3	9.9	10.3
	22		3	4p	5.0	2.2	2.9	1.0	3.7	0.4	4.1	4.3
				3p	5.2	2.2	2.7	1.0	3.7	0.4	4.2	4.6
	18		1-2	4p	14.2	5.1	33.2	2.2	37.0	0.8	38.4	39.1
				3p	15.0	5.1	29.0	2.2	37.4	0.8	41.4	43.7
	22		1-3	4p	19.2	7.1	36.0	3.1	40.5	1.2	42.3	43.3
				3p	20.2	7.0	31.4	3.1	40.9	1.1	45.5	48.2
High cut	14		1	4p	5.4	2.6	24.1	1.3	28.1	0.5	29.7	30.5
				3p	6.1	2.7	20.2	1.3	28.6	0.5	33.2	36.2
	18		2	4p	13.1	2.0	8.4	0.8	9.2	0.3	9.5	9.7
				3p	13.1	2.0	8.3	0.8	9.2	0.3	9.6	9.8
	22		3	4p	7.3	2.5	3.9	1.1	4.3	0.4	4.5	4.6
				3p	7.6	2.5	3.4	1.1	4.4	0.4	4.8	5.1
	18		1-2	4p	17.9	5.0	31.9	2.0	35.9	0.7	37.5	38.3
				3p	18.3	4.9	29.6	2.0	36.0	0.7	38.9	40.5
	22		1-3	4p	25.0	7.3	35.7	3.0	40.0	1.1	41.6	42.5
				3p	25.7	7.3	32.6	3.0	40.2	1.1	43.5	45.4
Control	22	1/3/77	3	4p	126.7	33.1	70.4	13.3	78.5	4.8	81.7	83.3
				3p	129.6	33.0	65.4	13.2	78.8	4.7	84.5	87.7

APPENDIX 4b. Root dry matter (Fig. 8).

Cutting Height	Parameter or Model	Relative Plant Frequency							
		G1.0	G.75	N.25	G.50	N.50	G.25	N.75	N1.0
Low cut	4p	5.9	2.8	15.4	1.3	21.0	0.5	23.8	25.6
	3p	6.1	2.8	14.6	1.3	20.9	0.5	24.5	26.7
High Cut	4p	9.0	3.2	23.2	1.4	26.0	0.5	27.2	27.8
	3p	9.4	3.2	20.2	1.4	26.2	0.5	29.0	30.7
Control	4p	33.3	8.9	59.8	3.6	65.8	1.3	68.1	69.3
	3p	34.0	8.8	54.6	3.6	66.1	1.3	71.0	73.8

APPENDIX 4C. Total plant dry matter (Fig. 9).

Cutting Height	Parameter or Model	Relative Plant Frequency							
		G1.0	G.75	N.25	G.50	N.50	G.25	N.75	N1.0
Low cut	4p	31.8	14.3	55.2	6.8	66.6	2.7	71.5	74.2
	3p	34.0	14.3	48.2	6.6	67.0	2.5	77.0	83.3
High Cut	4p	46.7	23.4	64.1	11.7	74.8	4.7	79.2	81.6
	3p	51.5	23.4	53.0	11.2	76.0	4.4	89.0	97.2
Control	4p	159.5	41.6	128.3	16.8	142.4	6.0	147.7	150.6
	3p	162.9	41.5	118.6	16.7	142.8	6.0	153.3	159.1

APPENDIX 4d. Sprouts/tillers (Fig 10).

Cutting Height	Weeks from Sowing	Harvest Periods	Parameter or Model	Relative Plant Frequency								
				G1.0	G.75	N.25	G.50	N.50	G.25	N.75	GO	N1.0
Low cut	18	1	4p	260	142	298	74	427	31	499		545
			3p	237	128	301	66	469	27	577		652
		2	4p	423	254	289	141	439	60	532		594
			3p	444	256	269	138	436	58	550		633
High cut	22	1	4p	205	117	281	63	420	26	503		558
			3p	214	118	264	62	417	25	517		588
		2	4p	403	226	262	120	396	50	478		533
			3p	415	227	250	119	394	49	487		552

APPENDIX 5. The effect of fertilisers plant ratios on shoot, root and total plant dry matter shoot:root ratio; nodule count/plant and Nui tillers/box.

Appendix 5a. Shoot DM.

Shoot DM

Fert-ilizer (F)	Plant Ratio (R)	Replicates I	II	III	IV
0	G1.0	5.3	5.1	2.9	3.2
	G.75	2.8	2.3	1.9	2.0
	N.25	12.1	10.5	3.3	7.9
	N1.0	16.7	18.6	11.3	11.8
N	G1.0	4.6	4.9	3.6	4.0
	G.75	2.6	2.8	1.8	2.1
	N.25	15.1	7.6	8.6	13.9
	N1.0	17.6	17.5	13.2	12.3
P	G1.0	7.3	10.6	8.5	9.2
	G.75	3.4	5.0	4.9	3.3
	N.25	14.0	21.7	14.6	13.3
	N1.0	21.6	19.8	14.1	24.6
K	G1.0	4.6	4.2	3.1	3.5
	G.75	2.1	2.3	1.8	1.7
	N.25	9.6	10.3	6.7	5.3
	N1.0	18.9	19.3	8.8	14.0
NP	G1.0	9.0	10.4	8.6	9.2
	G.75	4.2	4.2	3.2	4.6
	N.25	24.8	29.9	12.9	14.4
	N1.0	18.8	25.3	16.6	24.6
NK	G1.0	5.3	5.3	3.5	3.0
	G.75	3.0	2.7	2.0	1.7
	N.25	18.4	11.1	7.8	11.5
	N1.0	18.6	16.8	11.6	21.2
PK	G1.0	9.1	11.0	9.3	6.8
	G.75	3.9	4.6	3.2	3.5
	N.25	18.6	20.8	13.6	10.0
	N1.0	27.7	20.9	18.1	15.6
NPK	G1.0	9.6	12.0	8.3	6.7
	G.75	5.4	4.7	4.9	2.9
	N.25	25.7	21.4	12.7	16.8
	N1.0	15.4	20.6	18.0	25.7

Appendix 5b. Root DM

Root DM

F	R	Replicates I	II	III	IV
0	G1.0	2.0	2.1	1.9	2.0
	G.75	1.2	1.2	1.1	0.9
	G.25	11.8	14.6	4.1	7.0
	N1.0	13.2	18.7	14.7	10.8
N	G1.0	2.6	1.6	1.4	1.7
	G.75	1.2	1.6	1.7	1.1
	N.25	14.1	9.7	8.9	13.2
	N1.0	17.4	24.9	18.1	17.5
P	G1.0	2.2	2.7	2.6	2.7
	G.75	0.9	1.8	1.2	0.9
	G.25	18.6	26.5	23.0	18.5
	N1.0	23.4	25.3	22.8	29.9
K	G1.0	2.0	1.8	1.7	1.7
	G.75	1.4	0.9	1.1	1.1
	N.25	11.5	5.9	8.1	5.0
	N1.0	16.4	20.1	10.7	15.5
NP	G1.0	2.0	2.6	2.2	2.2
	G.75	1.3	1.3	1.0	1.0
	N.25	25.0	28.1	22.0	20.4
	N1.0	23.9	28.9	22.1	23.6
NK	G1.0	2.5	2.3	1.7	1.5
	G.75	1.2	1.5	1.8	1.0
	N.25	17.3	15.1	12.0	11.8
	N1.0	18.8	16.5	18.1	17.5
PK	G1.0	2.2	1.7	2.6	2.1
	G.75	1.1	1.3	1.1	1.0
	N.25	17.9	24.7	19.4	15.5
	N1.0	29.7	29.8	27.0	26.4
NPK	G1.0	2.2	3.4	2.0	1.9
	G.75	1.3	1.0	1.0	0.9
	N.25	26.9	23.5	18.3	21.9
	N1.0	18.1	27.2	25.6	34.1

APPENDIX 5 Contd

Appendix 5c.
Shoot + Root DM

F	R	I	II	III	IV
		Replicates			
0	G1.0	7.3	7.2	4.8	5.2
	G.75	4.0	3.5	3.0	2.9
	N.25	23.9	25.1	7.4	14.9
	N1.0	29.9	26.0	22.6	
N	G1.0	7.2	6.5	5.0	5.7
	G.75	3.8	4.4	3.5	3.2
	N.25	29.2	17.3	17.5	27.1
	N1.0	35.0	42.4	31.3	29.8
P	G1.0	9.5	13.3	11.1	11.9
	G.75	4.3	6.8	6.1	4.2
	N.25	32.6	48.2	37.6	31.8
	N1.0	45.0	45.1	36.9	54.5
K	G1.0	6.6	6.0	4.8	5.2
	G.75	3.5	3.2	2.9	2.8
	N.25	21.1	16.2	14.8	10.3
	N1.0	35.3	39.4	19.5	29.5
NP	G1.0	11.0	13.0	10.8	11.4
	G.75	5.5	5.5	4.2	5.6
	N.25	49.8	58.0	34.9	34.8
	N1.0	42.7	54.2	38.7	48.2
NK	G1.0	7.8	7.6	5.2	4.5
	G.75	4.2	4.2	3.8	2.7
	N.25	35.7	26.2	19.8	23.3
	N1.0	37.4	33.3	29.7	38.7
PK	G1.0	11.3	12.7	11.9	8.9
	G.75	5.0	5.9	4.3	4.5
	N.25	36.5	45.5	33.0	25.5
	N1.0	57.4	50.7	45.1	42.0
NPK	G1.0	11.8	15.4	10.3	8.6
	G.75	6.7	5.7	5.9	38
	N.25	52.6	44.9	31.0	38.7
	N1.0	33.5	47.8	43.6	59.8

Appendix 5d
Shoot/Root Ratio

F	R	I	II	III	IV
		Replicates			
0	G1.0	2.65	2.43	1.53	1.60
	G.75	2.33	1.92	1.73	2.22
	N.25	1.03	.72	.80	1.13
	N1.0	1.27	.99	.77	1.09
N	G1.0	1.77	3.06	2.57	2.35
	G.75	2.17	1.75	1.06	1.91
	N.25	1.07	.78	.97	1.05
	N1.0	1.01	.70	.73	.70
P	G1.0	3.93	3.92	3.27	3.41
	G.75	3.78	2.78	4.08	3.67
	N.25	.75	.82	.63	.72
	N1.0	.92	.78	.62	.82
K	G1.0	2.30	2.33	1.82	2.06
	G.75	1.50	2.56	1.64	1.55
	N.25	.83	1.75	.83	1.06
	N1.0	1.15	.96	.82	.90
NP	G1.0	4.50	4.00	3.91	4.18
	G.75	3.23	3.23	3.20	4.6
	N.25	.99	1.00	.59	.71
	N1.0	.79	.88	.75	1.04
NK	G1.0	2.12	2.30	2.06	2.00
	G.75	2.50	1.80	1.11	1.70
	N.25	1.06	.74	.65	.97
	N1.0	.99	1.02	.64	1.21
PK	G1.0	4.14	6.47	3.58	3.24
	G.75	3.55	3.54	2.91	3.50
	N.25	1.04	.84	.70	.65
	N1.0	.93	.70	.69	.59
NPK	G1.0	4.36	3.53	4.15	3.53
	G.75	4.15	4.70	4.90	3.22
	N.25	.96	.91	.69	.77
	N1.0	.85	.76	.70	.75

Appendix e

Nodule count of gorse seedlings in trial 2.

Fertilizer	Plant Ratio	Replicates			
		I	II	III	IV
0	G1.0	13.3	13.2	19.4	13.0
	G.75N.25	15.5	10.6	8.6	12.3
N	G1.0	16.1	16.9	12.8	15.8
	G.75N.25	15.4	12.1	8.3	8.0
P	G1.0	31.4	35.6	41.3	38.3
	G.75N.25	17.4	18.0	15.0	12.4
K	G1.0	14.6	13.4	20.0	17.0
	G.75N.25	11.0	12.1	7.3	11.8
NK	G1.0	18.7	20.0	16.0	10.3
	G.75N.25	14.7	11.4	11.0	12.3
NP	G1.0	26.4	24.8	26.6	33.8
	G.75N.25	18.2	17.2	9.8	13.8
PK	G1.0	21.2	18.9	30.4	28.9
	G.75N.25	17.1	23.1	12.8	14.7
NPK	G1.0	29.4	36.4	20.7	18.2
	G.75N.25	21.4	20.9	10.6	16.4

Appendix f

Nui tiller numbers/plant in trial 2.

Fertilizer	Plant Ratio	Replicates			
		I	II	III	IV
0	N1.0	6.0	6.9	6.1	6.5
	G.75N.25	16.4	15.0	8.0	13.3
N	N1.0	8.6	6.4	6.1	5.6
	G.75N.25	15.1	12.6	11.1	16.6
P	N1.0	7.5	6.2	6.4	9.6
	G.75N.25	18.0	18.2	19.2	18.1
K	N1.0	6.1	6.2	5.0	5.4
	G.75N.25	15.6	14.3	13.1	10.3
NP	N1.0	7.5	8.3	7.3	9.7
	G.75N.25	23.8	21.3	15.8	24.2
NK	N1.0	7.5	7.1	4.8	7.1
	G.75N.25	19.8	16.3	10.8	16.2
PK	N1.0	8.3	10.5	9.6	7.3
	G.75N.25	18.8	21.2	16.6	15.4
NPK	G1.0	8.9	8.1	9.1	10.6
	G.75N.25	23.6	20.8	18.2	21.8

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