THE AGRICULTURAL VALUE OF BIRDSFOOT TREFOILS IN SCOTLAND

by

JOHN FREDERIC LIVINGSTONE CHARLTON
B.Sc.(Agric.)(Hons.Agric.Bot.)(Dunelm)

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1. INTRODUCTION

Britain's most important agricultural crop for livestock production is grass with more than seven million hectares of rough grazing land, nearly five million hectares of permanent pasture and over two million hectares of temporary leys (HMSO 1970). The mild British climate is very suitable for the intensive development of grassland and many of our progressive farmers have demonstrated its potential output, particularly in lowland areas, yet the majority of permanent pasture and hill land is still underdeveloped (Davies 1960). Within the past twenty-five years the increasing use of fertilisers, especially those containing nitrogen, has greatly improved output in areas where intensive management is applied to grass; but in marginal and hill regions the herbage legume is the cheapest source of nitrogen and of high protein herbage. A major economic improvement of productivity within such areas can be achieved by encouraging legumes to grow and spread in these regions.

The only indigenous species of herbage legume to be widely sown in British grassland is white clover*, as the small-leaved wild white form (e.g. S.184) and the larger-leaved type such as the cultivar S.100. It is a most valuable agricultural species as it enhances the quality of the sward when it is encouraged by appropriate management; on poor soils it is a major key to sward improvement (Cooper 1962; HMSO 1966). Although widespread on well-drained acidic soils, there are vast areas of natural grassland where white clover is not a productive species.

The seventeenth century saw the introduction of two important legumes, red clover and lucerne. The former had a considerable

* Botanical names of plant species mentioned in this thesis are listed in Appendix 1.

effect on British farming via the development of the Norfolk four-course rotation. Lucerne is only of importance in the drier areas of south-east England. Neither of these species is suitable for the improvement of our rough-grazing land and thus they are not sown for this purpose, except in the Welsh border region where late-flowering red clover thrives under those particular conditions.

Other naturalised perennial legumes include sainfoin, kidney vetch, birdsfoot trefoil and marsh birdsfoot trefoil. Sainfoin is confined to calcareous soils in southern Britain and thus chances of its more widespread use are slight. Kidney vetch is also localised and does not behave as a perennial when sown in grassland (Robinson 1947).

Birdsfoot trefoil, on the other hand, is distributed throughout the British Isles on well-drained soils whereas marsh birdsfoot trefoil is prevalent on wet acidic areas (Clapham, Tutin and Warburg 1962). Recent years have seen the development of these species for use in the improvement of natural grassland in many countries and accordingly, investigation of their potential value as herbage legumes under British conditions was considered justifiable.

The experiments reported in this thesis were started in 1966 at Auchincruive and an upland site near Eaglesham, Renfrewshire, and later at a second upland site near Kirkoswald, Ayrshire, and on a lowland site on the Carse of Stirling. They were designed to examine the agronomic characteristics of a wide range of genetic material within both birdsfoot trefoil and marsh birdsfoot trefoil with a view to selection of the more promising types for more detailed agronomic assessment under conditions where they could be of special agricultural value.

Glasshouse pot experiments attempted to assess the competitive ability of birdsfoot trefoil during the establishment phase when growing with companion grasses. These were followed by spaced-clump trials of ecotypes and cultivars of birdsfoot trefoil, and later of marsh birdsfoot trefoil, to investigate the range within each important characteristic of the species. Sward experiments examined the behaviour of birdsfoot trefoil compared with white clover during and after establishment on upland pasture and at one exceptional lowland site where the presence of an acceptable legume could enhance the particular farming system.

A paper embracing the results obtained from some of the experiments described in this thesis was presented by the author at the Fourth general meeting of the European Grassland Federation, Lausanne, Switzerland (June 14-19th, 1971) in the section on improvement of natural grassland, entitled "The potential value of Lotus species in the improvement of natural grassland in Scotland" (Charlton 1971; Appendix 5).

2. REVIEW OF LITERATURE

Three species within the genus *Lotus* have been developed as herbage plants. Birdsfoot trefoil is the most widespread species, having been used in Europe for at least a century and developed extensively in North America during the past thirty years. It has also been adapted successfully in South America, throughout eastern Europe, the Soviet Union and in parts of Asia. Marsh birdsfoot trefoil has found favour in the north-west United States of America and in Australasia as a valuable sward component in areas of high rainfall, whereas slender birdsfoot trefoil has limited use in the drier regions of California and New York State. In general the agronomic position of these species has emerged as a replacement of other legumes in the problem areas of grassland where clovers and lucerne will not thrive.

The morphology and physiology of these species have been extensively studied by many workers all over the world, thus obtaining a greater knowledge and understanding of the species' agronomic behaviour eventually leading to improved crop management techniques. The range of literature on *Lotus* species under agricultural systems is wide and varied. Many studies, carried out in North America and in eastern Europe, found several major features which set the birdsfoot trefoils apart from other legumes and indicated their place in farming practice. Such experiments have examined these legumes under many different climatic and agricultural situations.

The relevant literature is reviewed for convenience in the following sections:-

(a) birdsfoot trefoils - the species;

(b) birdsfoot trefoils as agricultural plants;

(c) the use of *Lotus* in roughland improvement;

(d) birdsfoot trefoils in the British Isles.

2.1. BIRDSFOOT TREFOILS - THE SPECIES

The term birdsfoot trefoil is normally given to the agriculturally important species within the genus *Lotus*. Of these there are three perennial species worth consideration:-

L. corniculatus L. - birdsfoot trefoil,

L. pedunculatus Cav. (*L. uliginosus* Schkuhr; *L. major* auct.) - marsh birdsfoot trefoil,

L. tenuis Waldst. and Kit. ex Willd. - slender birdsfoot trefoil,

(Clapham, Tutin and Warburg 1962).

In his monograph on birdsfoot trefoil, MacDonald (1946) records more than twenty different local names for these species within the English language while other major languages each have specific names for the plants. This obviously reflects their wide area of distribution and their characteristic appearance in the flowering and fruiting stage.

In order to appreciate fully the agronomic features it is important to consider the morphology, physiology, cytology and ecology of these major species.

2.1.1. Morphology

The most common species *L. corniculatus* is usually divided into two botanical types on morphological grounds (MacDonald 1946). *L. corniculatus* var. *arvensis* is the dwarf prostrate type commonly naturalised throughout the British Isles; *L. corniculatus* var. *vulgaris* is a more erect form with larger leaves which is the basis of European and North American commercial birdsfoot trefoil. No such distinctions exist within *L. pedunculatus* or *L. tenuis*.

The normal root system is a taproot with numerous lateral roots. Rhizomes are usually seen only on *L. pedunculatus*, where they augment but rarely replace the taproot system. They arise at the crown of the plant and bear adventitious roots at the nodes (Robinson 1947). *L. corniculatus* is a deep-rooting species with a rooting depth second only to lucerne but superior to this species in lateral root development (MacDonald, *loc. cit.*).

L. tenuis has a short pronounced taproot with extensive lateral branching; so also has *L. pedunculatus* which is very densely distributed in the upper soil layers, especially where there are numerous adventitious roots from the rhizomes.

All forms of foliar growth habit are found in birdsfoot trefoil, from erect to prostrate positions and all intermediate angles (Robinson 1934; MacDonald 1946). *L. corniculatus* var. *arvensis* is nearly always low growing and prostrate while the var. *vulgaris* is usually more erect although cultivars range widely in this feature. Because the stems of *L. tenuis* are quite weak this species generally tends towards the prostrate forms whereas *L. pedunculatus* is prostrate, due to its rhizomatous form, when grazed or dormant, yet has the ability to produce erect stems in warmer weather and thus rise above dense shade caused by other vegetation (Mitchell 1956).

Several writers describe the stems of *Lotus* as being finer and less rigid than those of lucerne and red clover. Pubescence varies widely although completely glabrous stems are rarely found. MacDonald (1946) examined agricultural forms of *L. corniculatus* and found that these types were nearly glabrous. Branches develop in the leaf axis and secondary branching also occurs, resulting in multi-branched foliage.

The base of the *Lotus* shoot system forms a crown and the numerous stems are produced from this source. Some stems of *L. corniculatus* and *L. tenuis* lie horizontally and can be covered by soil but they do not produce adventitious roots as in

L. pedunculatus and are therefore not true rhizomes. The horizontal stems of *L. pedunculatus* are thicker than those of the other species and, although definitely rhizomes, they are sometimes exposed on the surface and behave as stolons (MacDonald, *loc. cit*). Length of the stem varies considerably and can be in excess of one metre in all three species.

The compound leaf of birdsfoot trefoils is characteristically pentafoliate despite its name which suggests that the basal pair of leaflets is a pair of stipules. Robinson (1934) drew attention to the evidence of several workers who concluded that the true stipules are rudimentary features at the base of the petiole.

Shape of the leaflet varies, the distinctly narrow leaflets of *L. tenuis* easily separating this species from *L. corniculatus* and *L. pedunculatus* which resemble each other in having broad leaflets. All three species closely resemble other herbage legumes in their ability to close the terminal leaflets together to reduce transpiration at night and in wilting conditions.

The inflorescence of birdsfoot trefoil is an umbel-like cyme borne at the end of a long axillary peduncle (Thomas and Davies 1954). *L. corniculatus* has one to six florets per head, *L. tenuis* rarely more than four while *L. pedunculatus* has from five to twelve florets in each head (Clapham *et al* 1962). The calyx is in the form of a dentate tube 3-5 mm in length. In *L. pedunculatus* the tips of the calyx turn outwards and remain star-like until mature, easily distinguishing this species from the other two species. The corolla is typically leguminous and is composed of five petals which are generally yellow but often tinged with red at some stage of development. There are nine joined stamens and one free stamen and the gynoecium has an ovary in the form of a cylindrical tube, 6-8 mm long at flower opening.

In mass, Lotus seed appears a chocolate-brown colour but individual seeds range from greenish-yellow to nearly black. Shape varies from oval to spherical and the surface is smooth yet often mottled. Of the three species *L. corniculatus* seed is largest, having a thousand- seed weight of 1.2 g (var *vulgaris*) and 1.4 g (var *arvensis*) whereas *L. tenuis* seed is 0.95 g and *L. pedunculatus* 0.55 g (MacDonald 1946).

2.1.2. Seed characteristics

Seed quality varies considerably, depending upon the harvesting time and process. There is a highly significant correlation between seed weight and seed size (Henson and Schoth 1962), and large plump seeds produce the most vigorous seedlings. Most *Lotus* seed samples contain hard seeds which are viable but do not absorb water during the germination test period due to an impermeable seed coat. Percentages of hard seed vary from 0.6% (Galgoczi 1964) to 4.5% (Schmidt and Majoros 1965) in samples from Hungary but averaged 31% in American commercial seed lots during 1941 to 1952 (Brown 1955). Brown (*loc. cit*) also reported that about a quarter of the hard seeds subsequently germinated after one winter in the soil. Galgoczi (1964) related environmental conditions during ripening to hard-seededness and reported increases in the proportion of hard seeds due to poor harvesting and storage methods.

Various treatments have been used to reduce hard seed content. Henson and Schoth (1962) recommended scarification of seed lots which had more than 15% of hard seeds and also mentioned an infra-red treatment. Brown (1955) treated *Lotus* seed with concentrated sulphuric acid for 45 minutes and reduced hard seed content to low levels without injuring the normal seed. Liquid oxygen and nitrogen successfully reduced hard-seededness within five minutes (Eynard 1958; Ghislem 1959) while Schmidt and Majoros (1965) overcame the problem by soaking seeds in 8% gypsum solution for three days and even recommended this as a practical field treatment.

MacDonald (1946) reported germination percentages of around 44% for both L. corniculatus and L. pedunculatus after six years of storage in laboratory conditions, declining to 6% for L. corniculatus and 25% for L. pedunculatus after ten years. Mukhina (1966) stated that the initial germination rate of birdsfoot trefoil seed was retained for five to ten years while Zelenchuk and Golemei (1965) compared longevity of sixteen grasses and nine legumes and found that only L. corniculatus and yellow trefoil retained any appreciable germinating capacity after seven years.

Woods (1966) reported that germination of L. corniculatus was delayed by temperatures below 15°C or above 30°C and by soil-moisture stresses above 4.5 bar. The cultivar Empire was least affected by high temperature but most affected by moisture stress. Germination in an atmosphere containing 0.3-3.0% carbon dioxide, 20.7-18.0% oxygen and 79% nitrogen was stimulated but was delayed in an atmosphere of 15% carbon dioxide, 6% oxygen and 79% nitrogen. Variation in emergence in field trials was attributed by Woods (loc. cit.) to differences in sowing depth or in related factors.

Soil temperatures of 20°C are required for optimum germination while soil moisture levels slightly below that of field capacity increase germination (Winch 1961). Excess and deficiency of soil moisture reduce germination markedly, thereby precluding sowing during summer (Emlick and Vogel 1959).

2.1.3. Seedling emergence

Caputa (1955) obtained results from greenhouse trials showing the optimum sowing depth of birdsfoot trefoil to be between 10 and 20 mm. Stickler and Wasson (1963) also found that rate of emergence and total emergence were significantly highest at 10-15 mm.

The ability of the seedling to emerge and establish itself while competing with other plants is an important factor in determining the vigour and density of a sward. Early studies revealed that Lotus is weak in this factor. Twamley (1967a) found that seedling vigour in Leo birdsfoot trefoil was influenced by seed size. More extensive trials (1967b) indicated that seedling vigour and forage yield decreased progressively with decrease in seed weight. In further studies using Morshansk birdsfoot trefoil tillering was observed to occur earlier in plants grown from large seeds than in those grown from small seeds (Twamley 1969). The condition of the maternal parent had little effect on seedling vigour. The study failed to explain the existence of some large-seeded lines which are only average in seedling vigour. Ouells and Cooper (1968) reported that speed of germination, elongation and speed of emergence at 15.6°C, 21.2°C and 26.7°C were significantly higher in birdsfoot trefoil cultivar Leo than in cultivars Tana, Viking and Empire. Relative yields were in the same descending order but respiration rates were similar for all cultivars within each of six age groups and each of three growth temperatures. There was a significant increase in respiration rate in all cultivars with rise in temperature.

2.1.4. Vegetative development

Mitchell (1956) compared marsh birdsfoot trefoil with white clover and subterranean clover at mean temperatures of 11.5°C and 22°C, some specimens being grown in full light and some in shade at each temperature. The experiment revealed that this species was well adapted to compete in a relatively tall plant association under moderate shading at cooler temperatures. A notable feature was that *Lotus* grew slowly at 11.5°C in full light yet quite rapidly at the higher temperature. Stem elongation began very soon after germination whereas in white clover it was delayed until around fifty days after germination.

Many other studies, all on *L. corniculatus*, have been carried out in Canada and the United States. Gist (1956) and Rykord (1957) studied seedlings of herbage legumes under various combinations of light intensity and duration, temperature and soil moisture and both drew attention to the slow growth of birdsfoot trefoil under all treatments. Moore (1958) also reported poor growth of birdsfoot trefoil when light intensity was low. In further trials Gist and Mott (1958) reported similar findings. Baylor (1958) obtained results which showed that both shoot and root growth were severely depressed by reduced light intensities, roots being affected more than shoots. Gilbert (1960) showed that irrigation resulted in highly significant increases in dry weight of birdsfoot trefoil at 50% of normal light intensity.

Photosynthetic ability was compared in Empire trefoil which has low seedling vigour, and Viking which has the greater seedling vigour (Shibles and MacDonald 1962). Both cultivars had a similar net photosynthetic rate per unit area of cotyledon or leaf surface but Viking had a higher rate of production of photosynthetic surface.

The effects of day length on birdsfoot trefoil growth were studied by McKee (1962) who submitted several types to various photoperiods at a latitude of 40° 48' N. Nodulation was better under 13 and 15 hour photoperiods and natural daylength whereas the greatest root growth occurred under natural and 24 hour photoperiods. The least shoot and root growth occurred under a 9 hour photoperiod, suggesting that late summer sowings would put birdsfoot trefoil at a disadvantage throughout establishment.

Large varietal differences were found in growth habit by Nittler and Kenny (1965) when plants were grown under short photoperiods with relatively high light intensity containing a limited proportion of energy in the spectrum, coupled with relatively warm (16-26°C) light periods and cold (5°C) dark periods. They concluded from this experiment that growth habit of birdsfoot trefoil may be controlled, at least partially, by the phytochrome system.

Shading effects on birdsfoot trefoil were further studied by Grime and Jeffrey (1965) who recorded the failure of the species to survive in heavy shade, and by Bandyopadhyay (1965) who observed that birdsfoot trefoil needed at least 50% of daylight at the seedling surface during early seedling growth for satisfactory establishment while lucerne required a minimum of 25% daylight. Lotus seedlings grew best in 82% of full daylight, the cultivar Viking being more shade tolerant than Empire.

Cooper (1966) published the first of a series of reports on growth of birdsfoot trefoil, stating that it showed a greater relative growth rate than lucerne under 0%, 51%, 76%, and 92% of shading as a result of its greater leaf area ratio. Net assimilation rate of trefoil was similar to that of lucerne under low light intensities but inferior when shading was less. The greater relative growth rate of trefoil was unable to outweigh the initial growth advantage of lucerne as a result of lucerne's greater seed size and greater initial amount of photosynthetic tissue. Further trials revealed that, as shading increased, less of the accumulated dry matter was partitioned into roots and more into the stems, and the leaf area ratio was increased. The poor seedling vigour of birdsfoot trefoil, as compared with lucerne, could not be attributed to differences in the effect of low light intensities on relative growth rate (Cooper 1967).

Both lucerne and birdsfoot trefoil were found to have more stomata per sq. cm when grown in the open than when grown in the shade, and leaves of plants grown in the open were thicker than those in the shade. Shaded plants contained more chlorophyll per unit of leaf weight but less per unit of leaf area than plants grown in the open (Cooper and Qualls 1967).

The cultivar Leo, which has markedly improved seedling vigour, was found to have a higher relative growth rate in growth chambers at 21°C than cultivars Tana, Viking and Empire, attributed by Cooper and Qualls (1968) to a higher leaf area ratio when compared with Tana and Viking and a higher net assimilation rate when compared with Empire. At 27°C relative growth rate was higher in Leo and Tana than in Empire due to a higher leaf area ratio.

Nelson (1967) studied growth in birdsfoot trefoil under field conditions comparing plants of Empire with those of Vernal lucerne. Spring growth was from the crown, but after cutting, birdsfoot trefoil formed buds at nodes on the upper ends of cut stems whereas lucerne formed buds on stem-base nodes. Shoots were observed to be winter-annual and axillary branches of trefoil continued to grow after the main stem stopped elongating. This latter feature was considered to make birdsfoot trefoil well adapted to frequent grazing if adequate leaf-containing stubble were left. Of the two species, birdsfoot trefoil had a higher shoot/root ratio and lower root carbohydrate reserves. Trefoil roots contained little potential energy except in early spring and late autumn. Crop growth rate and net assimilation rate were usually lower in birdsfoot trefoil than in lucerne.

Dry weight increases in birdsfoot trefoil plants resulted mainly from production of shoot growth (Nelson and Smith 1968) whereas in lucerne, root and crowns also increased in weight. Axillary branching was greater in birdsfoot trefoil and the process continued after flowering began.

MacAulay and Bilanski (1968) studied mechanical properties affecting leaf loss in birdsfoot trefoil. There was no appreciable leaf loss while the plants remained in the green stage and trefoil leaves could not be readily removed by wind or vibration. When subjected to any handling treatment, loss of leaf increased as moisture content declined. Leaves were susceptible to removal and shattering while in a brittle state at moisture contents below 15%.

2.1.5. Nodulation

This feature has been thoroughly investigated in countries where the species have been introduced for agricultural purposes and have generally required inoculation with effective rhizobial strains to achieve a successful establishment. Freire (1965) reported such a typical problem occurring in Brazil where local strains of *Rhizobium* are generally ineffective in legume species despite the presence of native legumes. Production of effective inoculants has been increased and their use on birdsfoot trefoil varieties in a field trial has increased fresh weight yields by from 11% to 91%.

Strain effectiveness has been studied in several countries. In the United States, Erdman and Means (1949) tested isolates from several species of *Lotus* and from kidney vetch for their effectiveness on birdsfoot trefoil cultivars and on marsh birdsfoot trefoil. Strains isolated from the latter species showed varying degrees of effective nitrogen fixation on the host species but only produced ineffective nodules on birdsfoot trefoil. Similarly, strains from birdsfoot trefoil were effective on this species and on slender birdsfoot trefoil but not on marsh birdsfoot trefoil. Some strains from other *Lotus* species were effective on both birdsfoot trefoil and marsh birdsfoot trefoil but the authors warned against mixing strains as the establishment of a parasitic strain in a plant prevents nodulation by an effective strain. Results showed that marsh birdsfoot trefoil fixes considerably more nitrogen than other *Lotus* species when each is effectively nodulated. This work was later endorsed by Gavigan and Curran (1962) with cross-inoculation between *Lotus spp.* and kidney vetch in Eire.

Jensen (1964) came to similar conclusions from studies in Denmark and considered that the ability of these bacteria to nodulate species other than their normal hosts was an ecological factor in maintaining survival in soils where their host plants were not growing. Further studies indicated the existence of an extensive cross-inoculation group which included nodule bacteria from at least nine genera of host plants (Brockwell *et al* 1966; Jensen and Hansen 1968).

The early growth and nitrogen fixation of birdsfoot trefoil was suggested by Kunelius and Clark (1970) to be dependent to a large extent on the strain of *Rhizobium* and root temperature. Optimum root temperature for symbiotic nitrogen fixation was the same for *Lotus* as for other herbage legumes, between 18° and 24°C. Some strains of rhizobia were able to fix up to 150% more nitrogen than the less effective ones when root temperature was low, indicating that careful selection of rhizobial strain could possibly improve early growth of birdsfoot trefoil in regions where soil temperatures are low for long periods in spring and autumn. Of the three cultivars tested, Leo and Viking grew much faster than Empire. Comparisons with control plants fed on fertiliser nitrogen did however indicate the inefficiency of symbiotic nitrogen fixation within these cultivars. According to Smith (1955) the lower limit of soil temperature for effective nodulation on L. corniculatus was between 7^{o} and $10^{o}C$ while optimum soil pH was approximately 6.2 although nodulation was satisfactory at pH values ranging from 5.0 to 7.5.

Desiccation by exposure of inoculated seeds of birdsfoot trefoil to sunlight for more than five hours reduced subsequent yields and plant-nitrogen content (Alexander 1957; Alexander and Chamblee 1965). Effects were more marked when the seeds were exposed on dry soil than on moist soil.

Shading and defoliation effects were observed by Butler et al (1959) when marsh birdsfoot trefoil and other legumes were studied in New Zealand. There was a rapid loss of nodules and also of some roots under both shading and defoliation treatments, with only slight regrowth in the defoliated Lotus plants.

Allos (1957) examined the influence of inorganic nitrogen on symbiotic nitrogen fixation in legumes and observed that the lowest levels of nitrogen failed to stimulate fixation in L. corniculatus although this occurred in the other legumes under trial. High nitrogen levels reduced nitrogen fixation. By itself, symbiotic fixation failed to provide enough nitrogen for maximum legume growth.

Herbicide effects are reported by Winch et al (1967) who found that nodulation of Empire birdsfoot trefoil was not influenced by dalapon at 3 kg/ha but was inhibited by 1 kg 2,4-DB per hectare or dalapon with 2,4-DB each at 1 kg/ha. Garcia and Jordan (1969) noted that dalapon appeared to enhance the inhibitory effect of 2,4-DB on nodulation. Growth chamber experiments showed that 2,4-DB caused plant damage and abnormal root growth thus affecting nodulation. Birdsfoot trefoil was found to be capable of degrading 2,4-DB. More detailed studies showed that the rhizobia appeared to be incapable of utilising 2,4-DB as sole source but were fully capable of degrading the herbicide (Jordan and Garcia 1969).

2.1.6. Flowering characteristics

The physiology of flowering in birdsfoot trefoils was initially studied by Joffe (1958) in L. corniculatus which was found to be a long-day plant. A day-length of about 16 hours was required before profuse flowering was initiated. At 15 hours the number, rate and degree of development of floral primordia were restricted. Abortive buds were almost exclusively formed at 14 hours or in plants which received a sub-optimum number of long duration light-cycles. Production of abortive inflorescences appeared to be characteristic of this species even under optimum photo-inductive conditions. Under the influence of long days flowering occurred in flushes. Temperature had little effect on the production rate of normal inflorescences.

McKee (1963) established the critical photoperiod for flowering in L. corniculatus from several distant sources as being between 14 and 14.5 hours. Weller (1964) reported that flowering in birdsfoot trefoil was not hastened by vernalisation. The flowering process in marsh birdsfoot trefoil was studied by Fordo and Thomas (1966) who concluded that it was very similar to birdsfoot trefoil both in its critical photoperiod for flowering and its need for a strong daylength and light intensity stimulus for full flower development.

2.1.7. Pollination

Pollination of birdsfoot trefoils has been amply reviewed by MacDonald (1946). The main pollinating agents are the large-bodied

Hymenoptera, especially bumblebees and honey bees. Marsh birdsfoot trefoil may also be pollinated by some of the smaller insects as its flowers are smaller.

The genus has one advantage over clovers in that pollination is effectively carried out by honey bees as well as wild species. In North America honey bee populations are relied upon to the mutual benefit of both seed producers and beekeepers. Morse (1955) concluded from studies in New York State that honey bee populations of slightly less than one bee per square metre were sufficient to pollinate all flowers in a sward of birdsfoot trefoil. Under cages, populations of four to seven bees per square metre appeared to reduce seed yields. Birdsfoot trefoil was able to compete well with other honey plants in terms of sugar concentration in the nectar.

2.1.8. Fertility

Fertility studies carried out by Tome and Johnson (1945) and many others show that under field conditions nearly all seed was set by cross-pollination due to bees. A study by McKee (1949) showed that birdsfoot trefoil is highly self-sterile, as is slender birdsfoot trefoil. Marsh birdsfoot trefoil is highly self-fertile but contains some self-sterile plants. Both birdsfoot trefoil and marsh birdsfoot trefoil would not set seed until the style was forced out through the keel and the surface of the stigma struck against a foreign object, indicating the dependence of these species on insect visitations. Inbreeding depression was found to occur within birdsfoot trefoil after only one generation (Longwell and Shirky 1951), a reflection of the normal out-breeding habit of the species.

Makus (1959) also reported low occurrence of natural self-fertilisation but was able to increase seed setting by artificial self-fertilisation.

Bubar (1958, 1959a, 1959b) made a detailed investigation of the fertility of *Lotus* species. He suggested that the fundamental distinction between self-compatibility and self-incompatibility might be found in the behaviour of the stigmatic membrane. Self-incompatible plants could have developed by losing the ability to rupture the stigmatic membrane automatically, and should be distinguished from self-sterile plants. Further studies suggested that the genetic mechanisms for self-sterility and self-incompatibility are probably independent, indicating eventual possibilities of breeding commercial varieties possessing hybrid vigour.

This aspect was pursued by Spiss and Hittle (1967) who studied pollen physiology in relation to incompatibility in birdsfoot trefoil while Seaney (1967) inbred plants and crossed the resulting lines to obtain F1 hybrids. The best F1 crosses yielded about 35% more herbage than Viking, unrelated S2 (second inbred generation) inbreds producing higher-yielding F1 hybrids than related inbreds.

2.1.9. Cytology

The basic diploid chromosome number of the genus has been established as being 12. Senn (1938) confirmed that the chromosome numbers of the major species were:-

L. tenuis 2n = 12

L. pedunculatus 2n = 12

L. corniculatus 2n = 24.

Prior to this many workers had suggested that *L. tenuis* was a botanical variety within the species *L. corniculatus* and had referred to it as *L. corniculatus* var. *tenuifolius* L. Dawson (1941) advanced the theory that *L. corniculatus* is an autotetraploid which probably arose from *L. tenuis* and which resembles the latter in seven of ten listed characters. No proof was produced for this theory and in 1954 Larsen surmised that *L. corniculatus* var *alpinus*, which is a diploid species (2n = 12), may be the progenitor of *L. corniculatus* rather than *L. tenuis*. *L. corniculatus* is therefore probably an autotetraploid although its origin is still rather obscure.

Successful crosses have been made between *L. pedunculatus* and *L. tenuis* and between both diploid and artificial tetraploid forms of *L. pedunculatus* and *L. corniculatus*. Artificial induction of aneuploids has also been achieved (Grant 1961, 1969; Henson and Schoth 1962). The cytogenetics of the genus has been and is being investigated in great detail by Grant and others at Macdonald College, Quebec, Canada.

2.1.10. Ecology

There are approximately two hundred species within the genus *Lotus* distributed throughout the world, sixty of these being endemic to North America, having their geographic centre of origin in the south-western United States (Grant, Bullen and Nettancourt 1962; Zandstra and Grant 1967). The agricultural species *L. corniculatus*, *L. tenuis* and *L. pedunculatus* are widely distributed throughout the world's temperate regions and are common on a wide range of soils at altitudes from sea level to 3000 metres (MacDonald 1946).

Birdsfoot trefoil, until recent years, did not occur naturally in the Americas but elsewhere it has been one of the most common and widely distributed native wild plants. Robinson (1934) describes its occurrence all over Europe to a northern limit of about 71° 58' N Lat. and from the Soviet Union to West Africa and the Azores. Liebenberg (1956) mentioned birdsfoot trefoil among forty forage species growing in the Transvaal region of South Africa and Panikkar (1949) described its distribution and cultivation in India, as did Sekizuka (1958) in Japan. MacDonald (1946) cited references to its assumed introduction from Europe into Australia and New Zealand and gave details of its introduction and spread throughout North and South America. In tropical areas, Hosaka (1957) reported birdsfoot trefoil's adaptation in the Hawaiian Islands and Quiros (1946) described its ecology and use in Costa Rica. Distribution of L. tenuis is similar to that of L. corniculatus but to a much lesser degree, while that of L. pedunculatus is geographically wide but ecologically confined to areas of high rainfall. MacDonald (loc. cit.) recorded European distribution of marsh trefoil and mentioned its adaption to certain parts of the American continent. Its distribution in Australia is described, along with its utilisation, by Hardy (1949) and Gardiner and Elliot (1945) while Levy (1918) noted its occurrence in New Zealand.

Birdsfoot trefoil is found in grassland of varying types, notably low grade pastures (Robinson 1934). Both common and marsh birdsfoot trefoils were observed to be common in water-logged pastures by Stapledon (1925), and Jenkin (1925) found birdsfoot trefoil to be almost the only legume present on open hill land in Wales. It thrives at high altitudes such as in the Swiss Alps where Caputa (1956) reports its excellent frost resistance even in severe winter conditions. The present author has frequently noted its abundance in sand-dune associations at sea level and there are cases where it has been used in seeds mixtures for sand stabilisation purposes (Midmer 1970). In Canada Chevrette and Gauthier (1957) were cognizant of its resistance to flooding and its value for combating erosion by water.

MacDonald (1946) and Henson and Schoth (1962) noted the strong drought resistance in birdsfoot trefoil and while marsh birdsfoot trefoil lacks this ability, it was recorded in New South Wales as giving a balanced high-quality pasture during drought conditions (Department of Agriculture NSW, 1967).

Numerous trials carried out during the past century have shown that birdsfoot trefoil is more adapted to soils lower in fertility than that required for other legumes.

In the Cockle Park pasture experiments birdsfoot trefoil was one of the chief legume components at the start but disappeared except in the unfertilised plots (Thomas and Elliott 1932). MacDonald (1946) described similar results in the Rothamsted grassland trials during the latter part of the nineteenth century when birdsfoot trefoil was the most abundant legume in the unfertilised plots. In his own trials MacDonald found that it tends to be more productive than other legumes at lower fertility levels and on normally poor soil, especially where calcium is deficient. He suggested that the main reason for this was the type of root system and its distribution, rather than any marked differences in nutrition requirement for growth.

In Denmark the species was recommended for use along with kidney vetch on lime-deficient soils where red clover was found to make poor growth, or where red clover eelworm (Ditylenchus dipsaci) was present (Anon. 1940).

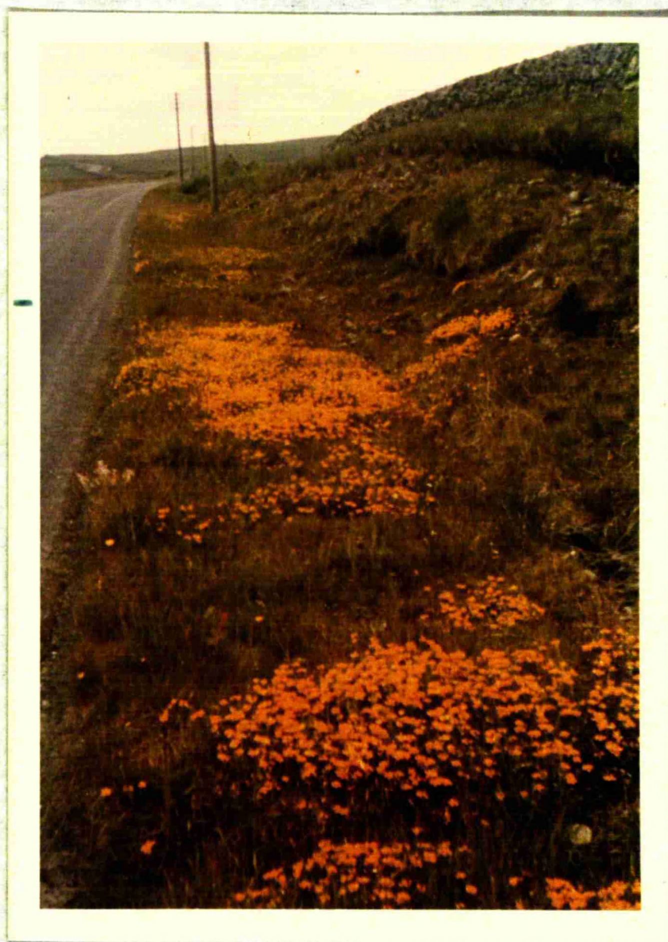


Plate 1

Birdsfoot trefoil growing wild on road verges in south-west Scotland. It is also common in other well-drained situations although not so easily noticed when grazed.

Plate 2

Marsh birdsfoot trefoil wild in poorly-drained areas.

2.2. BIRDSFOOT TREFOILS AS AGRICULTURAL PLANTS

2.2.1. History

The development of birdsfoot trefoils within agriculture has been reviewed in detail by Robinson (1934) and MacDonald (1946). The following account has been drawn mainly from these sources.

Lotus corniculatus

Robinson (1934) credits Ellis with supplying the first useful account of birdsfoot trefoil as a valuable herbage plant in Britain in 1744. By 1810 seed was being offered for sale in London. MacDonald quotes Sinclair (1826) who estimated the fresh weight yield at full bloom to be 10,000 kg/ha, and Morton (1855) who considered it a neglected yet a promising, highly palatable legume comparable with clover.

In France the species received little attention until the end of the nineteenth century but has been increasingly used by French farmers during the current century, more than in other parts of Europe. The Swiss, Germans and Italians started to use birdsfoot trefoil during the middle of the nineteenth century and other European countries have followed suit, especially in the eastern alpine regions.

Birdsfoot trefoil was introduced into Australasia in 1864 but has been of little value whereas marsh birdsfoot trefoil has proved of value.

Samples of birdsfoot trefoil were introduced to North America from Europe between 1885 and 1900 and were tested at several experimental stations, but its agricultural use was limited until Professor Johnstone-Wallace encouraged research on its potential agricultural use at Cornell University, New York State, prior to 1939. This led to the introduction of varieties, notably Empire and Viking birdsfoot trefoils, and a rapid increase in its use throughout the north-east and north-west United States and neighbouring provinces of Canada. In those areas the species is now an important herbage legume and a serious rival to lucerne and white clover wherever the performances of these species is less than first-class (Winch 1961; Henson and Schoth 1962).

In South America, L. corniculatus is now an important legume in the humid regions of Argentina and Uruguay where it forms a productive sward growing with tall fescue (Frame 1969). This species has also spread through Europe and Russia to India where it has been found useful in pasture mixtures (Sinha and Dey 1956).

Lotus pedunculatus

Marsh birdsfoot trefoil was developed for grassland use at about the same time as birdsfoot trefoil and soon developed a reputation as a legume for damp situations. Favourable results were obtained by Buckman (1868) in Britain when it was used in conditions too moist for clover or lucerne, but its use on other soils was rather limited.

Marsh birdsfoot trefoil has been cultivated in France and Germany on newly reclaimed moorland since the mid 1800's. It has become well adapted to the acidic coastal soils of the north-western United States where it is called big trefoil, thriving on low-lying areas which are often flooded during the mild winter months and also on the moist uplands where it grows well at pH values of 4.5 to 5.5. Under these conditions the application of lime has not increased its yield.

Gardner and Elliot (1945) described its use on moist peaty soils in Western Australia and Hardy (1949) discussed its relative merits in New South Wales.

Levy (1918, 1951) drew attention to the potential value of *L. pedunculatus* in New Zealand grasslands and Suckling (1965) has cited cases where its introduction has largely turned grassland failure into success by encouraging stock to graze in scrub and rush areas thereby obliterating these weeds by crushing. In recent years Barclay (1960, 1970) has greatly improved its characteristics by breeding cultivars with better seedling vigour and by crossing indigenous material with ecotypes from other countries.

Lotus tenuis

This species is the least important of the three agricultural species as it is similar to *L. corniculatus* in characteristics yet not so adaptable. It is well suited to poorly-drained clay soils and is an important herbage legume in France and surrounding regions of Western Europe.

In the United States, parts of New York State are particularly suited to slender birdsfoot trefoil (Henson and Schoth 1962) while in California and neighbouring states it is important in pastures, growing well in soils containing large quantities of soluble salts and it is the most common legume on saline and alkali soils in regions having relatively mild winters (Peterson *et al* 1953).

Because of its limited use and potential in intensive and natural grasslands this species will not be dealt with in this thesis, except in specific cases where it serves to illustrate a particular feature pertaining to the genus in general.

2.2.2. The development of bred varieties

The production of distinct cultivars of birdsfoot trefoil started during the 1930's. Before this, *Lotus* had been considered a secondary herbage plant by the breeders who had applied their newly-devised selection methods to the important species - red and white clovers, and lucerne. Local varieties of birdsfoot trefoil were used in some European countries but these were of doubtful value except in their own localities.

Several breeders simultaneously recorded the selection and testing of trefoil cultivars. In Europe, varieties were bred in Denmark and Czechoslovakia in the 1940's while in the United States selection was carried out in New York, Dakota and Oregon. More recently Canada, Russia, Poland and South America have developed their own varieties while in New Zealand marsh birdsfoot trefoil has been improved.

Frandsen (1943) bred the Roskilde variety of birdsfoot trefoil in Denmark in the 1930's and went on to produce Early Otofte II and Late Roskilde II by crossing local wild types of birdsfoot trefoil. Bøgh bred Early Pajbjerg II and Late Pajbjerg II at Børkop and these four varieties were awarded first-class rank in the 1951-4 strain trials in Denmark (Anon. 1955). Rasmussen (1958) described trial results with Danish varieties and quoted yields of 8300 kg/ha of dry matter during the first season and 4700 kg/ha in the second season. Mean crude protein yields ranged from 1610 kg/ha to 1450 kg/ha during the first year and from 930 kg/ha to 740 kg/ha during the second year. The use of these varieties has declined since these trials and now only one of Frandsen's varieties is available, called Lota (Bøgh 1970).

The reason for the decline in use of L. corniculatus in Denmark would appear to be that breeders have now improved red and white clovers for use on the light soils where birdsfoot trefoil had potential. Clover varieties with a high degree of eelworm resistance have now been bred and are much more productive in Danish conditions than *Lotus*. Seed production was also considered to be a problem with birdsfoot trefoil and it was prone to some diseases (Bøgh 1970).

Faljkovskii (1950) mentioned selection of birdsfoot trefoil varieties at the State Agricultural Research Station, Tabor, Czechoslovakia, where the species gave good results under arid conditions. New cultivars of both *L. corniculatus* and *L. pedunculatus* were produced at the Czechoslovakian State Research Institute at Roznov. Kiss (1967) mentioned the successful use of Czechoslovakian varieties in Hungary and Regel (1968) described the cultivars Taborsky and Trebiesky.

Various references are made to Russian varieties of birdsfoot trefoil. Bubar (1964) used the cultivar Morshansk 528 in the breeding programme which produced the variety Leo. Rodionov (1953) recorded the selection and use of varieties bred in Gorjkii province of the Soviet Union. In his book, Kolar (1956) devoted a whole chapter to breeding problems with *Lotus spp.* in eastern Europe. More recently Komov (1966) described the new varieties Dedinovskii and Moskovskii 25 while Zhidonite and Virbitskene (1969) reported the development of a birdsfoot trefoil variety called Gol'svis.

Varieties are available in several other European countries. OECD (1970) lists Diana and Lot (Poland), Oberhaunstadter and Odenwalder (Germany) and L9 from Italy as cultivars eligible for certification. Davies (1969) used eight Italian and nine French varieties in his Welsh trials although no mention of the development of these varieties is made in the scientific literature.

In the United States breeders noticed *L. corniculatus* in two agronomic forms, the New York type which was a prostrate, persistent form well suited for grazing and the European material, earlier, more vigorous and erect, yet less persistent (Pierre and Jacobs 1954). One of the earliest selections was made from the New York material and eventually named Empire (Seaney and Henson 1970). European material was developed into the cultivar Viking by breeders at Cornell University, Ithaca, New York State.

The first American variety to be approved for registration was Cascade (Hollowell 1954). This was developed from French material and has good seedling vigour and recovery growth but is not as winter hardy as Viking (Seaney and Henson 1970). Cascade was closely followed by Granger, developed in Oregon from British material and very similar to Cascade (Hollowell 1954, 1958).

Oregon Agricultural Experimental Station named two varieties of marsh birdsfoot trefoil in 1950 as Columbia and Beaver. Long-term trials, reported by Howell (1948), showed this species to be outstandingly successful on acidic soils and on winter-flooded land. A small seed-growing industry developed but limited markets and generally unfavourable weather for seed harvesting has discouraged production. At the same time the use of marsh birdsfoot trefoil in coastal pastures is decreasing. Columbia marsh trefoil has now disappeared but Beaver is being maintained for certification (McGuire 1970). The main drawback to the use of the species was failure in establishment most likely caused by failure to nodulate, although no difficulties were experienced on test or demonstration sites (McGuire loc. cit.).

Other varieties of L. corniculatus have been developed in the United States in recent years, notably Douglas, a selection developed in Oregon (Seaney and Henson 1970), Mansfield, a variety similar to Viking (Anon. 1956a; Gershoy 1956), Fargo, developed in North Dakota, Tana, released in 1956 (Davis et al 1956) by breeders in Montana, and Dawn, developed from the variety Empire (Baldridge 1970).

In Canada *L. corniculatus* is widely used in the farming areas of the eastern provinces (Winch 1958b). Dubar (1964) selected the variety Leo from Morshansk 528 and greatly improved seedling vigour and winter-hardiness in the crop. He described Leo as being a potential replacement for Empire but having particular value in hay production in eastern Canada. Its increased hardiness suggested that the species could be used over a wider area than previously thus possibly leading to the development of a trefoil seed industry in western Canada.

A second Canadian variety was released in 1968 from Guelph under the name Maitland (Twamley 1970; Seaney and Henson 1970). It is a synthetic selected from other cultivars for seedling vigour, forage yield and winter hardiness, and said to be an improvement on Viking.

Other Canadian developmental work includes selection within local material in Nova Scotia (Langille 1969).

Birdsfoot trefoil is widely used in the South American countries of Brazil, Argentina, Uruguay and Chile, and some varieties have been developed. San Gabriel (Brazil), Kimey (Chile), La Estanzuela (Uruguay) and Pergamino El Boyero from Argentina are named selections of *L. corniculatus* which are used in these countries (Gardner *et al* 1968). They have been developed from selections within other varieties and only recently have programmes been initiated using various genetic sources including native material to create improved cultivars (Frame 1971). *L. corniculatus* is in widespread use because it remains productive for a long period (Rockefeller Foundation 1960) and in Chile, selections were made within *L. corniculatus* for types persistent under extreme drought; similar work with *L. pedunculatus* was planned but no literature on this development has yet been published.

The breeding of *L. pedunculatus* in New Zealand has been reported in detail by Barclay and Lambert (1970). In 1957 a cultivar, now named Grasslands 4701, was developed from selections within New Zealand material. The possibility of improving seedling vigour by artificial induction of tetraploid marsh birdsfoot trefoil was investigated (Barclay 1957; Barclay and Armstrong 1966) and this project resulted in the variety Grasslands 4702, which has larger seeds and therefore greater seedling vigour but seed setting is lower than in normal diploids.

The next stage was improvement in winter growth by hybridisation between Grasslands 4702 and a Portuguese introduction. The hybrids were backcrossed to Portuguese and 4701 and two populations were produced:-

(i) Hybrid 1 (NZxP)NZ

(ii) Hybrid 2 (NZxP)P.

Recurrent selection within each backcross resulted in the named varieties Grasslands 4703 and 4704 respectively (Barclay 1960).

The most recent programme has aimed at the production of an autotetraploid hybrid between Grasslands 4702 and the Portuguese introduction. Elite plants of an induced tetraploid of Portuguese material were crossed with the tetraploid 4702 and the F1 plants were backcrossed to 4702. Recurrent selection within this material led to Grasslands 4705 (NZxP)NZ (Barclay and Lambert 1970).

These tetraploid varieties have proved successful in a series of trials throughout New Zealand, especially when oversown and when grazing pressure was low. Under harder grazing conditions the more dense diploids were clearly superior and Grasslands 4703 combined best winter and summer yields and had the highest three-year mean annual production. Further investigations are under way and the commercial use of these cultivars will depend on these results.

The improvement of birdsfoot trefoil has taken several different pathways in recent years. Interspecific hybridisation has been carried out at several plant breeding institutes with a view to combining the desirable features of each species within hybrid varieties. At Aberystwyth tetraploid forms of L. tenuis and L. pedunculatus were developed, for crossing with L. corniculatus (Davies 1961).

Some hybrids were produced by means of artificial embryo culture but no further progress was reported. At Cornell, New York, Bent (1962) obtained hybrids by crossing L. pedunculatus with L. tenuis, L. pedunculatus with diploid L. corniculatus and tetraploid L. pedunculatus with normal L. corniculatus using embryo culture techniques. The last cross was also carried out in New Zealand with the object of combining the competitive ability of L. pedunculatus with the drought resistance and palatability of L. corniculatus but some of the hybrids gave disappointing performances in field trials (Anon. 1964b; Harris 1970). Tetraploid L. tenuis was crossed with L. corniculatus resulting in hybrids with intermediate features (Jenson and Federer 1965; Wornsman et al 1965). Selection for greater seed size was carried out in Iowa by Draper (1964) and Draper and Wilsie (1964, 1965) who obtained, in three cycles of recurrent selection, 20% increase per cycle in the cultivar Viking and 5.25% increase per cycle in Empire.

Breeding for resistance to pod dehiscence in birdsfoot trefoil was carried out at Cornell, New York, by Gershon (1962) using tetraploid forms of L. coimbrensis and L. pedunculatus. Fertility of the progeny was found to be highly correlated with the rate of pod dehiscence but some interspecific hybrids with low dehiscence rates were produced. Buzzell and Wilsie (1964) studied early and late-flowering forms within Empire and Viking in an attempt to relate seed production potential to flowering time. Late-flowering forms were found to be low seed producers but difficulties in studying the genes responsible for greater seed production were encountered. Albrechtsen (1966) showed that prostrate plants had higher mean values for seed yield than upright plants. Progeny from prostrate types crossed with upright types were superior to those from prostrate crossed with prostrate or upright crossed with upright types for most of the features under study. The number of umbels setting seed had the greatest influence upon seed yield of the four components analysed in the investigation.

The inheritance of leaf size in birdsfoot trefoil was investigated by Donovan (1958, 1959) and later, Mowat (1967) suggested that selection for increased leafiness should markedly improve the digestibility of the species.

2.2.3. Description of cultivars

L. corniculatus

CASCADE originated from selections made in Washington State, U.S.A., in 1944 from European material, possibly of French origin (Hollowell 1954). The most vigorous plants were selected from three imported seed lots and grown on in isolation (Peterson et al 1953). It was the first American Lotus cultivar to be approved for registration in 1954. Hollowell (1954) described it as an erect, persistent broadleaf type with good seedling vigour, good recovery after cutting and capable of producing high forage yields. Its strong seedling vigour enables it to establish rapidly and grow well when mixed with an aggressive grass such as cocksfoot (Chapin et al

1951). It is reported in Seed World (1952) that it failed to survive on swamplands or peat or on extremely droughty soils although it did survive occasional flooding.

In Iowa State it was recommended for hay production as it proved superior to the prostrate varieties in this capacity yet inferior under permanent pasture conditions (Anon. 1956b). Rachie (1955) noted that Cascade was intermediate in winter hardiness and cold resistance when compared with Empire and Viking trefoils and Ranger lucerne.

DAWN is a four-clone synthetic developed from selections made within the variety Empire at the Missouri Agricultural Experimental Station and released in 1966, according to Seaney and Henson (1970). It was described as closely resembling the parent variety Empire but with greater resistance to root rot, caused by Phymatotrichum omnivorium, greater persistence and increased yields of herbage and seed (Anon. 1966). Seaney and Henson (1970) noted that it is earlier flowering than Empire and slightly more erect in growth habit.

DIANA is a certified variety (OECD 1970) bred and available in Poland. No further information is available.

DOUGLAS originated in Douglas County, Oregon and was selected from several European lots of birdsfoot trefoil under test. Henson and Schoth (1962) describe it as an erect, vigorous European type.

EMPIRE is a selected ecotype found in fields in Albany County, New York, during the 1940's. It is a semi-erect, hardy, late-maturing type with leafy but very branched stems (Henson and Schoth 1962). Flowering occurs from ten days to two weeks later than the European forms and is rather indeterminate as flowers are continually produced on new growth which originates from node buds along the stem (Seaney and Henson 1970). Spring growth and recovery after exploitation are rather slow in Empire but the variety is very winter-hardy in north-eastern United States and in Canada. Henson and Schoth (1962) noted that seedlings are generally poor in vigour but once established, the variety is very persistent and productive for grazing and for conservation purposes. Baldridge et al (1966) pointed out that stands of Empire birdsfoot trefoil are prone to rapid thinning when mown for hay or seed, or when closely grazed - thereby preventing volunteer re-seeding, when aggressive companion grasses are not held in check, or when disease such as root rots or pests (especially grasshoppers) are rife.

FARGO is a late-flowering prostrate type bred in North Dakota (Bubar 1967).

GRANGER was released in Oregon in 1951 after extensive trials. It is claimed that this variety originated from British material (Anon. 1951) whereas Seaney and Henson (1970) state its origin in French seed lots. Two outstanding features of this variety mentioned are its vigorous seedling development which aids establishment and its rapid recovery after harvesting. Its consistently high yields of forage are comparable with other types of Lotus; its forage is both palatable and nutritious. Granger was registered for certification purposes in 1958 (Hollowell 1958).

LEO was selected in Quebec, Canada, by Bubar (1964) from the cultivar Morshansk 528 on account of its winter survival capabilities. Seedling vigour is high and it has excellent early spring growth - an advantage for hay. It matures about one week before Empire, has faster aftermath recovery and terminates autumn growth earlier than any other variety (Bubar 1967). In trials with Empire and Viking, Leo had similar herbage and seed yields but had greater winter hardiness (Bubar 1970).

LOT is a certified cultivar bred and used in Poland (OECD 1970). No information on its characteristic features can be cited.

MAITLAND was bred by Twamley (1970) at Guelph, Ontario, and licensed in Canada in 1968. It is an eleven-clone synthetic originating mainly in the variety Viking but with additional germplasm supplied by Mansfield, Cascade and the Danish Roskilde type.

Maitland has considerably more seedling vigour than Viking and is one or two days later in flowering. It resembles Viking in general appearance, being early, upright and large-leaved. Hardiness is inferior to that in Empire and Leo and it is not so well adapted to poorly drained soils as these varieties are.

MANSFIELD was developed and released by the Vermont Agricultural Experiment Station (Gershoy 1956). Erect, vigorously productive plants were selected from a Danish seed stock, a seed stock from Columbia County, Vermont, and another imported lot. Several hundred superior plants were combined to produce seed of the new variety (Henson and Schoth 1962). The variety is similar to Viking in growth habit, winterhardiness and range of adaptability.

MORSHANSK 528 is a Russian cultivar which was obtained by Bubar (1964) from the All-Union Institute of Plant Industry, Leningrad in 1956. Twamley (1969) described it as being late-maturing and very winterhardy. Leo was selected from this variety.

SAN GABRIEL was bred from unknown material at a research station in the Rio Grande do Sul province in southern Brazil (Frame 1969). It has been used in the production of other South American varieties such as Kimey, La Estanzuela and Forgemino El Boyero which are probably only local selections from San Gabriel. Gardner et al (1968) found these varieties to be very similar in behaviour to each other. They were the earliest flowering varieties in Uruguay trials against Italian and United States varieties, and also gave the highest yields at the first cut after establishment and in winter. Persistence was not high in San Gabriel.

TABORSKY and TREBICSKY are cultivars bred in Czechoslovakia which perform well in that country (Regal 1968) and also in east European grasslands (Kiss 1967).

TANA was released by the Montana Agricultural Experiment Station during the early 1950's and is a vigorous erect type very similar to Cascade and Granger (Henson and Schoth 1962) but appears to have more rapid recovery after cutting than those varieties

(Seaney and Henson 1970).

VIKING was developed at Cornell University, Ithaca, New York, by selecting desirable plants from a Danish importation and early, erect New York State local varieties. It is erect, broad-leaved, rapid growing and high yielding. Seedling vigour is good and it is more winter hardy than Granger, Cascade and European seed stocks (MacDonald 1957). It is well suited for conservation purposes when mixed with Medicago sativa on fields with a wide range of drainage conditions (MacDonald 1963).

L. pedunculatus

BEAVER is a selection from L. pedunculatus var. villosus, a hairy form within the species. It was developed in Oregon from indigenous material and has its foliage covered with fine hairs, giving the plant a grey-green appearance.

COLUMBIA was a variety of L. pedunculatus var. glabriusculus, the smooth form with relatively few hairs, also selected in Oregon and released at the same time as Beaver. Both these varieties were bred for both pasture and hay utilisation, Columbia being slightly more palatable and therefore more valuable for grazing (Howell 1948; Anon. 1950). Columbia has now disappeared but Beaver is being increased to maintain it in the current certification programme (McGuire 1970).

GRASSLANDS 4701 to 4705 are varieties of marsh birdsfoot trefoil bred by the Grasslands Division, Palmerston North, New Zealand, during the last ten years (Barclay and Lambert 1970). 4701 is based on nine elite parents selected from indigenous New Zealand material. 4702 is a tetraploid developed by colchicine treatment of 4701 followed by three generations of recurrent selection. It is based on 13 elite mother plants and has larger seed and greater seedling vigour than its predecessor, but lower seed setting.

4703 was the result of a cross between 4701 and a Portuguese introduction which was back-crossed with 4701, while 4704 was produced from back-crossing the 4701-Portuguese hybrids with the Portuguese material. Both varieties are diploid with 12 chromosomes.

4705 was bred by treating the Portuguese material with colchicine, obtaining tetraploids which were then crossed with the tetraploid 4702. The first generation obtained was back-crossed to 4702 and the resulting material submitted for selection. In general the tetraploid types have superior seedling vigour due directly to increased seed size. The plants are vigorous, have thick leafy stems and a more open growth habit. Persistency is significantly greater in the diploid varieties which have more dense foliage and withstand harder grazing conditions.

L. tenuis

LOS BANOS is the only cultivar of L. tenuis available, bred in California (Henson and Schoth 1962). It is semi-erect with fine foliage.

2.2.4. Establishment

One of the major factors responsible for the slow acceptance of birdsfoot trefoil as a herbage legume has been its reputation for poor establishment. Local varieties and initial selections had low seedling vigour compared with other herbage legumes. Competition from companion crops and weeds has often resulted in poor plants that later succumbed to winter conditions. Sowing techniques were used which emphasised the low vigour and competitive ability of Lotus, resulting in swards which remained unproductive until two or three years after seeding. Improved techniques have been developed as a result of research into this problem at many centres and the improved cultivars of birdsfoot trefoil can now be easily established without delay in production (Winch 1961; Henson and Schoth 1962).

Like other legumes birdsfoot trefoil establishes best when the seedbed is firm and fine, thus ensuring close contact with soil particles and an adequate supply of soil moisture. The optimum depth of sowing is approximately 10-15 mm (Stickler and Wassom 1963). Deeper placement retards emergence (Ahlgren 1955) whereas surface-seeding delays and reduces germination (MacDonald 1946).

Several sowing methods may be used but experience in North America (Winch 1961; Henson and Schoth 1962) indicates that more uniform swards result from drilling than from broadcasting.

Early spring sowing is generally most successful in northern regions. Actual date of sowing varies from mid-March to June but MacDonald (1946) showed that sowing later than the first week in June was not advisable. Autumn sowing does not allow the trefoil seedling enough time to develop to a stage capable of winter survival because of low seedling vigour (Winch 1961). October sowing is advocated by Peterson et al (1953) as an alternative to February sowing under the particular conditions in California. In Oregon (McGuire 1970) marsh birdsfoot trefoil is spring-sown whereas autumn sowing is preferred in Florida (Henson and Schoth 1962).

Trials of marsh birdsfoot trefoil in New Zealand were sown in autumn (Barclay and Lambert 1970).

Inoculation of seed is recommended, where Lotus is new to the particular area (MacDonald 1946; Winch 1961; Henson and Schoth 1962). A specific rhizobial culture is required for each species and any imbalance in nutrient supplies must be corrected at sowing time. New Zealand trials indicated the superiority of pelleted seed of L. pedunculatus (Harris 1970).

Lotus species are known to be productive on soils less fertile than those needed for other herbage legumes, on poorly drained and heavily textured soils or where clay, saline or alkaline content is high; crops have been grown successfully on soils with pH levels significantly lower than those required by clovers and lucerne (Anon. 1967a).

Lime is needed, however, on soils which are very acidic, the optimum pH value for trefoil varying from 5.2 to 7.5 depending on soil type (Dionne 1969). Liming increases uptake of phosphate but depresses potassium uptake, so soil analysis should be carried out to assess supplies of these minerals and restore any deficiencies. Nitrogen fertiliser was found by Ward and Blaser (1961) to have adverse effects on herbage legumes including birdsfoot trefoil; the number of seedlings emerging was reduced with increasing applications of nitrogen and legume yield in the first year was decreased. In other work it was found that up to 25 kg/ha of nitrogen has increased seedling vigour and this was stated to be the recommended practice for trefoil establishment in Ontario (Winch 1961). The same author later suggested the use of 100 kg/ha of a nitrogen-free compound fertiliser for surface-seeding of rough grassland, and the avoidance of nitrogen during the establishment year. McClellan (1963) found that Viking and Empire birdsfoot trefoils established successfully when sown in July or August, the process being unaffected by manuring.

Band placement of fertiliser in the seed bed was found to be superior to broadcasting in some trials (Tesar 1954; Baylor 1958) while Duell (1957, 1964) found no improvement with birdsfoot trefoil. Forbes (1959) attributed band placement responses to closer positioning of fertiliser in low fertility soils.

Although the average hard seed content in birdsfoot trefoil sold in North America is approximately 30% (Brown 1955) the recommended seed rates make scarification unnecessary. L. corniculatus and L. tenuis are usually sown at 5 to 8 kg/ha while L. pedunculatus is sown at 3 or 4 kg/ha. He also found that, unlike other legumes birdsfoot trefoils cannot withstand competition from red, white and alsike clovers and to a lesser extent, lucerne.

In Canada recommendations suggest the use of birdsfoot trefoil in simple mixtures, either alone or preferably with timothy (Winch 1961). Some lucerne seed may also be included. A typical mixture would contain 4 kg/ha of timothy with 8 kg/ha birdsfoot trefoil. Henson and Schoth (1962) also mention similar mixtures in widespread use, including one where smooth-stalked meadow-grass replaces timothy at the same seed rate. Cases are mentioned where cocksfoot, tall fescue and brome-grass have been mixed with birdsfoot trefoil - normally 4 to 5 kg/ha of grass seed with 6 kg/ha of a trefoil variety which has good seedling vigour - and productive pastures have been produced (Henson and Schoth 1962). For improvement of natural pastures in North America L. corniculatus is surface-sown alone at 10 kg/ha.

In New Zealand the price of marsh birdsfoot trefoil seed is high and only 0.5 to 1 kg/ha is included in mixtures for this reason (Suckling 1965). Trials of cultivars in North Island were sown at 2.2 kg/ha for diploids and 4.4 kg/ha for the tetraploids 4702 and 4705, along with perennial ryegrass at 5.6 kg/ha. In a South Island trial the diploids were sown at 4.5 kg/ha and the tetraploids at 9 kg/ha, each with perennial ryegrass at 11.2 kg/ha and cocksfoot at 6.7 kg/ha. For comparison white clover was sown at 2.2 kg/ha in North Island and 5.6 kg/ha in South Island (Barclay and Lambert 1970).

Although direct seeding of birdsfoot trefoil is advocated in Canada undersowing it in an oat crop is the most widespread practice as this crop offers less competition to Lotus than other cereals (Winch 1961). Where this method is practised the seed rate of oats should only be 35-50 kg/ha as this produces similar yields as higher rates yet does not seriously interfere with establishment of birdsfoot trefoil (Winch 1961; Buxton and Wedin 1970). The danger of smother from lodging can be reduced by using a stiff-strawed variety.

Competition from oats can be further reduced by use of 350 mm drills instead of the usual 170 mm spacing, or by grazing when the oats are 300 mm high leaving a 150 mm stubble. Harvesting at the soft dough stage and conserving as silage is another possibility. Peters (1961) observed that a cover crop of oats reduced yield of trefoil more than did weeds which invaded the areas seeded without a cover crop. Steppler et al (1965) suggested that there was an optimum number of plants that could be established per unit area of land and that this number was not materially influenced by seed rate. Competition was found to vary during the establishment season but birdsfoot trefoil was shown to be sensitive to competition at all times. Watson *et al* (1968) studied the influences of sowing method, seed rate and nitrogen fertiliser on the establishment of birdsfoot trefoil and found that a cover crop of oats markedly reduced the chances of a successful establishment. Nitrogen at up to 28 kg/ha had no significant effect and stands established at trefoil seed rates of 4.5 and 9 kg/ha had almost equal densities.

Unfortunately direct seeding of trefoil allows annual weeds to invade the crop and these must be controlled either by mowing or by herbicide applications. The method used to control the weeds has an effect on yields during the first and second years of the sward, as shown by Scholl and Brunk (1962). Herbicidal treatment affected yield less than a cover crop of oats during the first year; size of seedling markedly affected subsequent yields.

Mowing of weeds also reduced the trefoil plant population (Winch 1961) so that chemical weed control was deemed to offer most promise.

Recommended treatments of seedling swards of birdsfoot trefoil include applications of 1 kg/ha of 2,4-DB at the second true leaf stage in trefoil, dalapon at 2 kg/ha before weed grasses are more than 80 mm high; EPTC applied at the same rate to the seedbed prior to sowing and worked into the surface by discing and harrowing (Scholl and Staniforth 1958; Anon. 1967a). Success has also been achieved by use of EPTC and/or 2,4-DB in similar methods (Linscott *et al* 1967; Linscott and Hagin 1969a, 1969b). Other effective treatments involved the use of mixtures of herbicides (Kerr and Klingman 1957; Peters and Kerkin 1957; Vengris 1957; Schreiber 1959; Fertig 1960; Kerr and Klingman 1960; Peters and Davis 1960; Peters 1964; Wakefield and Skaland 1965). Paraquat at 1 to 2 kg/ha, applied to emerged weeds prior to sowing trefoil, controlled couch-grass sufficiently to allow excellent establishment while only 0.3 kg/ha. was sufficient for control of annual weeds (Linscott *et al* 1969).

In the rough pasture improvement technique developed in eastern Canada by Winch *et al* (1969), granular dalapon at 36 kg/ha is mixed with trefoil seed and granular fertiliser and applied by aircraft or more conventional means. An alternative method with the same objective is spraying six litres of paraquat per hectare in 300 litres of water per hectare after fertilising and surface-seeding but before the trefoil has germinated.

2.2.5. Development studies

Once established, birdsfoot trefoil is a persistent perennial under North American conditions and produces a high-quality permanent pasture for both grazing and conservation as hay or silage (Anon. 1967a). Natural reseeding by continual seed dispersal is a feature in these pastures as seed pods are produced even under severe grazing conditions. This rejuvenates the sward and provides the means necessary for the replacement of, or addition to, the old plants.

Birdsfoot trefoil has a wide range of tolerance for drainage conditions. It is at least as drought resistant as lucerne and will withstand less well drained conditions than clovers and still produce good yields. Winch (1958b) mentioned evidence of varietal differences in tolerance of poor drainage. Empire will persist where spring flooding is prolonged and on the poorly-drained soils which are late in onset of growth whereas Viking will only withstand soils where the excess water is quickly removed.

The range of literature on birdsfoot trefoil under agricultural systems is wide and varied. Many of these studies were carried out in North America and in eastern Europe. Yield of Lotus has been compared with that of the other major legumes, as has herbage quality and behaviour under grazing systems and conservation techniques.

McCloud and Mott (1953) conducted studies to determine the behaviour of legumes and grasses when in association. Birdsfoot trefoil was observed to be mutually compatible with smooth-stalked meadow-grass but this combination was not as productive over a three-year period as a mixture of trefoil with timothy, the latter being more productive when mixed with trefoil than when alone. Brome-grass likewise benefited from association with trefoil but not so much as with lucerne and Ladino clover. Under the dry conditions of New Mexico birdsfoot trefoil improved the yields of grass mixed with other legumes and after two years, the grass content of a trefoil sward was nearly the same as in the sowing year whereas with Ladino clover it was reduced to 25% of the original. The greater drought resistance of trefoil was thought to be responsible for these results (Jones 1954).

Interactions between competition and defoliation effects were investigated in Wisconsin by Wall (1957). Average yields of Empire trefoil were greater throughout a four-year period than those of the European type of L. corniculatus.

Production of trefoil alone and when mixed with smooth-stalked meadow-grass was greater than in a mixture with lucerne, red clover and brome-grass (Wall loc. cit.). Both varieties of trefoil yielded more when cut two or four times than when cut eight times per annum. Frequent defoliation adversely affected the upright European type but favoured the prostrate Empire, particularly where sown with lucerne, red clover and brome-grass. Empire, unlike European trefoil, was not affected by height of cutting but was only able to develop favourably where competition was reduced by a cutting frequency detrimental to the taller plants.

In contrast to this Pierre and Jackobs (1953) reported a reduction in plant number after two years of cutting to a height of 25 mm, stands of Empire being reduced less than those of European types by defoliation in late autumn. Duell and Gausman (1957) reported serious stand reductions when plants were cut back to 25 mm every twenty days while Parsons and Davis (1961) found that trefoil stand density was greater after four years of growth with the late S.37 variety of cocksfoot than with earlier American cocksfoot, due to different patterns of competitive stress.

An established sward of Mansfield birdsfoot trefoil in Pennsylvania gave higher total yields of dry matter and crude protein when cut to 25 or 50 mm than when cut to 100 mm (McClellan 1963). Lenient cutting of pure swards encouraged invasion by annual grasses. Nevertheless, cutting a sward of Climax timothy and Viking birdsfoot trefoil to 100 mm in late September gave better winter survival in the legume than more severe cutting. After the second year of growth, cutting in October gave better winter survival. McClellan (loc. cit.) also noted that most legume regrowth came from the plant crowns irrespective of height of cut.

Smith and Nelson (1967) examined responses to height and frequency of cutting in trefoil by harvesting plots three, four, five or six times before early September for two consecutive years, leaving a stubble 25, 76, or 152 mm high. Yields of forage decreased as cutting frequency increased. In a second experiment the legumes were cut three or six times a year with stems pulled upright to leave stubble 76 mm high, or to a height of 76 mm with the stems left in their natural position. Forage yields were found to be higher for three than for six cuts per season. Yields of trefoil were highest when stems were pulled upright to leave a 76 mm stubble due to the prostrate growth habit. Birdsfoot trefoil was seen to require a tall stubble to maintain good forage yields. Grueb (1968) studied the effects of 45, 75 and 115 mm cutting heights on leaf area index, dry matter yields and total available carbohydrate levels by taking weekly measurements during two seven-week regrowth periods (early June-late July and mid July-late August) of one-year-old stands of Empire birdsfoot trefoil in 1965 and 1966. During the first regrowth period, leaf area index values were 0.05, 0.37 and 1.10 respectively while dry matter yields varied from 4418 kg/ha at 45 mm cutting height to 5146 kg/ha at 75 mm and 5296 kg/ha at 115 mm. Total available carbohydrates in the roots, measured as percent of root dry weight, declined from 4.76% at the beginning of the regrowth period to 3.68% at 45 mm, 4.18% at 75 mm and 4.57% at 115 mm. Cutting heights during the July-August regrowth period responses were similar but leaf area index values and yields were lower, whereas total available carbohydrate in roots increased in late August.

The stage of growth at which birdsfoot trefoil is cut has a marked effect on yield of forage. Duell and Gausman (1957) obtained the highest yields of L. corniculatus when the sward was cut in the 10% bloom stage at a height of 25 mm. Cutting for hay at this stage was also advocated by Smirnova-Ikonnikova and Muhina (1956) under Russian conditions. Studies in Canada (Anon. 1967b) showed maximum production from birdsfoot trefoil alone or with Climax timothy, when the legume was cut at 25% flowering.

In field trials in Nova Scotia during 1964-6 (Langille et al 1968) Viking and Empire trefoils were sown in mixtures with timothy and cut

(a) four times a year at the pre-bud stage,

(b) three times at 10% flowering,

(c) twice at 50% flowering,

and (d) twice at 75-100% flowering.

The last treatment resulted in the highest dry matter yields and in general, forage production was reduced by frequent cutting. Viking's yield decreased in the second harvest year in all treatments but that of Empire increased when cut three times at 10% flowering and when cut twice at 75-100% flowering. Gasser and Lachance (1969) investigated the effects of two or three cuts per year and the best date for the last cut, in Quebec. Three cuts, with the last on September 5th, depressed yields of Empire birdsfoot trefoil in the subsequent year but not those of Viking, which out-yielded Empire in all treatments. Dry matter production in the following year was not adversely affected by taking a third cut in late October.

Twamley (1968) carried out a management study on a birdsfoot trefoil variety trial and used three variables - variety, stubble height and harvest date. Range of maturity used was 12 to 14 days between earliest and latest varieties, all plots being harvested thrice per season. The harvest dates imposed differed by about two weeks for the first cut, one week for the second cut and were identical for the third cut. Stubble heights were 50 and 150 mm. Late-cut material out-yielded that cut early but suffered more winter damage whereas material cut at 50 mm height out-yielded that cut at the greater height, but it also suffered more winter-killing. Ranking of varieties was found to vary with the management imposed.

Girard and Chevrette (1968) also stressed the importance of choice of variety and management in utilisation of birdsfoot trefoil in trials using Leo and Empire varieties grown with timothy, and subjecting them to two cuts (July and August) to simulate ordinary hay cuts, three cuts (June, July and September) for intensive hay, and four cuts (early and late June, early August and October) to simulate pasture. Leo out-yielded Empire in the hay treatments but Empire was more productive under the simulated pasture management, especially when rested in August and September.

2.2.6. Use in seeds mixtures

The yield of birdsfoot trefoil varies according to the other species present in the sward in which it is growing. Ritchey (1947-9) reported high forage yields from marsh birdsfoot trefoil when grown with carpet-grass in wet areas of Florida. Tomka and Pristas (1964) recorded yields of *L. corniculatus* in monoculture and in various mixtures when grazed and cut. Yields of trefoil alone and mixed with 50% of various grasses were about 20% lower than those of lucerne, and mixtures of trefoil with white clover with or without grasses gave even lower yields. Birdsfoot trefoil with lucerne yielded almost as much as lucerne alone but the trefoil was suppressed by lucerne. After grazing, yields of lucerne and lucerne/birdsfoot trefoil were reduced but those of *Lotus* with white clover and/or grasses were unaffected. Birdsfoot trefoil was not suppressed by grasses such as golden oat-grass, swamp meadow-grass, soft brome-grass, crested wheat-grass and cocksfoot, even under grazing in these Czechoslovakian trials.

Griffeth *et al* (1965) compared the yields of birdsfoot trefoil and lucerne when grown together in a mixture with timothy on a well-drained site and a poorly-drained site in New York State at different competition.

2.2.7. Response to fertilisers

Kolar (1950) published recommendations for fertiliser rates on *L. corniculatus* swards, depending upon method of utilisation. For fodder production, 100 kg/ha of potassic fertiliser and 60 kg/ha of phosphate fertiliser were advocated, to be augmented by 15 to 30 kg/ha of nitrogen fertiliser and 30 to 45 kg/ha of lime as calcium oxide. For seed production purposes the phosphate fertiliser was increased to 80 kg/ha. Hunt and Wagner (1963) recorded greatly increased yields of birdsfoot trefoil and increases in trefoil content in mixtures when potash was applied at 80 kg/ha. McClellan (1963) obtained better yields from an established stand of Mansfield birdsfoot trefoil by applying 400 kg/ha of an 0-15-30 NPK fertiliser in April rather than 200 kg/ha in April and 200 kg/ha after the first cut.

Ward and Blaser (1961) studied the effects of nitrogen on seedling growth and subsequent yields of forage plants including birdsfoot trefoil. Production during the first season was not increased by application of nitrogen, and legumes yielded less when dressed with 40 to 80 kg/ha nitrogen. After the first year, yields of trefoil (like those of lucerne) were unchanged in two out of three years, and increased at the 20 kg/ha rate of nitrogen during the other year while yields of red and white clovers were continually depressed. Contrasting results were obtained by Lichner and Folkman (1967) in Czechoslovakia where applications of NPK fertiliser retarded growth of trefoil and other legumes in mixed swards. They were also adversely affected by nitrogen at rates of 50 kg/ha and above. In Bulgaria Yakimova and Petrovski (1968) fertilised a sward of birdsfoot trefoil/red clover/lucerne/cocksfoot/

perennial ryegrass/brome-grass with annual dressings of nitrogen at 60 to 480 kg/ha plus various combinations of potash, phosphate and lime. Cocksfoot, red clover and birdsfoot trefoil were the main sward components in the first year of utilisation, cocksfoot and red clover in the second year, and cocksfoot, birdsfoot trefoil and lucerne in the third year.

On the other hand, Watson et al (1968) applied nitrogen at 28 kg/ha on birdsfoot trefoil, alone or with cocksfoot in Missouri and found no significant effects on root/shoot ratios, botanical composition and yield. Boehle et al (1961) tried deep placement of fertiliser but found no yield increases.

Hunt and Wagner working in Maryland (1963) reported that birdsfoot trefoil was the only legume which produced significantly more herbage under low lime levels at around pH values of 5.0 than under high levels, and its percentage of the herbage was also increased. Murphy (1970) also noted that birdsfoot trefoil content in a natural sward was decreased by lime and was not increased by phosphate or potash.

Dionne (1969) thoroughly investigated the response of trefoil to liming in Quebec and found that liming increased yields on certain soils while on others it had no effect or else it decreased yields. Yields increased with increasing pH on clay; they increased to pH 6.0 and then declined on a muddy loam; the response was almost logarithmic on a loam and irregular on a stony loam. Liming increased uptake of phosphate but depressed that of potash. Dionne (loc. cit.) concluded that the effect of pH on yield in birdsfoot trefoil varied according to the soil type.

Response to other nutrients has been observed in birdsfoot trefoil. Sabardina et al (1970) reported that applied copper increased the contents of legumes, including birdsfoot trefoil, in permanent pastures in Latvia while in the Belorussia region of the Soviet Union foliar application of 0.5 kg boric acid in 500 l of water per hectare markedly increased trefoil seed yields and also increased yields of aftermath herbage by 25% (Strelkov and Azovtseva 1970). Dionne (1969) noted that birdsfoot trefoil withstood high soil levels of manganese better than lucerne or Ladino clover.

From the evidence presented it would appear that Lotus resembles other herbage legumes in general fertiliser requirements in that it is depressed by nitrogen at levels of 50 kg/ha and above, especially when growing in mixed swards. Potash and phosphate are beneficial under most circumstances while calcium, although essential as a plant nutrient in some quantities, is not necessary for reasonable yields of birdsfoot trefoil.

Some workers have studied the effects of irrigation on the response of trefoil to fertiliser treatments. Boehle et al (1961) reported little or no response to irrigation. Frequent irrigation resulted in decreased stands of birdsfoot trefoil in trials conducted by Cooper (1961) and these plots were also invaded more by weeds. Lack of response in trefoil was attributed to the presence of a water table within reach of birdsfoot trefoil roots.

2.2.8. Utilisation by grazing

Utilisation of birdsfoot trefoil by grazing should be undertaken with rotational systems rather than set-stocking where the sward is never rested (Washko 1961). Davis and Bell (1958a) compared rotational and continuous grazing systems using cross-bred wether lambs and noted that Ladino clover was almost eliminated by dry summer conditions whereas birdsfoot trefoil persisted well under rotational grazing but not under continuous grazing. A greater herbage yield was obtained under continuous grazing by lambs during the first year and under rotational grazing thereafter (Davis and Bell 1958b). There was a close relationship between dry-matter yield and animal carrying capacity and between the percentage of nitrogen in the forage and daily gain of lambs but not between yield and animal gain per hectare.

Henson and Schoth (1962) reported varietal differences in response to grazing in that the erect European type of birdsfoot trefoil varieties behaved differently from the prostrate types typified by the variety Empire. The former types, such as Cascade, Viking, Granger, Mansfield and Douglas, resembled lucerne in this characteristic. Continued close grazing greatly reduced their vigour and swards could be rendered unproductive if this treatment was allowed to continue too long. The authors suggested that pastures containing these varieties which are to be continuously grazed should be left with a minimum of 100 mm of herbage stubble at all times to maintain a vigorous sward. Rotational grazing or a system of supplemental grazing is preferable for these erect-growing varieties as such systems prevent overgrazing and even enable some of the trefoil to be conserved as hay or silage when growth is plentiful.

Empire and prostrate types were notably less affected by close grazing due to their growth habit. The leaf stems near to the ground remained ungrazed and provided nutrients for continued plant growth as well as seed for natural reseeding.

Attention has also been drawn to the fact that sheep are more selective than cattle in grazing habits and may overgraze birdsfoot trefoil under continuous grazing (Anon. 1967a). Rotational grazing would therefore be more beneficial for the trefoil sward as well as for the sheep. As L. tenuis and L. pedunculatus are prostrate in form of growth, grazing management for these species was said to be very similar to that for Empire and other prostrate trefoil types. Van Keuren and Davis (1968) reported on six years of field trials on the behaviour of birdsfoot trefoil under grazing and contradicted the previous statement (Anon. 1967a) concerning species of grazing animal, stating that this was not a major factor affecting persistence. Stands of Empire were found to be significantly better than those of Viking birdsfoot trefoil after the first season when grown with smooth-stalked meadow-grass. Rotational systems involving grazing for 2.5 weeks and recovery for 5 weeks were superior to continuous grazing treatment. After four years the persistence of Empire became significantly better than that of Viking.

The companion species with which birdsfoot trefoil is associated may influence its persistence under grazing. Washko (1961) found that when the variety Empire was grazed six times annually over a four-year period, sward content was reduced from 40% to 30% whereas with S.37 cocksfoot the percentage decreased from 35% to 15% under similar conditions. Chevrette et al (1960) achieved satisfactory results with birdsfoot trefoil when used in simple mixtures with the less competitive grasses such as timothy although a birdsfoot trefoil-cocksfoot mixture performed extremely well when grazed under dry conditions on gravelly loam. Gomm (1969) working in Montana, reported that a birdsfoot trefoil/smooth-stalked meadow-grass mixture was generally superior to other mixtures in terms of length of grazing season, yield of consumed forage, carrying capacity and yield of total digestible nutrients. Trefoil content in the pasture under trial remained almost constant during the season while other legumes fluctuated.

In another trial of several species in simple mixtures, birdsfoot trefoil/brome-grass gave higher weight gains, a higher total digestible nutrients equivalent and a higher stock-carrying capacity than other mixtures when grazed by sheep for one week then rested for two weeks.

The effect of grazing management on the animal production from birdsfoot trefoil pastures has been investigated by Wedin et al (1967), Van Keuren et al (1969) and Van Keuren (1970). In Iowa during 1958-63 the average beef yield from a pasture renovated by ploughing and sowing with Empire birdsfoot trefoil was 423 kg/ha, with 556 grazing days per hectare and a daily gain of 0.76 kg per yearling steer compared with 250 kg/ha beef yield, 454 grazing days/ha and 0.55 kg live weight gain per steer on fertilised grass, and 157 kg/ha beef yield, 254 grazing days/ha and 0.62 kg live weight gain per steer on unimproved grass pastures. There was a decline of useful legumes in the renovated pastures from 58 to 28% as the trial progressed but this was accompanied by an increase in useful grasses. Wedin and his colleagues also found that distribution of herbage growth and the grazing pattern were more uniform on the birdsfoot trefoil area than on the fertilised grass.

Van Keuren et al (1969) studied animal production and response on trefoil/smooth-stalked meadow-grass pastures using a "put-and-take" grazing procedure with yearling steers and feeder lambs, obtaining a greater liveweight gain per hectare from a three-paddock rotational system than from continuous grazing. Empire once more proved superior to Viking, producing more total gain per hectare for the six-year period. In further trials Van Keuren (1970) recorded higher weight gains of yearling steers from a deferred grazed system on meadow-grass/trefoil than from a rotationally grazed pasture. In the deferred grazing treatment the pastures were grazed until mid-May, after which regrowth was allowed to accumulate until mid- to late-summer.

Washko (1961) had already investigated and discussed the use of deferred grazing with birdsfoot trefoil in Pennsylvania, where he recorded higher forage yields than from rotational grazing, when grazing was deferred until onset of bloom (early June) and mid-bloom (June 15th). However, herbage quality was better under rotational grazing. Deferment of grazing beyond mid-June did not appear to be justified because of deterioration in herbage quality and decreased intake by cattle. Removal of herbage by grazing in early June also resulted in better distribution of forage throughout the rest of the grazing season. Viking apparently reacted similarly to Empire birdsfoot trefoil under both rotational and deferred grazing systems.

A similar system of management applied by Templeton et al (1967) in Kentucky enabled birdsfoot trefoil to persist and increase in an area where the legume was previously considered to be non-persistent. An eight to ten week rest period in mid-summer permitted seed-setting and natural reseeding of trefoil so that after three seasons the trefoil constituted about half the herbage present in summer, thereby increasing the productivity of a trefoil/meadow-grass sward to that of one containing Ladino clover and smooth-stalked meadow-grass.

The major factor concerning the grazing of birdsfoot trefoil which emerges from the literature is that the legume is more likely to thrive and persist under a grazing system involving adequate rest periods after exploitation. Its sensitivity to competition from companion species can be considerably modified by the grazing management imposed. Evidence is published to indicate that, in short-term trials, yields obtained by mowing are reliable for predicting the performance of birdsfoot trefoil under grazing (Matches 1968).

The greatest use of birdsfoot trefoil, especially under North American conditions, is in mixtures for permanent pastures where persistence is more important than high production and where a greater flexibility of grazing management can be employed (Anon. 1961). In eastern areas of Canada where most of the pastures are composed of low-yielding grasses, birdsfoot trefoil is used to replace these species thus increasing carrying capacity and live-weight gain. On intensively managed farms trefoil is recommended only for the rough-grazing sections or where other legumes are questionable due to soil type and poor drainage.

2.2.9. Utilisation by conservation

Conservation of birdsfoot trefoil as hay or silage can be carried out satisfactorily. *Lotus* species are not usually grown solely for conservation but it is frequently desirable to cut for hay or silage, especially where rotational grazing systems are practised. In periods of rapid growth, cutting for conservation purposes saves loss by trampling and fouling of tall growth (Henson and Schoth 1962).

The trefoils compare favourably with other herbage legumes under conservation. Most of the literature refers to hay production but Wittwer (1957) ensiled several species in a two-year trial in New York State and found *L. corniculatus* to be equal in quality to the other legumes, especially when all were pre-wilted.

Highest yields of trefoil hay are obtained when the sward is cut at the 10% bloom stage at 25 mm above ground level (Smirnova-

Ikonnikova and Muhina 1956; Duell and Gausman 1957). Russian sources report yields of birdsfoot trefoil hay varying from 5000 to 7000 kg/ha in several regions (Kuprijanov 1946) and up to 13210 kg/ha in the Krasnodar region (Anon. 1945). In Canada dry matter yields of 9000 kg/ha were recorded during the first harvest year at Guelph, Ontario, rising to 10,000 kg/ha during the third season of a mixture composed of timothy with birdsfoot trefoil, whereas a red clover/timothy sward yielded 10,000 kg/ha in the first season and subsequently declined to 6000 kg/ha (Anon. 1961). Buber (1964) quoted average hay yields from trefoil mixtures as 7000 kg/ha in eastern Canada and 5000 kg/ha in western Canada while Popov and Totev (1969) obtained the most productive hay yields averaging 7240 kg/ha from similar mixtures in Bulgaria, containing around 16% crude protein.

Quality of trefoil hay has been described by several sources as higher than that of red clover and lucerne. Kuprijanov (1946) reported this in Russia, whilst Kostov and Zakov (1964) found trefoil to be the best legume for hay and green fodder in south-east Bulgaria. L. corniculatus was reputed to produce a finer-textured and better coloured hay than red clover in Canada (Anon. 1961), the more erect varieties such as Viking being preferable for long-term hay stands in eastern Ontario while Empire birdsfoot trefoil was preferred by farmers in Central Ontario because of its winter-hardiness and tolerance of flooding and poor drainage.

Birdsfoot trefoil was intended to supplement but not replace lucerne in these regions except where the latter did not grow well. Where long-term stands were required the use of birdsfoot trefoil was recommended instead of red clover as this latter species only lasted one season.

A trial of birdsfoot trefoil varieties under hay management in Ontario led to a successful selection programme by Buber (1961). Although seasonal total yields were similar, some interesting differences between varieties were noted at each cutting. A selection from Russian material had not only increased hardiness but out-yielded some varieties at the first hay cut and all varieties at the second cut, yet was itself out-yielded at the third cut in autumn. Low yield in the third cut was suggested to be associated with the hardening-off process which gave the variety its improved hardiness, and the feature was fortunately not linked with a later start in spring growth as the selection was among the highest yielders at the first seasonal cut.

The success of this selection - released as the cultivar Leo - was due to this growth pattern being the main requirement by Canadian farmers for hay production, enabling them to produce a good hay crop in late June or early July and a second crop in August or early September.

2.2.10. Herbage quality

Herbage quality compares favourably with lucerne and clovers. Chemical content is similar and the herbage is palatable during the vegetative phase of development, retaining its succulence throughout the flowering and fruiting processes (Winch 1958a).

Trefoil quality has been assessed by methods ranging from measurements of palatability and chemical composition to the more recent digestibility determinations by the in-vitro technique. While this is the case for L. corniculatus there have been fewer, less accurate attempts to assess L. pedunculatus and L. tenuis, due mainly to their limited utilisation in countries where the more refined analytical techniques are in widespread use.

MacDonald (1946) concluded that the legume was as palatable as others and, when maintained in the vegetative state, was equal to white clover in protein content, maintenance of protein level throughout the season, and in nitrogen-fixing power and effect on the protein content of the associated grasses. In a recent survey (MacDonald 1963) figures showing the chemical composition of trefoil hay compared with lucerne and timothy hay:

Table 2.2.10.1. Chemical composition of birdsfoot trefoil, lucerne and timothy hay (MacDonald 1963)

Species	% protein	% fat	% fibre	% nitrogen-free extract	% ash
birdsfoot trefoil	16.3	2.2	25.7	41.0	6.4
lucerne	12.5	2.2	26.5	45.5	6.1
timothy	6.0	1.7	35.7	46.5	3.3

Loosli et al (1950) reported that birdsfoot trefoil was high in quality when conserved as hay and similar to Ladino clover hay in terms of total digestible nutrients. It appeared to increase the stability of milk produced by cows fed on trefoil hay whereas Ladino clover possibly predisposed the milk to an early development of oxidised flavours.

Furtwick (1958) applied herbicides to forage legume crops and observed that crude protein content of birdsfoot trefoil was increased by application of the herbicide CIPC although yield was lowered. Trimberger et al (1962) at Cornell, New York State, made the first detailed study of the feeding value of birdsfoot trefoil and reported favourably, noting particularly that the higher digestibility coefficient of trefoil over a longer period than in other legumes extended the time for harvesting good hay from its forage.

Smith (1964) considered that birdsfoot trefoil was similar to lucerne and red clover in protein and fibre content while White (1965) reported a higher potash content, especially where available potash was at low levels in the soil.

Brazilian studies with the variety San Gabriel revealed that the contents of soluble carbohydrates and pentosans increased with stage of growth, the former predominating in the leaves and the latter in the stems. Hexosans remained almost constant but crude protein and dry matter digestibility decreased with advancing maturity (Lopez et al 1965). Further investigations showed the effects of fertilisers on chemical composition. Phosphate significantly increased the percentages of hexosans, crude protein and dry matter digestibility while it reduced lignin and soluble carbohydrate contents. Nitrogen fertiliser increased dry-matter digestibility and phosphate content but reduced the percentage of soluble carbohydrates whereas potash increased crude protein content but reduced that of pentosans (Prestes et al 1966).

Pure swards of herbage species including birdsfoot trefoil were harvested simultaneously for three cuts in 1961 and two cuts in 1962 in Michigan (Ingalls et al 1965, 1966). Legumes tended to contain more fibre than grasses and two to three times as much lignin. A positive correlation was found between lignin content and dry matter intake. Studies using wether lambs ranked the 1961 forages, in terms of dry matter intake, with birdsfoot trefoil highest and in the 1962 material it was second only to lucerne. Similar results were obtained in Michigan State by Allinson et al (1969).

Birdsfoot trefoil was compared with lucerne by means of in-vitro digestible dry matter determinations at Cornell, New York State

(Monson and Reid 1968). Both Viking and Empire birdsfoot trefoils were higher in quality than lucerne and timothy when cut in mid-May and mid-June. Mixtures of grasses with late-cut birdsfoot trefoil showed consistent increases in dry matter digestibility, the largest occurring with timothy. Timothy and birdsfoot trefoil were used separately and in mixtures in feeding trials with sheep and cattle, with the result that average dry matter intake values of herbage containing 33, 67, and 100% of birdsfoot trefoil were 17, 24, and 36% higher respectively than that of timothy fed alone.

Winch (1969) compared herbage quality in Empire and Viking birdsfoot trefoils over a three-year period in Canada. His results indicated that Empire's leaves were consistently higher in dry-matter digestibility throughout the first period of growth in each season. In contrast, Viking's stems were slightly higher than those of Empire over the same period of time. As a result, the dry-matter digestibility and crude protein of the whole plant was weighted in favour of Empire yet this variety was only slightly different from Viking. These results can be related to the portion of leaf and stem of the two varieties. Generally, Empire's dry weight has more leaf content than Viking's whereas Viking contains a higher percentage of stem. Thus, the differences in dry-matter digestibility and crude protein between the leaves of Empire and Viking are due to the actual contribution of these components in the total yield. This indicates that selection for leafiness in Lotus might lead to higher quality of herbage.

There are no records of assessment of quality in birdsfoot trefoil in Britain as it is not cultivated here. Likewise marsh birdsfoot trefoil has not been assessed although reports by MacDonald (1946) suggest that this species is not inferior to other legumes in digestibility.

One particular aspect of herbage quality which has been of special consideration is the reputation of birdsfoot trefoil as a legume which has not been known to cause bloat in livestock (Henson and Schoth 1962; Frame 1969). MacDonald (1946) found European birdsfoot trefoil to be relatively high in hydrocyanic acid content while marsh birdsfoot trefoil was almost free from this compound. Dougherty and Christensen (1953) concluded that the high HCN content of birdsfoot trefoil had no significance in causing bloat.

Birdsfoot trefoil was compared with lucerne and Ladino clover in bloat studies carried out by Foundon (1959). Ladino clover and lucerne produced more gas than birdsfoot trefoil when incubated for one hour in-vitro with rumen contents. Similar results were obtained with marsh birdsfoot trefoil in New Zealand (Jones et al 1970).

More recent reports suggest that bloat is inhibited in birdsfoot trefoils and other non-bloating legumes by the tannin content of the herbage as well as the rumen pH level (Kendall 1966). In any case it would appear that this feature is one of the main advantages of both trefoils in their utilisation for grazing and conservation.

2.2.11. Seed production

Seed yields are usually low compared with other legumes and seed cost is high. These factors limit its widespread use. In the United States average seed yields of birdsfoot trefoil range from 40 to 100 kg/ha with maximum yields of between 300 and 400 kg/ha (Henson and Schoth 1962). East European yields ranged from 130 to 200 kg/ha with a maximum of 500 kg/ha for seed yield of *L. corniculatus* (Afrikyan 1966; Rodionov 1966; Popov and Petrovski 1967; Negovitsina 1968). In Saskatchewan Province, the variety

Leo gave average seed yields of 600 kg/ha (Anon. 1967c). Commercial seed production has started in the north-eastern part of this province and considerable expansion is expected within the next few years. Yield levels would appear to be improving as seed producers gain in experience with the crop. The most recent general statistics (Henson and Schoth 1962) mention annual seed production of between 250,000 and 500,000 kg of birdsfoot trefoil seed within the United States while a similar quantity is imported into the country mainly from France and Italy.

In some regions lodging of the crop markedly reduces seed yields (MacDonald 1946). A possible solution to this problem was the use of mixtures of trefoil with grasses such as timothy. A two-year experiment in eastern Canada (Anon. 1956c) produced yields of 113 kg/ha when trefoil was grown alone, 99 kg/ha from trefoil with red fescue, 64 kg/ha from trefoil and timothy and only 30 kg/ha from trefoil and brome-grass.

Anderson and Metcalfe (1957) obtained increased seed yields and reduced lodging when birdsfoot trefoil was grown with smooth-stalked meadow-grass and also timothy and cocksfoot although tall stands of the latter two grasses tended to delay maturity. After the first harvest year, trefoil/grass mixtures also gave slightly higher forage yields. In Ontario, Winch (1958) reported reduced seed yields from mixtures with companion grasses due to decrease in number of flowering stems. Henson and Schoth (1962) concluded that mixtures of birdsfoot trefoil with smooth-stalked meadow-grass or timothy did increase seed yields in areas where lodging was a problem otherwise mixtures offered no advantage, in terms of seed production.

For seed crops of pure birdsfoot trefoil, Winch (1958) advocated sowing in rows at one metre spacing for high yields. Widely spaced rows were endorsed by Afrikyan (1966) in the Kharkov region of Russia although Miladinovic (1967) preferred rows 40 cm apart in Yugoslavia, with an optimum seed rate of 12 to 16 kg/ha. Midgley (1961) stipulated that intra- and inter-specific competition should be at a minimum to obtain good seed yields, and recommended band seeding and fertiliser placement in rows about 50 cm apart which allowed the mature plants to shade and smother, preventing any young plants from re-seeding.

Californian recommendations included ensuring that the crop was free from other legume species, especially white clover, alsike clover and hop trefoil, seeds of which are difficult to separate from those of birdsfoot trefoil during cleaning operations (Peterson et al 1953).

Several authors mention defoliation effects on seed yield of *L. corniculatus*. Anderson and Metcalfe (1957) observed that spring and summer clipping of trefoil greatly reduced seed yields, compared with unclipped stands, whereas Winch (1958) claimed that clipping stands of Empire birdsfoot trefoil as late as the end of May did not reduce seed yields although it delayed the seed harvest by four days. Later clipping reduced yields and further delayed the harvesting process.

Weather conditions during the processes of pod development and seed maturity have been noted to affect the seed crop considerably. Moist cool conditions caused delays while hot dry conditions hastened ripening (Winch 1958). Irrigation is used in California to keep the soil moist during this period, maintaining a canopy of new growth above most of the seed pods, thus keeping the humidity at a level high enough to reduce seed dehiscence

(Peterson *et al* 1953).

Time of harvest is critical. It takes approximately thirty days from flowering to pod maturity (Henson and Schoth 1962). Many sources recommended early harvesting to obtain the highest proportion of easily germinated seeds and the lowest content of hard seeds, at a stage when the pods are at least two-thirds light brown to brown in colour (Winch 1958; Midgley 1961; Henson and Schoth 1962; Mukhina 1966).

The main cause of variations in seed yield of birdsfoot trefoil is the tendency for the seed pods to dehisce rapidly when they are mature and submitted to relative humidities of less than 35%. Excellent crops are often lost in a few days.

Relative humidity, moisture content of trefoil pods and pod splitting are very closely interdependent (Metcalfe *et al* 1957). Selection for resistance to seed shattering was initiated by Peacock and Wilsie (1956) by subjecting six clones, which showed a tendency to retain seeds at maturity, to different degrees of relative humidity in desiccation chambers. A level of 35% relative humidity for 72 hours was found best for distinguishing resistant clones which did not shatter from others with up to 55% of shattering. Further studies were made on various selections and crosses between types with *L. corniculatus* and seed-pod dehiscence was reduced by 17% in one cycle of selection (Peacock and Wilsie 1957). It was considered that further recurrent selection cycles would increase resistance to shattering still further. However, despite this promising start the programme appears to have been discontinued.

Hood (1964) investigated physiological factors controlling pod dehiscence in birdsfoot trefoil but since completely indehiscent plants of this species had not been discovered, a screening of available *Lotus* species was undertaken with an interspecific hybridisation programme in mind, by Phillips and Keim (1968) in Indiana. Pods of 39 types representing 16 species were tested at 38, 33, 25 and 10.5% relative humidities. *L. coimbrensis* was the only species with completely indehiscent pods while *L. angustissimus*, *L. tetragonolobus* and two types of *L. ornithopodioides* demonstrated a high degree of indehiscence. *L. coimbrensis* (2n = 12) was crossed with *L. corniculatus* (2n = 24) in an attempt to incorporate the indehiscent seed-pod character into the latter species, and although four selections were backcrossed to *L. corniculatus* the results were somewhat indifferent.

Harvesting operations must be carried out as quickly as possible once the birdsfoot trefoil seed crop is ready. A cutter bar with windrow attachment is generally used in the United States and Canada (Midgley 1961; Henson and Schoth 1962). If properly executed, the operation rolls the pods into the centre of the windrow where they are more protected from drying out while the rest of the foliage dries. The windrows are then combine-harvested as soon as the herbage is dry enough. Large seed losses have been observed when the crop was cured in the windrow for more than ten hours after mowing (Winch 1958). Direct combine-harvesting has been found to be a slow and difficult process due to the bulk of leafy foliage in the birdsfoot trefoil crop. Defoliants such as Dinoseb can be used successfully but they increase dehiscence and make time of harvesting even more critical. The optimum time for direct combine-harvesting was suggested by Winch (1958) to be between 24 and 30 hours after application of a defoliant. Chilean studies reported by Obrador (1966) advocated the use of desiccants as they shortened the time of harvest and significantly increased the seed yields of birdsfoot trefoil and other herbage legumes, except white clover. Diquat at about 2 litres/ha proved to be the best desiccant for birdsfoot trefoil.

The seed collected from the combine harvester contains varying quantities of green stems, pods, leaves and other matter. It must be screened immediately to remove these moist contaminants and then put into drying bins. Drying by unheated air is recommended by Midgley (1961) as it not only dries the seed but cools it by evaporation, thus reducing growth of mould. Other methods are also acceptable so long as the seed is rapidly and completely dried to approximately 13% moisture.

2.2.12. Weed, pest and disease control

The control of weeds during the establishment phase involves the application of selective herbicides, mowing or light grazing treatments, either used separately or in combination. Similar methods control weed competition in established pastures and seed crops of birdsfoot trefoil. Broadleaved weeds can be mown when they have reached a height of around 30 cms with repeated mowing if necessary, but the treatment must avoid excessive injury to the trefoil plants. Mowing also makes the grass weed problem worse unless herbicides are also used (Anon. 1967a).

Light grazing with cattle, except when soils are wet, followed by mowing of ungrazed weeds can markedly reduce weed populations without harm to birdsfoot trefoil. American and Canadian authorities publish lists of recommended treatments using current herbicides in varying combinations (Anon. 1957; Furtwick 1965; Frank 1966; Anon. 1967a).

MacDonald (1963) drew attention to the fact that, in America, birdsfoot trefoil is less affected by insects and disease than many other herbage legumes although it is by no means free from these pests. This reputation was endorsed by Kolar (1956) under Russian and east European conditions. The meadow spittle bug (*Philaenus spumarius* L.) is particularly injurious in the mid-west and eastern States where it can seriously limit first harvest yields. The potato leafhopper (*Empoasca fabae*) also feeds on birdsfoot trefoil foliage in both nymph and adult stages. Several other insects are sporadic pests (MacCollom 1958; Ridgway and Gyrisco 1961; Henson and Schoth 1962). In Denmark Bovien (1941) reported that *L. corniculatus* was never seen to be attacked by eelworms, unlike other legumes. In eastern Canada, Willis and Thompson (1969) studied effects of infecting legumes with the root-lesion nematode (*Pratylenchus penetrans*). Although birdsfoot trefoil forage yields were least affected, nematode attack decreased yields of trefoil and white clover in a relatively short time, under glass-house conditions.

Birdsfoot trefoil seed crop losses due to disease in the United States have been estimated at 18% compared with 24% for white clover and 32% for red clover (Anon. 1964a).

Rhizoctonia solani is the most destructive fungal pathogen causing disease on common and marsh birdsfoot trefoils according to Kreitlow (1962). It results in crown and root rots and also foliage blight, occurring in dense swards during hot humid weather from May to September (Lewis and Sherwin 1949). Selections with varying degrees of resistance have been made in Virginia (Anon. 1960) and these have been incorporated into breeding programmes.

Several other pathogenic fungi produce root rots on trefoils, especially birdsfoot trefoil. The variety Empire is rather prone to these diseases and much research is now directed towards the production of disease-resistant varieties as a means of control (Kreitlow and Yu 1956; Ford 1960; Leffel 1970). The recent introduction Dawn from Missouri has Empire's characteristics but greater resistance to root rot than either Empire or Viking (Baldridge 1970).

Marsh birdsfoot trefoil was observed to be attacked by pests and diseases during establishment, in North Carolina by Halls et al (1957), especially where soil moisture was lacking. Suckling (1965) reported similar depletion of marsh trefoil seedlings in New Zealand by insects although the development of varieties with improved seedling vigour has overcome this problem to some extent. In the same country Fry (1959) failed to infect marsh birdsfoot trefoil with clover mosaic virus which is widespread in New Zealand grassland.

2.3. THE ROLE OF BIRDSFOOT TREFOILS IN ROUGHLAND IMPROVEMENT

The principal potential use of birdsfoot trefoil lies in the field of marginal land and hill-land improvement. Research on this particular aspect however was limited until the 1940's despite many suggestions that it could prove valuable. It was not advocated on the better soils since other legumes out-yield it there (Robinson 1934).

In the United States and Canada the development of birdsfoot trefoil for agricultural use has been mainly for sown grassland. Nevertheless MacDonald (1946) pointed out that L. corniculatus had great potential when surface-sown on permanent grassland in New York State as shown by several renovation trials during 1940 to 1945. The theories of the Frenchman Schribaux were cited by MacDonald, suggesting that the important use of Lotus could be in the maintenance of large areas, at present not needed or economically unproductive, in a condition which would facilitate their conversion to more intensive agricultural use when the need arose. These extensive areas would be seeded to birdsfoot trefoil and could be economically used as community pastures until more intensive utilisation was possible. Such vast areas exist in many countries where this use of birdsfoot trefoil would be worthy of serious consideration.

Buckley (1949) reported the successful use of birdsfoot trefoil in transforming a poor hill farm of seventy hectares into a productive concern involving dairy cattle. Many fields were seeded by top-dressing old meadows with manure from cows fed on birdsfoot trefoil hay. The cows themselves spread the seed in their droppings while further spread was carried out by the plant self-seeding. Lime requirement was less than for white clover while superphosphate (20% P_2O_5) at 350 kg/ha improved the trefoil stand significantly. Trials in Minnesota showed that trefoil was better alone or with a companion grass but not another legume when used for pasture renovation (Yawalkar and Schmid 1954).

During the same period Lotus was being studied in renovation trials throughout Europe. L. corniculatus was evaluated for alpine use by Caputa (1948) and Koblet (1951) while in Bulgaria Kostov and Zokov (1965) found it to be the best herbage legume on hilly land when grown along with brome-grass, cocksfoot or tall oat-grass. Rougerie (1956) economically improved deteriorated sheep pastures in France by surface-seeding with a grass/legume mixture which included birdsfoot trefoil. In Yugoslavia, grasslands characterised by mat-grass were improved by rotary cultivation and seeding with a mixture of birdsfoot trefoil with several grasses (Ocokoljic and Colic 1964).

Although original trials gave doubtful results (Leach 1957) it is now apparent that the use of herbicides for pasture renovation was a development which greatly improved the establishment of many herbage species including Lotus. The technique when used with birdsfoot trefoil was first reported in American literature by Parsons (1957) who used dalapon and amino-triazole to kill smooth-stalked meadow-grass dominating the natural Ohio sward before broadcasting birdsfoot trefoil at 8 kg/ha and 500 kg/ha of phosphate fertiliser (20% P_2O_5). Sowing was preceded by disc harrowing and although dalapon could be applied in autumn or spring, amino-triazole had to be applied in autumn to avoid damage to the birdsfoot trefoil. Peters (1960) also used dalapon at rates of 8-11 kg acid equivalent per hectare in surface-seeding trials in Connecticut, applying the herbicide in late autumn to the closely grazed sward and broadcasting birdsfoot trefoil, white clover, timothy and cocksfoot in the following spring when the frost had cracked the exposed soil. Bordeleau (1959) reported similar success in eastern Canada, providing that the seed was inoculated with effective rhizobia.

There are extensive areas of natural pasture in north-eastern United States and neighbouring areas of Canada where production from the sward dominated by smooth-stalked meadow-grass is low. The possibilities of improving such land using herbicides and birdsfoot trefoil, were realised by Winch et al (1966a). Six kg/ha active ingredient of dalapon or 1 kg/ha paraquat killed or reduced the vigour of the natural sward in September and birdsfoot trefoil was then sown in late November or April. In the first two years after this treatment, dry matter yields of treated plots were twice that of non-renovated plots.

From further trials Winch and his colleagues (1966b) concluded that:-

(i) The native grass sward must be severely depressed or destroyed;

(ii) Granular dalapon is just as effective as spray formulations for sward depression;

(iii) Birdsfoot trefoil can be surface-seeded at 10 kg/ha in November, March or at the normal time in April;

(iv) Cultivation is not necessary for trefoil establishment;

(v) Broad-leaved weeds must be controlled by herbicides which do not damage birdsfoot trefoil.

When put into practice, this technique established a birdsfoot trefoil population of at least 80 plants per square metre, the density suggested by Scholl and Staniforth (1958) as being necessary for good forage production. When the system was developed and refined by Watkin and Winch (1969a; 1970) dry matter yields obtained from renovated areas were nearly 400% greater than those from untreated areas after only one year and 450% greater after three to six years. A more detailed herbicidal treatment advocated 2,4-DB at 1.1 kg/ha plus dalapon at 3.4 kg/ha, applied to young seedlings or established stands of birdsfoot trefoil and followed in late autumn of the same and subsequent years by around 1 kg/ha of simazine (Winch et al 1968).

The same team streamlined the technique into two separate systems (Winch et al 1969a; 1969b). The first system was based on the use of granular materials broadcast by aircraft, by hand or by normal farm equipment in a once-over operation. Use of this system was restricted to swards containing more than 20-25% of grasses. Ten kg/ha of Empire birdsfoot trefoil, 100 to 120 kg/ha of 0 - 46 - 0 granular fertiliser and 36 to 42 kg/ha of 12.5% granular dalapon are applied in mid-April two to three weeks before grass growth starts. Components are mixed just before application.

The second system was designed for swards with less than 20-25% of grasses and where ground spraying equipment can safely and effectively be used. Birdsfoot trefoil seed and granular fertiliser are applied in mid-April as previously and then one month later six litres of paraquat in 200 to 350 litres of water per hectare are sprayed on the sward when the grass is about 5 cm tall and before the trefoil has germinated.

The once-over system is recommended for more widespread use because of the greater flexibility in the methods of application. The technique has resulted in pasture production increases of from 500% to 1000% and has proved to be a practicable method of pasture renovation in natural grasslands such as those in eastern Canada.

Many workers have recorded the use of birdsfoot trefoil in the improvement of hill-land and natural pastures throughout European countries, especially Czechoslovakia, Hungary, Bulgaria, Poland and Russia during the 1950's and 1960's (Afrikjan 1964; Treter 1966). L. corniculatus is frequently mentioned as a constituent of high-yielding mixtures used on such areas, but no mention is made of herbicidal treatment during the process of renovation, except in one trial reported by Tomka and Tomasik (1968) when mechanical and chemical treatments given to a Nardetum grassland were compared with unfertilised and fertilised controls. In this case rotary cultivation followed by the sowing of a mixture containing birdsfoot trefoil appeared to be the most promising system. More recent reports mention satisfactory swards produced using birdsfoot trefoil with fertilisers (Afrikjan and Grigoryan 1970; Strelkov 1970).

Mechanical renovation with birdsfoot trefoil has also been devised. Sheard (1967) stated that mechanical treatment of a poorly-drained soil led to better seedling growth of trefoil than did chemical renovation. He also reported counts of 18 plants per 30 cm^2 in June after application of dalapon in September and sowing birdsfoot trefoil in December.

Decker et al (1964; 1969) developed a sod-seeding technique in which paraquat was applied in a 15 cm band over each row to reduce competition from the smooth-stalked meadow-grass sward. It was concluded that birdsfoot trefoil and another legume, crown vetch offer good possibilities under such conditions. The same principle was applied by Van Keuren and Triplett (1970) in Ohio where both lucerne and birdsfoot trefoil have been successfully seeded into established grass swards using paraquat and dalapon, sprayed in narrow bands over the seeded rows, to reduce the grass competition and the amount of herbicide needed. Paraquat at about 1 kg/ha and dalapon at 5 kg/ha, and combined applications were sprayed in bands 10 cm wide. Spraying, seeding and fertilising were done in one operation with a grassland drill.

The slow establishing Empire birdsfoot trefoil did not develop as rapidly as lucerne and generally required an additional year to produce satisfactory stands, which then improved with each successive year.

Although significant differences were recorded between the herbicide treatments there was a distinct improvement in growth of trefoil with the cheapest herbicidal treatment compared with seeding without herbicide. The choice of herbicide was therefore dependent on the economic aspects of each particular renovation scheme.

Hill pasture improvement using marsh birdsfoot trefoil has been carried out in New Zealand since the 1940's when the development of aerial top-dressing heralded vast improvement schemes for the country's extensive area of rough pasture.

Smallfield (1947) and Levy (1951) mentioned L. pedunculatus as playing an important role under wet conditions where soil fertility is below average and where shade restricts other legumes. Oversowing with marsh trefoil on wet, steep hill-land where top-dressing is minimal, has been successful as its fertility requirements are low and it will withstand excess and deficiency of water, although it is generally associated with a high annual rainfall (1000 mm to 2500 mm per annum).

Suckling (1965) records areas where the introduction of L. pedunculatus has largely turned grassland failure into success by its ability to grow vigorously among fern, scrub and rushes, encouraging stock onto country where they obliterate these weeds by crushing them.

One of the main assets of this legume is its natural reseeding capability, enabling a rapid recovery of valuable ground cover after scrub has been burned.

Certain disadvantages have also shown up with marsh birdsfoot trefoil. The establishment rate is slow, taking up to three years in some areas. Because of this it is subject to stress from insect pests, by summer drought during the seedling stage and by competition from more vigorous herbage plants. The growing season of marsh birdsfoot trefoil is relatively short and seed prices are high due to production difficulties.

These features have been subjected to change by means of a breeding programme at Palmerston North where Barclay and Lambert (1970) have used Portuguese material to introduce winter growth, and polyploidy to increase seed size and seedling vigour, thereby greatly improving the rate of establishment.

L. pedunculatus is used elsewhere in natural grassland improvement. McGuire (1970) described its value and future in the wetter areas of Oregon and neighbouring states. Preliminary investigations on its potential use in the Soviet Union have been reported (Mikloss and Olesinski 1969; Olesinski 1969). Agronomic features have been studied in ecotypes growing wild in a Russian province.

2.4. BIRDSFOOT TREFOILS IN THE BRITISH ISLES

Five species of Lotus are found in the British Isles - *Lotus corniculatus*, *L. pedunculatus*, *L. tenuis*, *L. hispidus* and *L. angustissimus*. Of these the most widespread by far are the first two species.

Birdsfoot trefoil has been recorded in all 112 vice-counties of Britain and all 40 of Ireland as well as the Channel Islands while marsh birdsfoot trefoil, although less common than birdsfoot trefoil, occurs in 107 of the British vice-counties and in all 40 vice-counties of Ireland and the Channel Isles (Clapham, Tutin and Warburg 1952).

Robinson (1934) made a comprehensive review of the history of birdsfoot trefoil as an agricultural plant in Britain and Western Europe which was extended by MacDonald (1946) to include its development on a world-wide basis.

The earliest reference to Lotus in British farming was made by Ellis in 1744, followed by Anderson (1777) and Martyn (1792) who considered it "equal, if not superior, to most of the trefoils and might doubtless be cultivated to good advantage alone." Robinson refers to trefoil being listed by a seedsman in London in 1810 and during the nineteenth century it was cited by several British writers as a promising and yet neglected forage plant.

Both Robinson (1934) and MacDonald (1946) give details of its occurrence in various types of British grassland, being more plentiful in second- and third-rate pastures than in first-class swards. Jenkin (1925) found birdsfoot trefoil to be almost the only herbage legume present in open hill pastures and considered that it would assume considerable importance when these areas were improved without seeding.

Birdsfoot trefoil was involved in British agricultural experiments as early as 1856 when it was one of the legumes present in an area laid down to a fertiliser trial at Rothamsted (MacDonald 1946). In the plots receiving no fertiliser it was consistently the most prominent legume. It persisted in only small quantities when mineral fertilisers were applied to the sward and disappeared rapidly when additional nitrogen fertilisers were used. Results similar to these were obtained at Cockle Park in Northumberland in the early grassland experiments there.

In trials on hill-land in Wales Thomas (1936) observed that L. corniculatus appeared to be unable to recover from heavy grazing, but he unfortunately omitted any details of stocking rates and system of grazing.

In trials at Rothamsted good yields of green fodder were obtained from L. corniculatus, although in subsequent seasons drought reduced the yields of this legume and others (Mann, 1955).

At the Grassland Research Institute, Hurley, in Berkshire, Cowling (1954) studied many introductions of herbage plants including birdsfoot trefoil, marsh birdsfoot trefoil and slender birdsfoot trefoil by observation of spaced plants. In the evaluation process, criteria used included yielding ability, growth periodicity, disease susceptibility, general vigour, ability to flower and set seed and successful nodulation in the case of legumes. Initially, plants were allowed to grow to maturity but in later stages of the trials, managements based on the assumed value of the plant were imposed and thus a more complete picture was obtained.

In the Hurley trials, birdsfoot trefoil from the United States of America was productive during mid-summer, having a growth periodicity similar to lucerne. Its yield was not as high as lucerne's but it tended to be more succulent. Cowling suggested that it might have more potential than its scale of use in Britain suggested. Slender birdsfoot trefoil, also from the U.S.A., was found to be less prostrate and far more hardy than birdsfoot trefoil and it also remained winter-green while marsh birdsfoot trefoil produced less bulk and was also less persistent. In later sward trials reports, Green et al (1964) reported that birdsfoot trefoil, as well as lucerne and sainfoin, appeared to be promising companion legumes for the Syn II variety of tall fescue but the trials comparing each legume with white clover were not successful (Green 1967).

Gavigan and Curran (1962) reported on results of observation and experiments carried out in Ireland. The prostrate form of birdsfoot trefoil - sometimes referred to as var. arvensis - was seen to be widely distributed on soils ranging in pH from under 5.0 to above 7.0. This species was found in several different plant associations ranging from the open sand-dune community to the closed community of the poor overgrazed pasture. A row trial which included three varieties of marsh birdsfoot trefoil from Oregon, Empire, Viking and commercial European varieties of birdsfoot trefoil was sown in May 1961. One of the marsh birdsfoot trefoil types established well, producing a bulk of semi-prostrate herbage whereas Viking and European birdsfoot trefoils successfully produced vigorous upright herbage.

In a second experiment, European birdsfoot trefoil was broadcast in mixtures with S.50 timothy, Mimer meadow fescue and Viris perennial ryegrass. Although slow in establishing the trefoil plants sent up increasing numbers of stems from their crowns and came to form an important component of the swards, although no data on yield of herbage is presented for these trials. Sowing at a depth of 10-15 mm produced the best establishment.

Further trials were carried out by Gavigan and Curran (1962) to investigate nodulation in birdsfoot trefoil and kidney vetch. _Rhizobium_ isolates from nodules of birdsfoot trefoil and kidney vetch proved effective in nitrogen fixation on birdsfoot trefoil, slender birdsfoot trefoil, marsh birdsfoot trefoil and kidney vetch but were consistently ineffective in nitrogen fixation when associated with marsh birdsfoot trefoil. Strains of _Rhizobium_ effective on marsh birdsfoot trefoil do occur in Irish soils but attempts to isolate them failed. Results from experiments did support the conclusion of Erdman and Means (1949) that when each legume species is effectively nodulated, marsh birdsfoot trefoil fixes considerably more nitrogen than the other species of _Lotus_. Gavigan and Curran concluded that under Irish conditions there were wide variations within _Lotus_ species and their associated rhizobia and that further agronomic research on the group was justified. Also in Ireland, O'Toole (1968) encountered difficulties with nodulation under peatland conditions.

In Scotland where the improvement of rough pasture has been studied intensively for many years, the use of birdsfoot trefoils has been largely neglected until the present time. Copeman and Roberts (1960) mentioned that marsh birdsfoot trefoil proved slow in establishment under water-logged conditions and that livestock tended to reject it. Heddle and Herriott (1968) tested pelleted seed of clover and trefoil, with calcium and phosphate in the coating, at three sites in a sod-seeding technique but they found little advantage over unpelleted seed.

The most recent research on the potential of _Lotus_ in Britain has been carried out by Davies (1969) who examined birdsfoot trefoil and marsh birdsfoot trefoil in three experiments in Wales during 1960-63. Varieties of the former species were obtained from North America (Cascade, Viking, Mansfield, Granger, Tana and Empire), Italy and the Azores (nine varieties) and from Germany (Odenwalder), Denmark (Øtofte II) and several local French varieties. Marsh trefoil varieties under test included S.335 (New Zealand), San Miguel (Azores) and unnamed types from the U.S.A. and Germany. These varieties were compared with two red clover and three white clover varieties (four Aberystwyth varieties and one local variety from Kent). The legumes were sown at 4.5 kg/ha with Aberystwyth S.23 perennial ryegrass at 13.5 kg/ha and no cover crop, at the three centres which ranged from 230-400 m above sea level. The swards received adequate potash, phosphate, lime and boron.

Establishment of the varieties was quite consistent between the trial sites but differences between groups were noted (Table 2.4.1).

Table 2.4.1. Establishment of legumes in Trials 1 and 2 (Davies 1969)

Varieties	Mean establishment (plants/m²)
Birdsfoot trefoil:	
North American	123.4
Italian and Azores	97.1
North European	91.1
Marsh birdsfoot trefoil	205.4
Red clover	88.0
White clover	206.9

The higher establishment counts of marsh trefoil and white clover could be attributed to greater numbers of seed sown but there were considerable differences between birdsfoot trefoil varieties, some poor due to low germination capacity while others established well because of possible increased seedling vigour.

Two methods of seed inoculation were tested but no marked differences were recorded between the soil transfer method and the skimmed-milk technique.

The initial growth of marsh birdsfoot trefoil was outstanding but the material over-wintered badly and failed to regain prominence. During the first and second years red clover and white clover out-yielded birdsfoot trefoil. Thereafter there was a marked increase in white clover in *Lotus* plots while the estimated percentage of trefoil declined. After the exceptionally severe winter of 1962-3 herbage yields were very poor, only white clover making a reasonable contribution.

In the third trial establishment was similar to the previous results. Legume growth was poor and the companion grass was affected by the severe 1962-3 winter. Birdsfoot trefoil made little progress during the experiment while white clover increased its contribution. Red clover was high in the first year then poor in later years. The evidence obtained under the particular conditions clearly indicated the superiority of white clover swards. Of the trefoil varieties tested, Øtofte II was the best introduction. Additional plots of this variety were sown with S.48 timothy, a mixture of S.48 timothy and S.215 meadow fescue, and bent-grass to see if performance improved with companion grasses less aggressive than S.23 perennial ryegrass. Results were not encouraging.

In his discussion of the results Ellis Davies mentioned that the yellowish-green colour of the swards containing *Lotus* indicated nitrogen deficiency and referred to the results of Gavigan and

Curran (1962); but it was suggested that the main cause of the trefoil's poor performance was its inability to recover from heavy grazing - although the system of stocking used throughout the duration of the trial was not mentioned. These experiences with Lotus have not been encouraging and the Welsh Plant Breeding Station has discontinued work on this genus (Davies 1968).

From this review of experimental evidence it may be concluded that recent British trials with birdsfoot trefoil have apparently not shown much promise for the use of this genus in our farming systems. However, evidence from abroad under similar conditions indicates potential in both birdsfoot trefoil and marsh birdsfoot trefoil in terms of output, especially when used in the improvement of low-grade pasture, and in terms of quality, not only inherent in nutritional value but also in non-bloating properties. Additional features - such as drought resistance in birdsfoot trefoil and the self-seeding ability in both birdsfoot trefoil and marsh birdsfoot trefoil - strengthen the case for further examination of these species, starting from a more fundamental basis.

There is an obvious need for assessment of the competitive abilities of the trefoils when establishing and growing with herbage plants under British conditions, a comparison of the many ecotypes and cultivars already available and a detailed study of the circumstances under which a satisfactory establishment of the species can be obtained in situations where they are of most potential value.

3. GLASSHOUSE EXPERIMENTS (P1 TO P4*)

3.1. General objectives

The main aim in the series of glasshouse experiments was to study the behaviour of birdsfoot trefoil at its most sensitive stages, during the process of establishment from seed and under competitive stress from other species. The environment of the unheated glasshouse was considered the most suitable for an intimate study of these features under the particular circumstances, and a series of simple pot experiments was designed to assess the effects of several factors on the establishment of the legume. In these experiments the growth of Lotus corniculatus was compared with that of the control variety S.100 white clover.

3.2. Outlines of Experiments P1-P4

Experiment P1

Specific object - assessment of the competitive abilities of birdsfoot trefoil compared with those of white clover when grown alone and with five major grass species widely used in British farming.

Species and varieties used:

Species	Cultivar	Origin
birdsfoot trefoil	MC/E/64	Canada
white clover	S.100	Wales
Italian ryegrass	S.22	"
perennial ryegrass	S.24	"
cocksfoot	S.37	"
timothy	S.51	"
meadow fescue	S.215	"

* Footnote. Code letters have been designated to the experiments throughout the thesis according to the experimental technique applied, and are as follows:

P - pot trials
C - experiments comparing cultivars of Lotus
E - experiments comparing ecotypes of Lotus
L - sward experiments at a lowland site
H - sward experiments at a hill-land site
R - row trials.

The Canadian variety of birdsfoot trefoil, an experimental selection from Macdonald College, Quebec, was chosen from several varieties available because it was said to be intermediate in growth habit, time of maturity and other agronomic features when compared with other trefoil varieties and was also suggested to be more suited to British conditions (Dubar 1967). S.100 white clover was an obvious choice of control variety as it has frequently been used for this purpose in British experiments. The grass cultivars were all selected as being representative of the early, erect-growing group used for conservation purposes as it was considered that this type, while less aggressive than the late, prostrate-growing types, would offer more stress to the legumes by shading and give birdsfoot trefoil a distinct opportunity to show any advantage it might have due to its more upright form of growth.

<u>Statistical design</u>

A split-plot randomised block design was used with four replicates of the five companion grasses as main-plots and the two legume species as sub-plots. This set of pots was completely replicated four times, enabling the plants to be harvested at four different dates during the establishment period. Main-plots and sub-plots were separately randomised, as were the four harvest blocks (Figure 3.2.1).

<u>Times of sowing and harvesting</u>

The experiment was sown on May 10th, 1966, and the blocks were planned to be harvested at 30, 60, 90, and 120 days after date of sowing. The dates were fixed for adequate coverage of the establishment period, so that the plants were at a reasonable size for the first harvest yet not too mature for the last harvest.

Experiment P2

Specific object - comparison of the competitive abilities of birdsfoot trefoil and white clover when grown alone and with five common upland grass species, during establishment.

Species and varieties used:

Species	Cultivar	Origin
birdsfoot trefoil	MC/N/64	Canada
white clover	S.100	Wales
red fescue	S.59	"
sheep's fescue	commercial seed	
browntop bent	"	"
creeping bent	"	"
smooth-stalked meadow-grass	"	"

The grass species were selected on the basis of being those most commonly associated with the two legume species on the well-drained areas of natural pasture in Britain. Although the grasses most often sown with herbage legumes in improvement schemes are those in experiment P1 it was considered that assessment of the compatibility of the legumes with the naturally-occurring species might be helpful in the planning and interpretation of future hill sward trials.

Statistical design

A split-plot randomised block design was used in the same manner as in experiment P1 (Figure 3.2.2).

Times of sowing and harvesting

This trial was sown on April 25th, 1966, at sixteen days prior to the first trial. This earlier sowing date was intended to allow for the slower rate of growth of the hill grasses and to enable staggering of harvesting dates with those of trial P1.

Figure 3.2.1. Statistical layout of experiment P1

Location - Botany glasshouse, Apiary, Auchincruive.

Harvests:

HARVEST 2 60 days	HARVEST 3 90 days	HARVEST 1 30 days	HARVEST 4 120 days

N

Layout of replicates and main-plots:

Harvest 2

MF	T	L	PR	C	IR
L	C	T	IR	PR	MF
C	L	IR	T	PR	MF
C	IR	PR	MF	T	L

Harvest 3

L	T	IR	PR	MF	C	Rep 1
T	C	L	PR	MF	IR	Rep 2
PR	T	MF	IR	L	C	Rep 3
PR	IR	L	T	C	MF	Rep 4

Harvest 1

MF	PR	C	T	IR	L
C	T	L	IR	MF	PR
L	MF	C	T	PR	IR
L	IR	PR	C	MF	T

Harvest 4

L	T	IR	MF	PR	C	Rep 1
C	L	T	IR	PR	MF	Rep 2
T	C	L	IR	MF	PR	Rep 3
L	IR	T	PR	C	MF	Rep 4

L - legume only

IR - legume with Italian ryegrass

PR - legume with perennial ryegrass

C - legume with cocksfoot

T - legume with timothy

MF - legume with meadow fescue.

Sub-plots of birdsfoot trefoil and white clover were randomised within each main-plot.

Figure 3.2.2. Statistical layout of experiment P2

Location - Botany glasshouse, Apiary, Auchincruive.

Harvests:

HARVEST 4	HARVEST 1	HARVEST 3	HARVEST 2
150 days	60 days	120 days	90 days

N

Layout of replicates and main-plots:

Harvest 4

CB	L	SM	BB	SF	RF
SM	L	SF	CB	RF	BB
L	RF	CB	BB	SF	SM
CB	SF	SM	RF	L	BB

Harvest 1

SF	L	SM	CB	RF	BB	Rep 1
BB	CB	SF	L	SM	RF	Rep 2
RF	BB	L	CB	SM	SF	Rep 3
L	BB	SF	SM	RF	CB	Rep 4

Harvest 3

SM	SF	BB	RF	CB	L
L	CB	SM	BB	RF	SF
CB	SM	BB	L	RF	SF
BB	SF	L	RF	CB	SM

Harvest 2

RF	BB	L	SM	SF	CB	Rep 1
CB	SM	L	RF	BB	SF	Rep 2
L	CB	SF	SM	RF	BB	Rep 3
BB	L	SF	CB	SM	RF	Rep 4

L - legume only

RF - legume with red fescue

SF - legume with sheep's fescue

BB - legume with browntop bent

CB - legume with creeping bent

SM - legume with smooth-stalked meadow-grass.

Sub-plots of birdsfoot trefoil and white clover were randomised within each main-plot.

Times of harvest were set at 60, 90, 120 and 150 days after sowing to ensure adequate yields at all cuts.

Experiment P3

Specific object - comparative study of the competitive abilities of two birdsfoot trefoil varieties with one variety of white clover when grown alone and with four increasing densities of companion grass during the establishment phase.

Species and varieties used:

Species	Cultivar	Origin
birdsfoot trefoil	MC/H/64	Canada
birdsfoot trefoil	Empire	U.S.A.
white clover	S.100	Wales
Italian ryegrass	S.22	Wales

Two birdsfoot trefoil varieties were used in an effort to span the reported range of material whose performance, under British conditions, was relatively unknown, compared with that of the white clover variety. Italian ryegrass was selected as a species capable of providing intense competitive stress to the legumes from the earliest stages of the experimental period until the final harvest.

Companion grass densities

Five increasing densities of companion grass were imposed by growing three legume plants in each pot surrounded by 6, 12, 18, and 24 grass plants respectively and an additional treatment consisting of legume plants only. These densities were calculated from the basis of past experience of plant populations with pot trials 1 and 2 and from the aspect of the legume-grass ratios simulating legume percentages of 33, 20, 14, and 10% respectively as legume/grass numbers ranged from 3/6, 3/12, 3/18, to 3/24. The legume percentages thus obtained coincide with those normally observed in actual swards.

Statistical design

The same statistical design was used as in the previous trials with four replicates of the five densities as main-plots and the three legumes as sub-plots. This experiment was then replicated five times to enable five separate harvests to be taken throughout the trial period (Figure 3.2.3).

Sowing and Harvesting

The date of sowing this experiment was March 31st, 1967, with harvest dates starting at 60 days after sowing and continuing at fortnightly intervals, at 75, 90, 105 and 120 days. Delay of the first harvest until 60 days after sowing was planned to ensure that shading would have started to affect the legume plants by this date.

Experiment F4

Specific object - to compare the performances of three birdsfoot trefoil varieties and one variety of white clover when grown with a companion grass under differing severities of defoliation, during and after the process of establishment.

Species and varieties used:

Species	Cultivar	Origin
birdsfoot trefoil	MC/H/66	Canada
birdsfoot trefoil	Empire	U.S.A.
birdsfoot trefoil	Viking	U.S.A.
white clover	S.100	Wales
Italian ryegrass	S.22	Wales

MC/H/66 was used instead of MC/H/64 because the seed was fresh compared with that of the latter, and it was said to be similar in performance. Empire and Viking varieties were used in addition to

<u>Figure 3.2.3. Statistical layout of experiment P3</u>

<u>Location</u> - Botany glasshouse, Apiary, Auchincruive.

<u>Harvests:-</u>

Harvest 2 (75 days)	Harvest 1 (60 days)	Harvest 4 (105 days)	North bench

	Harvest 3 (90 days)	Harvest 5 (120 days)	South bench

						Rep No.
Harvest 2	M E W 6	W M E 0	W E M 12	W E M 24	M W E 18	1
	M E W 24	E W M 0	M E W 12	W M E 6	E M W 18	2
	M E W 6	W E M 12	W E M 0	E M W 18	M E W 24	3
	W E M 24	E W M 0	E M W 18	E W M 12	M E W 6	4

						Rep No.
Harvest 1	W M E 0	W E M 24	E W M 18	M E W 12	M W E 6	1
	W E M 6	M E W 24	E W M 12	E M W 18	M E W 0	2
	M W E 12	W M E 0	W E M 18	M W E 6	M W E 24	3
	M W E 24	W M E 18	M E W 6	E W M 12	M E W 0	4

						Rep No.
Harvest 4	M E W 12	E W M 6	M W E 24	M E W 0	W M E 18	1
	M E W 24	M E W 0	E M W 18	M E W 6	W E M 12	2
	E M W 12	E W M 18	M E W 0	M W E 6	E W M 24	3
	M E W 24	E W M 12	M E W 18	E M W 0	W E M 6	4

						Rep No.
Harvest 5	M W E 0	W M E 12	E M W 18	E W M 24	M W E 6	1
	E M W 24	E M W 18	M W E 12	M E W 0	M W E 6	2
	M E W 6	M W E 18	E M W 0	E M W 12	W E M 24	3
	W E M 12	W E M 0	W E M 6	W M E 24	W E M 18	4

Figure 3.2.3 (continued)

Harvest 3						Rep No.
	E W M 0	M W E 12	M W E 24	M E W 6	E M W 18	1
	W M E 6	M W E 0	M W E 24	E M W 18	W E M 12	2
	W M E 12	E W M 0	M E W 6	M W E 24	M W E 18	3
	M E W 18	E M W 12	M W E 0	E W M 6	W M E 24	4

Sub-plots

M - MC/M/66 birdsfoot trefoil

E - Empire birdsfoot trefoil

W - S.100 white clover

Main-plots

0 - legume only

6 to 24 - legume with 6 to 24 grass plants

represent the prostrate late-growing and erect, early maturing extremes within the reported range of varieties.

Defoliation treatments

It was decided to cut the herbage, when it reached an exploitable height of 30 cm, to three levels to simulate different severities of defoliation - to 12.5 cm, 7.5 cm, and 2.5 cm above soil level. Subsequent defoliations would be carried out independently and the relative frequencies recorded.

Statistical design

A split-plot randomised block design was used with defoliation treatments as main-plots and the legume varieties as sub-plots. There were five replications but no separate harvest blocks as in the previous pot experiments (Figure 3.2.4).

Date of sowing

Experiment P4 was sown on August 11th, 1967, under heated glasshouse conditions. Unlike the previous trials, the duration of the experiment was undetermined at the outset and so the trial was sown in late summer with the intention that it would be established by the following spring enabling several cuts to be taken during the 1968 season.

3.3. Investigational technique

The technique used in the series of trials had been used successfully by Harkess (1969, 1964-71) in studies on the behaviour of both grasses and legumes under glasshouse conditions. Certain modifications were introduced as the pot trials developed but the basic technique remained the same.

All the trials were carried out using plastic plant pots of 12.5 cm diameter as they were more easily cleaned and handled than clay pots. Identification codes could also be written on the

Figure 3.2.4. Statistical layout of experiment P4

Location - Botany glasshouse, Gibbsyard, Auchincruive.

												Rep No.
7.5 cm				2.5 cm				12.5 cm				5
E	V	M	W	V	W	M	E	M	E	V	W	
12.5 cm				2.5 cm				7.5 cm				4
E	M	V	W	M	W	V	E	W	M	V	E	
12.5 cm				7.5 cm				2.5 cm				3
V	E	W	M	V	W	E	M	M	W	V	E	
7.5 cm				2.5 cm				12.5 cm				2
W	V	E	M	M	W	V	E	E	V	W	M	
2.5 cm				12.5 cm				7.5 cm				1
M	E	W	V	W	V	M	E	M	W	V	E	

Main-plots

2.5 cm }
7.5 cm } height of cut above soil level.
12.5 cm }

Sub-plots

M - MC/B/66 birdsfoot trefoil

E - Empire birdsfoot trefoil

V - Viking birdsfoot trefoil

W - S.100 white clover

outside of the pot with indelible ink instead of using plant label pegs which can easily be mixed or lost.

Vermiculite was selected as the growing medium for all the trials because of its uniformity, sterility, inertness (from the aspect of nutrients), and ease of handling.

Nutrients were supplied in the form of a balanced liquid solution which had been in commercial use under the name of Mullard's Solution. The formula of ingredients was obtained by Harkess (1965) and used successfully in his glasshouse trials, and was composed of the following ingredients:-

Nitrate of Soda	224 g
Sulphate of Ammonia	28 g
Superphosphate	210 g
Potassium sulphate	98 g
Magnesium sulphate	56 g

These nutrients were mixed and thoroughly ground in a pestle-and-mortar until the mixture passed through a fine mesh sieve. 10 g of powder was then dissolved as recommended in 4.5 l of water and applied at the weekly rate of 50 ml per pot. Preliminary tests indicated that the application of the nutrient solution at this rate adjusted the pH level of the vermiculite to between 6.5 and 7.0, entirely suitable for plant growth. In terms of chemical analysis, the nutrient mixture contained approximately 6.8% N, 7.2% P_2O_5 and 8.6% K_2O.

Prior to sowing the clean plastic plant pots were labelled on the exterior rim with a permanent felt tip pen, according to legume variety, main-plot treatment, replicate number and harvest number where applicable. A sterile filter paper was then placed inside each pot to prevent loss of vermiculite through the drainage holes, and the pots were filled with dry vermiculite to within 2.5 cms of the top. A measured quantity of cold tap water was then applied to each pot.

Accurate placement of seed was accomplished by placing a thick cardboard disc on the vermiculite surface which was designed to leave an uncovered area of 3 cms around the perimeter and a circle of 3.5 cms in the centre. Twice the number of seeds required were evenly placed in the pot, the grass seeds towards the edge and the legumes in the centre. Seeds were finally covered with dry vermiculite to a depth of 1 cm which was subsequently moistened by an even application of tap water as a fine spray.

Inoculation of the legume seeds was carried out at 7 to 14 days after sowing, when the legume seedlings were emerging. Isolates of rhizobia known to be effective on Lotus were obtained from a source in the United States. Cultures effective on Trifolium were already available at the West of Scotland Agricultural College. Three Lotus isolates and one Trifolium isolate were sub-cultured and incubated thrice for 40 hour periods at the time of sowing the trials. The cultures were added to separate flasks containing quarter-strength Ringer's Solution and thoroughly stirred before inoculating the pots of each legume species with the specific inoculum at a rate of 25 ml of solution per plant pot.

No nutrient solution was applied to the plant pots until 21 days after sowing as a precaution against scorching the emerging seedlings. Mullard's Solution was then applied weekly at the standard rate, supplemented by additional applications of water when this was considered necessary. For experiments P3 and P4 application of nutrient solution was modified to weekly applications of 100 mls in order to maintain a more vigorous growth of companion grass. These trials also received additional applications of water as and when required.

Experiments P1, P2 and P3 were carried out on long narrow side benches standing 1 to 1.5 m above floor level in a glass-sided unheated glasshouse at the West of Scotland Agricultural College, Auchincruive. The plant pots were placed on a 2.5 cm layer of sterile, coarse, river-washed sand under which was a layer of polythene sheeting to prevent water loss. The sand bed was maintained in a moist condition by regular spraying with water. This helped to produce a uniform relative humidity and was also designed to support any root growth which might emerge through the drainage holes of the plant pots.

The experiments were arranged according to the statistical designs (Figures 3.2.1-4). Replicates were arranged in rows parallel with the glasshouse sides. Plant pots were initially touching within replicates with approximately 5 cms spacing between replicate rows. As the experiments progressed and harvest blocks were removed, the spacing between pots having different treatments was increased to some extent so that there was minimum interference between treatments. With experiment P4, spacing of pots was about 2.5 cms throughout the duration of the trial.

Control of glasshouse temperatures was attempted by opening and closing of ventilators and doors, and later by shading of glass roof and sides. Nevertheless average temperatures ranged from 10°C to 24°C throughout the periods under study, with extremes of 35°C to 1°C at unguarded moments. Relative humidity was regularly around 50%. With experiment P4, the heated glasshouse permitted a narrower range of temperature, from 15 to 20°C, with relative humidity very regular, at 45%. Actual temperature and humidity figures are presented in Appendix 4.

Seedling populations were reduced to the required numbers within 20 days of sowing. Any pots with less than the necessary number received transplants from pots containing spare seedlings. Each pot of experiments P1 and P2 had three legume plants and six grass plants where required. Experiment P3 had three legumes and 0, 6, 12, 18, or 24 grass plants per pot while experiment P4 pots each had 3 legumes and twelve grass plants, for increased competitive stress.

The growth of legumes in the first two pot trials was noticeably affected by light which entered the simulated sward (created by the closeness of the pots to each other) from the side at the level of the plant bases. This problem was tackled in experiments P3 and P4 by erection of hardboard panels 30 cm high around the sides of the blocks of plant pots. The panels were painted with a "clover leaf" shade of green emulsion paint to simulate the natural reflectivity of surrounding herbage.

Assessment of agronomic features

Harvesting procedure was the same in the first three trials. Before any plants were cut, several measurements of herbage features were recorded for both legumes and companion grasses. Average shoot length of each plant was measured in every pot being harvested and tiller counts were made and recorded individually. In experiments P1 and P2 the number of leaves per plant was recorded at harvests one and two (30 and 60 days after sowing).

Plate 3. Experiment P2 at three weeks after sowing. The pots were placed on river-washed sand prior to sowing; this was a useful medium for roots developing through the pot drain holes and also maintained adequate humidity in the trial environment.

Plate 4. Experiment P4 at two months after sowing. The side boards were painted clover-leaf green and erected to reduced light entry at the base of the simulated sward.

After the foliage measurements were recorded the legume and grass components of each plant pot were cut with scissors at soil level and placed into separate drying trays. Fresh weight figures for these components were obtained before the trays were placed in a ventilated oven and dried at 60-70°C for 18-20 hours. The dried herbage was reweighed to obtain dry matter yields.

In experiment P3 the shoot length and tiller number of the companion grasses proved impractical to record for each grass plant, so the average shoot length of grass in each pot was assessed and the total number of grass tillers per pot was recorded. Legume plants were still individually recorded. These factors were similarly recorded in experiment P4 prior to defoliation. In this last trial, cutting height was determined by the use of a peg marked at soil level and at the required cutting heights. The peg was inserted in the pot up to the soil level mark and the herbage was then cut with scissors at the particular height, and separated into grass and legume components for placing into the drying trays.

3.4. RESULTS*

3.4.1. Experiment P1 - results

Growth of legumes was assessed by recording leaf number (at 30 and 60 days only), length of shoots and number of branches prior to cutting for dry-matter determinations. The results obtained are therefore presented in this sequence.

* Footnote. The results of the experiments reported in this thesis were analysed by computers at the Agricultural Research Council's Unit of Statistics in Edinburgh. The complete collection of basic data is held by the Botany Department, The West of Scotland Agricultural College, Auchincruive, Ayr; only the relevant information is presented in the results sections. Conventional statistical abbreviations are explained in Appendix 6.

Leaf number. This was greater with birdsfoot trefoil than with white clover at both 30 days and 60 days after sowing. At 60 days there were differences between the companion grass treatments, the legumes having more leaves when growing by themselves than with the grasses. Differences between legumes growing with different grass species were not significant (Table 3.4.1.1).

Shoot length. The shoot length was significantly greater in birdsfoot trefoil at all harvests. At 30 days and 60 days after sowing the grasses had no effect on this feature but after 90 days, the legumes were significantly taller when alone than when grown with any of the grass species. This was again obvious at 120 days after sowing and the different grass species were also exerting some effect, the legumes grown with timothy being significantly taller than those grown with the ryegrasses and meadow fescue, but not those with cocksfoot.

Interactions emerged at 60 days and also at 90 and 120 days. Birdsfoot trefoil was shortest with the ryegrasses whereas white clover was shortest when grown with cocksfoot at 60 days. At the third harvest (90 days) trefoil was tallest alone then with cocksfoot, meadow fescue and timothy respectively, and shortest with the ryegrasses, while white clover shoots were longest with cocksfoot, followed by Italian ryegrass, timothy, meadow fescue and perennial ryegrass and shortest when alone. At 120 days after sowing, both birdsfoot trefoil and white clover were at their longest alone and with timothy but trefoil was shortest when with Italian ryegrass and meadow fescue whereas white clover was shortest with Italian and perennial ryegrasses (Table 3.4.1.2).

Number of branches. This factor varied as the trial progressed.

Table 3.4.1.1. Experiment P1. Mean number of leaves per legume plant

Companion grass/ Legume	Harvests (days after sowing) 30	60
None/		
birdsfoot trefoil	3.3	21.5
white clover	2.3	11.5
Mean	2.8	16.5
Italian ryegrass/		
birdsfoot trefoil	3.3	12.3
white clover	1.9	5.0
Mean	2.6	8.6
Perennial ryegrass/		
birdsfoot trefoil	3.5	12.0
white clover	2.0	5.5
Mean	2.8	8.8
Cocksfoot/		
birdsfoot trefoil	3.0	15.0
white clover	2.0	6.3
Mean	2.5	10.6
Timothy/		
birdsfoot trefoil	3.0	15.5
white clover	2.0	8.5
Mean	2.5	12.0
Meadow fescue/		
birdsfoot trefoil	3.0	14.8
white clover	2.0	6.8
Mean	2.5	10.8
Legume means:-		
birdsfoot trefoil	3.2	15.2
white clover	2.0	7.3

	Sign	SE±	Sign	SE±
Companion grasses	NS	0.10	**	1.3
Legumes	***	0.07	***	0.6
Interaction	NS	0.16	NS	1.4

Table 3.4.1.2. Experiment F1. Shoot length of legumes (mm)

Companion grass/ Legume	Harvests (days after sowing) 30	60	90	120
None/				
birdsfoot trefoil	38	194	464	692
white clover	21	108	191	470
Mean	30	151	327	581
Italian ryegrass/				
birdsfoot trefoil	33	143	305	432
white clover	19	102	203	305
Mean	26	122	254	368
Perennial ryegrass/				
birdsfoot trefoil	37	133	292	457
white clover	24	102	197	311
Mean	30	117	244	384
Cocksfoot/				
birdsfoot trefoil	40	165	349	492
white clover	19	92	210	337
Mean	30	129	279	414
Timothy/				
birdsfoot trefoil	32	159	318	565
white clover	19	111	203	368
Mean	25	135	260	467
Meadow fescue/				
birdsfoot trefoil	41	159	327	394
white clover	19	102	200	362
Mean	30	130	263	378
Legume means:-				
birdsfoot trefoil	37	159	342	506
white clover	20	103	201	359

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	NS	2.0	NS	6.9	*	14.5	***	25.7
Legumes	***	1.0	***	3.3	***	10.2	***	11.2
Interaction	NS	2.5	*	8.1	*	24.9	*	27.4

At the first harvest there was no difference between legumes but at 60 days birdsfoot trefoil was more branched. At 90 days white clover surpassed birdsfoot trefoil in this feature, only to be superseded by trefoil at 120 days. Species of grass affected the legumes similarly during the early stages but at 90 days those legumes growing without companion grasses were more branched than those with any of the grasses, those with Italian ryegrass having fewer branches than those associated with meadow fescue. Trefoil's branching was greatest when alone and with timothy, and least with the ryegrasses whereas white clover had more branches alone and with meadow fescue and less with timothy and Italian ryegrass. In the last harvest at 120 days, the legumes were more branched alone than with any grass species. Italian ryegrass affected birdsfoot trefoil's branching least and perennial ryegrass had the greatest effect but white clover with meadow fescue had most branches while with perennial ryegrass and cocksfoot it had the least number of branches (Table 3.4.1.3).

Dry-matter yields of legumes followed a definite progression. At 30 days birdsfoot trefoil out-yielded white clover significantly but no difference was apparent at 60 days. White clover was more productive at 90 days and increased its production over birdsfoot trefoil at 120 days. Both legumes were heavier yielding when growing with cocksfoot and meadow fescue and with timothy and Italian ryegrass at the first harvest date. At 60 days, the legumes growing without grass plants had greater dry weights than those growing with any of the grass species, although those with timothy out-yielded those grown with ryegrasses.

Dry-matter production was better in the legumes-only pots at third and fourth harvests than in the grass pots, although at 120

Table 3.4.1.3. Experiment P1. Number of branches per legume plant

Companion grass/ Legume	Harvests (days after sowing) 30	60	90	120
None/				
birdsfoot trefoil	1.0	3.0	5.8	10.0
white clover	1.0	3.0	6.3	6.5
Mean	1.0	3.0	6.0	8.3
Italian ryegrass/				
birdsfoot trefoil	1.2	2.0	2.5	7.0
white clover	1.0	1.3	4.9	5.3
Mean	1.1	1.6	3.7	6.1
Perennial ryegrass/				
birdsfoot trefoil	1.4	2.3	3.0	5.0
white clover	1.0	1.3	5.0	5.0
Mean	1.2	1.8	4.0	5.0
Cocksfoot/				
birdsfoot trefoil	1.0	2.5	3.5	6.5
white clover	1.0	1.5	5.0	4.8
Mean	1.0	2.0	4.3	5.6
Timothy/				
birdsfoot trefoil	1.0	2.3	4.0	6.3
white clover	1.0	2.0	3.8	5.3
Mean	1.0	2.1	3.9	5.8
Meadow fescue/				
birdsfoot trefoil	1.5	2.3	3.3	6.3
white clover	1.0	1.5	5.6	5.5
Mean	1.3	1.9	4.4	5.9
Legume means:-				
birdsfoot trefoil	1.2	2.37	3.7	6.8
white clover	1.0	1.75	5.1	5.4

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	NS	0.11	NS	0.326	***	0.22	***	0.39
Legumes	NS	0.07	**	0.128	***	0.11	***	0.19
Interaction	NS	0.16	NS	0.315	***	0.28	*	0.47

days, legume yield in the timothy pots was greater than in the Italian ryegrass pots (Table 3.4.1.4).

Total yields of grass and legumes followed the same pattern as the legume yields in that the trefoil pot herbage outweighed that from the white clover pots at 30 days, equalled at 60 days and thereafter the rapid growth of white clover ensured heavier yields from pots containing this legume.

Main-plot differences were recorded at all four harvests. The ryegrasses out-yielded the other species, including legumes only, at the first cut, although cocksfoot and meadow fescue were better than yields of timothy and of legumes grown alone. From 60 days onwards the grass pots gave greater dry weights of herbage than those with legumes only, except at 120 days when the ryegrasses were similar in yield to the legumes grown alone.

At cut 2, Italian ryegrass pots gave the highest dry weights with timothy pots least productive, but at 90 and 120 days after sowing, cocksfoot and timothy pots out-yielded the ryegrass pots. Interactions between yields of legumes and grass species were not at a significant level in any of the harvests (Table 3.4.1.5).

The same measurements were recorded and statistically analysed for the companion grass species. At no time were there significant differences between grasses grown in birdsfoot trefoil pots and those grown with white clover. Differences between the grass species were significant at all harvests and examination of these differences might reveal reasons for some of the variations in behaviour between the legumes.

Leaf number was greater in the ryegrasses than in the other species at 30 and 60 days (Table 3.4.1.6).

Tiller number was also higher in the ryegrasses throughout the trial,

Table 3.4.1.4. Experiment P1. Legume dry weights (g/pot)

Companion grass/ Legume	Harvests (days after sowing) 30	60	90	120
None/				
birdsfoot trefoil	0.02	0.4	3.7	8.5
white clover	0.01	0.4	5.6	15.4
Mean	0.01	0.4	4.8	11.9
Italian ryegrass/				
birdsfoot trefoil	0.02	0.2	0.9	1.7
white clover	0.01	0.2	2.4	6.6
Mean	0.01	0.2	1.6	4.1
Perennial ryegrass/				
birdsfoot trefoil	0.02	0.2	1.0	1.9
white clover	0.01	0.2	1.9	7.9
Mean	0.01	0.2	1.5	4.9
Cocksfoot/				
birdsfoot trefoil	0.02	0.2	1.4	2.2
white clover	0.01	0.2	2.5	8.7
Mean	0.01	0.2	1.9	5.4
Timothy/				
birdsfoot trefoil	0.01	0.3	1.4	3.6
white clover	0.01	0.3	2.7	9.8
Mean	0.01	0.3	2.0	6.7
Meadow fescue/				
birdsfoot trefoil	0.02	0.2	1.2	1.9
white clover	0.01	0.2	2.4	8.2
Mean	0.01	0.2	1.8	5.0
Legume means:-				
birdsfoot trefoil	0.02	0.2	1.6	3.3
white clover	0.01	0.3	3.0	9.4

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	*	0.001	***	0.03	***	0.3	***	0.6
Legumes	***	0.000	NS	0.01	***	0.1	***	0.3
Interaction	NS	0.001	NS	0.03	NS	0.3	NS	0.6

Table 3.4.1.5. Experiment F1. Total dry weights (g/pot)

Companion grass/ Legume	Harvests (days after sowing) 30	60	90	120
None/				
birdsfoot trefoil	0.02	0.4	3.7	8.5
white clover	0.01	0.4	6.0	15.4
Mean	0.01	0.4	4.8	11.9
Italian ryegrass/				
birdsfoot trefoil	0.07	2.0	6.1	11.0
white clover	0.07	1.9	7.3	16.6
Mean	0.07	1.9	6.7	13.8
Perennial ryegrass/				
birdsfoot trefoil	0.08	1.5	5.5	10.4
white clover	0.06	1.4	6.8	15.9
Mean	0.07	1.5	6.2	13.1
Cocksfoot/				
birdsfoot trefoil	0.05	1.8	7.8	12.7
white clover	0.04	1.8	9.3	18.7
Mean	0.04	1.8	8.6	15.7
Timothy/				
birdsfoot trefoil	0.03	1.4	8.2	13.7
white clover	0.02	1.4	9.8	17.9
Mean	0.03	1.4	9.0	15.8
Meadow fescue/				
birdsfoot trefoil	0.05	1.6	5.3	10.8
white clover	0.05	1.6	7.4	17.7
Mean	0.05	1.6	6.3	14.3
Legume means:-				
birdsfoot trefoil	0.05	1.4	6.1	11.2
white clover	0.04	1.4	7.8	17.0

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	***	0.01	***	0.07	***	0.4	**	0.7
Legumes	**	0.00	NS	0.03	***	0.1	***	0.3
Interaction	NS	0.04	NS	0.07	NS	0.4	NS	0.8

Table 3.4.1.6. Experiment F1. Mean number of leaves per grass plant

Companion grass/ Legume	Harvests (days after sowing) 30		60	
Italian ryegrass/				
birdsfoot trefoil	4.5		19.9	
white clover	4.6		17.8	
Mean	4.6		18.8	
Perennial ryegrass/				
birdsfoot trefoil	4.1		21.0	
white clover	4.1		20.5	
Mean	4.1		20.8	
Cocksfoot/				
birdsfoot trefoil	2.9		13.1	
white clover	3.1		13.9	
Mean	3.0		13.5	
Timothy/				
birdsfoot trefoil	3.0		11.6	
white clover	3.0		11.6	
Mean	3.0		11.6	
Meadow fescue/				
birdsfoot trefoil	3.3		13.5	
white clover	3.3		13.3	
Mean	3.3		13.4	
Legume means:-				
birdsfoot trefoil	3.6		15.8	
white clover	3.6		15.4	
	Sign	SE±	Sign	SE±
Companion grasses	***	0.2	***	0.8
Legumes	NS	0.1	NS	0.3
Interaction	NS	0.2	NS	0.6

especially in perennial ryegrass which had more tillers than Italian ryegrass after 120 days. The grasses with least tillering capacity under the trial conditions were cocksfoot and timothy (Table 3.4.1.7).

The ryegrasses were superior in length of shoot at 30 days but were overtaken by timothy which was tallest at 60 and 90 days, followed by cocksfoot which joined timothy as the tallest species at 120 days after sowing (Table 3.4.1.8).

Dry-matter yields of grass were similar when growing with birdsfoot trefoil and white clover. At 30 days the ryegrasses were higher in dry weight than the other grasses but at 60 days cocksfoot and Italian ryegrass were most productive. At this stage timothy was the lowest yielding grass, but its dry weight increased rapidly and by 90 days, timothy and cocksfoot were significantly heavier than the other grasses. At the final harvest 120 days after date of sowing the grasses were all similar in dry weight (Table 3.4.1.9).

3.4.2. Experiment P2 - Results

Growth of legume and grass plants was estimated as in the first trial, except that leaf number was not recorded after the first harvest at 60 days.

Leaf number. At 60 days this was greater in birdsfoot trefoil than in white clover. The legumes grown alone had more leaves than those growing with red fescue and the bent-grasses (Table 3.4.2.1).

Shoot length. This factor was also greater in birdsfoot trefoil than in white clover throughout the trial period. As expected, the legumes alone were taller than when grown with the grasses. At 60 days the difference between legumes with red and sheep's fescues and those alone was not significant, although the latter plants were taller than those with bent-grasses and meadow-grass. At

Table 3.4.1.7. Experiment P1. Number of tillers per grass plant

Companion grass/ Legume	Harvests (days after sowing)			
	30	60	90	120
Italian ryegrass/				
birdsfoot trefoil	1.9	6.0	10.9	11.9
white clover	1.9	5.3	11.3	10.8
Mean	1.9	5.6	11.1	11.3
Perennial ryegrass/				
birdsfoot trefoil	1.8	5.8	11.8	14.4
white clover	1.8	6.0	11.3	13.4
Mean	1.8	5.9	11.5	13.9
Cocksfoot/				
birdsfoot trefoil	1.0	4.0	5.4	7.0
white clover	1.0	4.0	5.3	5.9
Mean	1.0	4.0	5.3	6.4
Timothy/				
birdsfoot trefoil	1.0	3.3	7.4	7.0
white clover	1.0	3.1	6.5	6.3
Mean	1.0	3.2	6.9	6.6
Meadow fescue/				
birdsfoot trefoil	1.3	4.1	7.3	8.8
white clover	1.1	4.0	7.5	7.8
Mean	1.2	4.1	7.4	8.3
Legume means:-				
birdsfoot trefoil	1.37	4.6	8.5	9.0
white clover	1.35	4.5	8.4	8.8

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	***	0.127	***	0.2	***	0.63	***	0.5
Legumes	NS	0.053	NS	0.1	NS	0.22	NS	0.4
Interaction	NS	0.119	NS	0.2	NS	0.49	NS	0.8

Table 3.4.1.8. Experiment P1. Shoot length of grasses (mm)

Companion grass/ Legume	Harvests (days after sowing) 30	60	90	120
Italian ryegrass/				
birdsfoot trefoil	100	250	350	430
white clover	100	260	310	420
Mean	100	250	330	425
Perennial ryegrass/				
birdsfoot trefoil	90	220	250	420
white clover	90	230	270	390
Mean	90	220	260	405
Cocksfoot/				
birdsfoot trefoil	60	300	510	690
white clover	60	290	490	780
Mean	60	295	500	730
Timothy/				
birdsfoot trefoil	60	310	570	850
white clover	50	310	580	700
Mean	55	310	575	775
Meadow fescue/				
birdsfoot trefoil	80	260	330	550
white clover	80	270	360	520
Mean	80	265	345	535
Legume means:-				
birdsfoot trefoil	80	270	400	590
white clover	80	270	400	560

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	***	5	***	6	***	15	***	30
Legumes	NS	2	NS	4	NS	3	NS	9
Interaction	NS	4	NS	8	***	7	***	20

Table 3.4.1.9. Experiment F1. Grass dry weights (g/pot)

Companion grass/ Legume	Harvests (days after sowing)			
	30	60	90	120
Italian ryegrass/				
birdsfoot trefoil	0.06	1.8	5.3	9.3
white clover	0.06	1.7	4.9	10.0
Mean	0.06	1.8	5.1	9.6
Perennial ryegrass/				
birdsfoot trefoil	0.06	1.3	4.5	8.5
white clover	0.05	1.3	4.9	8.0
Mean	0.06	1.3	4.7	8.2
Cocksfoot/				
birdsfoot trefoil	0.03	1.6	6.4	10.4
white clover	0.03	1.6	6.8	10.0
Mean	0.03	1.6	6.6	10.2
Timothy/				
birdsfoot trefoil	0.01	1.1	6.8	10.1
white clover	0.01	1.1	7.2	8.2
Mean	0.01	1.1	7.0	9.1
Meadow fescue/				
birdsfoot trefoil	0.04	1.4	4.1	8.9
white clover	0.04	1.4	5.0	9.5
Mean	0.04	1.4	4.6	9.2
Legume means:-				
birdsfoot trefoil	0.04	1.5	5.4	9.4
white clover	0.04	1.4	5.8	9.1

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	***	0.005	***	0.07	***	0.3	NS	0.4
Legumes	NS	0.002	NS	0.05	NS	0.2	NS	0.3
Interaction	NS	0.005	NS	0.07	NS	0.3	NS	0.6

Table 3.4.2.1. Experiment P2. Leaf number per legume plant

Companion grass/ Legume	60 days
Mono/	
birdsfoot trefoil	11
white clover	6
Mean	8
Red fescue/	
birdsfoot trefoil	9
white clover	4
Mean	7
Sheep's fescue/	
birdsfoot trefoil	9
white clover	5
Mean	7
Browntop bent/	
birdsfoot trefoil	9
white clover	4
Mean	7
Creeping bent/	
birdsfoot trefoil	7
white clover	4
Mean	6
Meadow-grass/	
birdsfoot trefoil	7
white clover	4
Mean	5
Legume means:-	
birdsfoot trefoil	9
white clover	4

	Sign	SE±
Companion grasses	*	0.5
Legumes	***	0.2
Interaction	NS	0.6

90 days the unaccompanied legumes were taller than those with grasses, but differences between the latter were not significant. This trend was also evident at the 120 days and 150 days harvests (Table 3.4.2.2). Branch number was less consistent within the legumes (Table 3.4.2.3). At the first cut, birdsfoot trefoil was more branched than white clover under all treatments but differences between the legumes were not significant at 90 days, although those alone had more branches than those with the grasses, with the exception of sheep's fescue. Birdsfoot trefoil had the lowest number of branches with bent-grasses while clover was least branched when growing with red fescue and smooth-stalked meadow-grass. This low level of interaction was not considered to be of much importance at this stage. White clover proved to be more branched than birdsfoot trefoil at the third harvest (120 days) with differences between legumes accompanied and alone being the same as at 90 days. No interaction was obvious. In the final harvest at 150 days, birdsfoot trefoil was once more superior to white clover in this feature, the plants grown alone having significantly more branches than those under the grasses, which were similar to each other in branch number.
Legume dry weights. These showed a clear-cut pattern which emerged strongly in favour of white clover under the experimental conditions. At 60 days birdsfoot trefoil out-yielded white clover, with those plants alone and with sheep's fescue being more productive than the others except those with red fescue. At 90 days the positions were reversed with white clover having greater dry weight - a trend which was enhanced at each successive harvest. The legumes grown alone gave higher dry weights than those with grasses from 90 days onwards, those with sheep's fescue being more productive than those with red fescue and meadow-grass at the second harvest, and better than those

Table 3.4.2.2. Experiment F2. Shoot length of legumes (mm)

Companion grass/ Legume	Harvests (days after sowing) 60	90	120	150
None/				
birdsfoot trefoil	150	310	610	640
white clover	90	150	400	340
Mean	120	230	510	490
Red fescue/				
birdsfoot trefoil	140	230	400	480
white clover	70	130	330	370
Mean	100	180	410	420
Sheep's fescue/				
birdsfoot trefoil	150	250	480	490
white clover	80	150	400	360
Mean	110	200	440	420
Browntop bent/				
birdsfoot trefoil	120	240	530	500
white clover	60	150	390	340
Mean	90	200	460	420
Creeping bent/				
birdsfoot trefoil	100	220	430	500
white clover	60	130	360	310
Mean	80	180	390	400
Meadow-grass/				
birdsfoot trefoil	110	220	480	530
white clover	70	130	340	370
Mean	90	180	410	450
Legume means:-				
birdsfoot trefoil	130	250	500	520
white clover	70	140	370	350

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	*	8	*	10	**	19	NS	19
Legumes	***	5	***	6	***	12	***	12
Interaction	NS	13	NS	16	NS	29	NS	31

Table 3.4.2.3. Experiment P2. Branch number per legume plant

Companion grass/ Legume	Harvests (days after sowing) 60		90		120		150	
None/								
birdsfoot trefoil	2.4		4.5		6.5		16.8	
white clover	1.0		4.5		6.0		6.5	
Mean	1.7		4.5		6.3		11.6	
Red fescue/								
birdsfoot trefoil	2.0		4.6		3.8		8.5	
white clover	1.0		3.3		5.5		5.3	
Mean	1.5		4.0		4.6		6.9	
Sheep's fescue/								
birdsfoot trefoil	2.4		4.4		4.8		11.0	
white clover	1.0		4.2		5.8		5.3	
Mean	1.7		4.3		5.3		8.1	
Browntop bent/								
birdsfoot trefoil	2.3		3.5		4.5		9.3	
white clover	1.1		4.0		5.3		4.5	
Mean	1.7		3.8		4.9		6.9	
Creeping bent/								
birdsfoot trefoil	1.6		3.0		4.0		10.3	
white clover	1.0		3.9		4.8		5.0	
Mean	1.3		3.4		4.4		7.6	
Meadow-grass/								
birdsfoot trefoil	1.5		3.9		4.5		8.0	
white clover	1.0		3.3		5.3		5.5	
Mean	1.3		3.6		4.9		6.8	
Legume means:-								
birdsfoot trefoil	2.0		4.0		4.7		10.6	
white clover	1.0		3.9		5.4		5.3	
	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	NS	0.1	**	0.2	*	0.4	***	0.7
Legumes	***	0.1	NS	0.1	**	0.2	***	0.4
Interaction	NS	0.2	*	0.3	NS	0.4	*	1.1

with red fescue and meadow-grass at the second harvest, and better than those grown with red fescue and creeping bent at the third cut. In the last cut at 150 days the legumes grown with grasses were all similar in yield (Table 3.4.2.4).

Total yield. The figures were influenced by the increasing dry matter production of white clover as the experiment progressed. At 60 days, birdsfoot trefoil was superior but the positions were permanently reversed at 90 days and by 150 days white clover out-yielded trefoil by at least 50%. The pots containing companion grasses were generally higher in dry weight than those containing legumes only but there were exceptions. At 60 days all grass treatments out-yielded the unaccompanied legumes with red fescue and creeping bent the highest. At 90 days after sowing, the bent-grasses were better than other treatments and this trend was also obvious after 120 days when sheep's fescue equalled the yields of browntop and creeping bents. The bent-grasses were also superior to the other grass species at 150 days, there being no significant difference between the latter at this stage (Table 3.4.2.5).

Growth of companion grasses was recorded as in the previous trial. The results show no significant differences between grasses grown with the different legumes on any occasion although there were considerable differences between species of companion grass.

Number of tillers per grass plant. This was similar in all pots at the first harvest (Table 3.4.2.6). From the second harvest, sheep's fescue had a tillering capacity superior to all other grass species, smooth-stalked meadow-grass producing the lowest number of tillers.

Grass shoot length. Table 3.4.2.7 shows bent-grasses to be generally superior during the period of establishment. Creeping bent, along with red fescue, was tallest at 60 days while these

Table 3.4.2.4. Experiment F2. Dry weights of legumes (g/pot)

Companion grass/ Legume	Harvests (days after sowing) 60	90	120	150
None/				
birdsfoot trefoil	0.2	1.8	5.0	8.8
white clover	0.1	2.8	7.2	16.6
Mean	0.1	2.3	6.1	12.7
Red fescue/				
birdsfoot trefoil	0.1	1.0	2.0	2.4
white clover	0.1	1.0	5.3	10.5
Mean	0.1	1.0	3.7	6.4
Sheep's fescue/				
birdsfoot trefoil	0.1	1.0	2.5	3.3
white clover	0.1	2.1	8.4	9.7
Mean	0.1	1.6	5.5	6.5
Browntop bent/				
birdsfoot trefoil	0.1	1.0	2.4	3.5
white clover	0.05	1.8	6.3	8.5
Mean	0.08	1.4	4.4	6.0
Creeping bent/				
birdsfoot trefoil	0.07	0.9	1.9	2.5
white clover	0.05	1.6	4.2	7.4
Mean	0.06	1.2	3.1	4.9
Meadow-grass/				
birdsfoot trefoil	0.08	0.8	2.9	4.3
white clover	0.06	1.3	6.1	10.1
Mean	0.07	1.0	4.5	7.2
Legume means:-				
birdsfoot trefoil	0.1	1.1	2.8	4.1
white clover	0.07	1.8	6.3	10.5

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	**	0.01	***	0.1	**	0.5	***	0.8
Legumes	***	0.06	***	0.1	***	0.3	***	0.5
Interaction	NS	0.02	*	0.2	NS	0.6	NS	1.3

Table 3.4.2.5. Experiment P2. Total dry weights (g/pot)

Companion grass/ Legume	Harvests (days after sowing) 60	90	120	150
None/				
birdsfoot trefoil	0.2	1.8	5.0	8.8
white clover	0.1	2.8	7.2	16.6
Mean	0.1	2.3	6.1	12.7
Red fescue/				
birdsfoot trefoil	0.4	2.2	5.0	10.7
white clover	0.4	2.4	8.5	18.2
Mean	0.4	2.3	6.7	14.5
Sheep's fescue/				
birdsfoot trefoil	0.3	2.2	5.3	9.5
white clover	0.2	3.3	11.0	15.6
Mean	0.3	2.7	8.2	12.6
Browntop bent/				
birdsfoot trefoil	0.4	3.4	7.6	16.6
white clover	0.2	4.2	11.6	22.0
Mean	0.3	3.8	9.6	19.4
Creeping bent/				
birdsfoot trefoil	0.4	3.2	8.1	14.5
white clover	0.4	4.2	9.3	20.3
Mean	0.4	3.7	8.7	17.4
Meadow-grass/				
birdsfoot trefoil	0.3	2.0	5.8	11.0
white clover	0.2	2.4	9.6	16.9
Mean	0.3	2.2	7.7	13.9
Legume means:-				
birdsfoot trefoil	0.3	2.5	6.1	11.9
white clover	0.2	3.2	9.5	18.3

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	***	0.02	**	0.3	**	0.6	***	0.9
Legumes	**	0.01	***	0.1	***	0.3	***	0.6
Interaction	NS	0.02	*	0.2	NS	0.7	NS	0.1

Table 3.4.2.6. Experiment P2. Number of tillers per grass plant

Companion grass/ Legume	Harvests (days after sowing) 60	90	120	150
Red fescue/				
birdsfoot trefoil	4	6	13	20
white clover	4	7	11	16
Mean	4	6	12	18
Sheep's fescue/				
birdsfoot trefoil	4	23	28	38
white clover	4	24	26	35
Mean	4	24	27	37
Browntop bent/				
birdsfoot trefoil	5	8	20	20
white clover	4	8	21	19
Mean	4	8	20	20
Creeping bent/				
birdsfoot trefoil	3	6	15	16
white clover	4	6	12	15
Mean	3	6	14	16
Meadow-grass/				
birdsfoot trefoil	3	4	7	11
white clover	2	4	6	10
Mean	3	4	7	11
Legume means:-				
birdsfoot trefoil	4	10	16	21
white clover	4	10	15	20

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	NS	0.4	***	1.0	***	1.0	***	2.1
Legumes	NS	0.14	NS	0.6	NS	0.6	NS	1.2
Interaction	NS		NS		NS		NS	

Table 5.4.2.7. Experiment P2. Mean shoot length of grasses (mm)

Companion grass/ Legume	Harvests (days after sowing) 60	90	120	150
Red fescue/				
birdsfoot trefoil	239	268	456	572
white clover	242	268	482	515
Mean	241	268	469	544
Sheep's fescue/				
birdsfoot trefoil	110	150	324	361
white clover	120	158	330	349
Mean	115	154	327	355
Browntop bent/				
birdsfoot trefoil	198	305	456	648
white clover	176	286	431	648
Mean	187	296	444	648
Creeping bent/				
birdsfoot trefoil	225	255	419	551
white clover	222	266	426	501
Mean	224	261	422	526
Meadow-grass/				
birdsfoot trefoil	219	230	445	521
white clover	186	249	411	509
Mean	202	239	428	515
Legume means:-				
birdsfoot trefoil	198	242	420	531
white clover	190	245	416	504

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	***	6.3	***	11.8	***	15.4	***	28.9
Legumes	NS	14.1	NS	4.8	NS	7.5	NS	14.6
Interaction	NS		NS		NS		NS	

species and browntop bent were superior to the other species at 90 days. Sheep's fescue had the shortest foliage at 120 days, there being little difference between other grasses at this harvest; whereas at 150 days browntop bent was the tallest species, sheep's fescue retaining the shortest foliage.

Dry weights of grasses. These results are shown in Table 3.4.2.8. Red fescue and creeping bent out-yielded the other grass species at the first harvest but thereafter creeping bent and browntop bent had higher dry weights than the others. There were no significant interactions in any of the assessments of grass growth.

3.4.3. Experiment P3 - results

Assessment of this trial was carried out as in the previous experiments except that no attempt was made to record leaf number as this was considered to be impractical because of the larger number of grass plants; adequate records of the plants' dimensions were obtained by measurement of shoot length and branch or tiller numbers.

Shoot length. This was consistent in the legumes during establishment (Table 3.4.3.1). MC/H/64 was taller than the Empire variety of birdsfoot trefoil, which was in turn taller than white clover, at all harvests. At first no differences were found between the different densities of companion grass but at 90 days after sowing, the legumes grown with 12, 18 and 24 grass plants had taller shoots than those grown alone or with 6 grass plants. Density differences were not significant at 105 days but an interaction effect existed, the birdsfoot trefoil varieties being shortest when alone while white clover was tallest in this state, and yet white clover was shortest grown with 6 grass plants yet birdsfoot trefoil was shortest at this density. This effect was not experienced in the final

Table 3.4.2.6. Experiment P2. Dry weights of grasses (g/pot)

Companion grass/ Legume	Harvests (days after sowing)			
	60	90	120	150
Red fescue/				
birdsfoot trefoil	0.3	1.2	3.0	8.3
white clover	0.4	1.4	3.2	7.8
Mean	0.3	1.3	3.1	8.1
Sheep's fescue/				
birdsfoot trefoil	0.1	1.1	2.8	6.3
white clover	0.1	1.2	2.6	5.9
Mean	0.1	1.1	2.7	6.1
Browntop bent/				
birdsfoot trefoil	0.2	2.4	5.2	13.1
white clover	0.2	2.4	5.3	13.7
Mean	0.2	2.4	5.3	13.4
Creeping bent/				
birdsfoot trefoil	0.3	2.4	6.2	12.0
white clover	0.3	2.5	5.1	12.9
Mean	0.3	2.4	5.7	12.5
Meadow-grass/				
birdsfoot trefoil	0.2	1.2	2.9	6.7
white clover	0.2	1.2	3.5	6.8
Mean	0.2	1.2	3.2	6.8
Legume means:-				
birdsfoot trefoil	0.2	1.6	4.0	9.3
white clover	0.2	1.7	3.9	9.4

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Companion grasses	***	0.02	**	0.3	***	0.2	***	0.6
Legumes	NS	0.01	NS	0.1	NS	0.1	NS	0.3
Interaction	NS	0.02	NS	0.2	NS	0.3	NS	0.6

Table 3.4.3.1. Experiment P3. Shoot length of legumes (mm)

Grass plant number/ Legume	Harvests (days after sowing)				
	60	75	90	105	120
0/MC trefoil	80	130	125	220	370
Empire trefoil	25	105	60	115	400
white clover	20	65	20	140	150
Mean	40	100	70	160	300
6/MC trefoil	90	210	150	270	350
Empire trefoil	65	105	80	220	310
white clover	30	100	60	135	200
Mean	60	140	100	210	290
12/MC trefoil	80	170	200	290	260
Empire trefoil	50	110	210	260	240
white clover	40	90	90	60	100
Mean	60	120	170	200	200
18/MC trefoil	70	180	200	230	210
Empire trefoil	80	160	180	150	170
white clover	50	70	100	70	110
Mean	70	130	160	150	160
24/MC trefoil	100	180	240	230	270
Empire trefoil	60	140	200	200	200
white clover	40	70	120	120	80
Mean	70	130	190	180	180
Legume means:-					
MC trefoil	80	170	180	250	290
Empire trefoil	60	120	150	190	260
white clover	40	80	80	100	130

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	NS	6	NS	15	***	13	NS	15	**	21
Legumes	***	4	***	8	***	8	***	10	***	17
Interaction	NS	8	NS	16	NS	19	**	22	NS	40

harvest at 120 days after sowing when the legumes were taller alone and with 6 grass plants than with 12, 18 or 24 grass plants.

Branch number. Results showed the same sequence of legumes, MC/H/64 having more branches than Empire which had more than white clover. This order was recorded at all five harvests. At 60 days, main-plot differences were not significant whereas at 75 days, the unaccompanied legumes were more branched than those growing with 6 grass plants, which still had more branches than those at the greater densities. Interaction effects were significant between grass densities and legumes at harvests one and two but they were merely differences in sequence of high and low branch numbers, and as the differences were so small, no real conclusions were obvious. At 90 and 105 days there were no differences in branch number between legumes grown at varying grass densities but at 120 days after sowing, those grown alone had more branches than those under competition from companion grass plants, although branch numbers were similar in the grass pots. MC/H/64 was least branched when 18 grass plants accompanied it whereas Empire trefoil and S.100 white clover had the lowest branch numbers at the 24 plant density (Table 3.4.3.2).

Legume dry weights. Dry weights showed a changed sequence compared with those of previous trials. MC/H/64 birdsfoot trefoil was the highest yielding legume at all harvests, significantly better than Empire birdsfoot trefoil which equalled S.100 white clover, except at the third harvest (90 days after sowing) when it out-yielded the latter (Table 3.4.3.3). Legume dry weights were similar under all densities of Italian ryegrass until the final harvest, when those legumes grown alone gave higher dry weights than those with 12, 18 and 24 grass plants. Legumes at the 6 plant

Table 3.4.3.2. Experiment P3. Number of branches per legume plant

Grass plant number/ Legume	Harvests (days after sowing)				
	60	75	90	105	120
0/MC trefoil	2.3	3.3	2.7	2.2	4.0
Empire trefoil	1.4	2.3	2.5	1.6	2.9
white clover	1.0	1.5	0.8	2.0	1.1
Mean	1.6	2.4	2.0	1.9	2.7
6/MC trefoil	2.1	2.1	1.9	2.3	2.4
Empire trefoil	1.3	2.1	1.3	1.2	1.8
white clover	1.0	1.1	1.0	1.0	1.1
Mean	1.5	1.8	1.4	1.5	1.8
12/MC trefoil	1.7	1.6	2.1	2.5	2.4
Empire trefoil	1.2	1.3	2.0	1.4	1.3
white clover	1.0	1.0	1.0	0.8	1.0
Mean	1.3	1.3	1.7	1.6	1.6
18/MC trefoil	1.3	1.3	2.7	2.3	1.7
Empire trefoil	1.5	1.4	1.6	1.1	1.4
white clover	1.0	1.0	1.0	1.0	1.0
Mean	1.3	1.2	1.8	1.5	1.4
24/MC trefoil	1.4	1.2	2.6	1.8	2.6
Empire trefoil	1.2	1.2	1.3	1.0	1.0
white clover	1.0	1.0	1.0	1.0	0.8
Mean	1.2	1.1	1.6	1.3	1.4
Legume means:-					
MC trefoil	1.8	1.9	2.4	2.2	2.6
Empire trefoil	1.3	1.7	1.8	1.3	1.7
white clover	1.0	1.1	1.0	1.2	1.0

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	NS	0.1	***	0.1	NS	0.3	NS	0.1	**	0.2
Legumes	***	0.1	***	0.1	***	0.1	***	0.1	***	0.1
Interaction	*	0.2	***	0.2	NS	0.3	NS	0.3	*	0.3

Table 3.4.3.3. Experiment P3. Dry weights of legumes (mg/pot)

Grass plant number/ Legume	Harvests (days after sowing) 60	75	90	105	120
0/MC trefoil	70	110	200	140	470
Empire trefoil	30	60	560	50	320
white clover	25	60	30	300	210
Mean	40	70	100	160	330
6/MC trefoil	60	90	100	250	340
Empire trefoil	30	40	30	80	180
white clover	20	50	30	70	150
Mean	30	60	60	130	220
12/MC trefoil	40	90	150	160	180
Empire trefoil	20	30	140	90	40
white clover	30	30	50	20	30
Mean	30	50	110	90	80
18/MC trefoil	40	80	150	150	110
Empire trefoil	20	50	80	50	30
white clover	30	20	50	40	30
Mean	30	50	90	80	60
24/MC trefoil	50	80	220	170	240
Empire trefoil	20	40	90	70	40
white clover	20	30	60	60	30
Mean	30	50	130	100	100
Legume means:-					
MC trefoil	50	90	170	170	270
Empire trefoil	30	40	80	70	120
white clover	20	40	40	100	90

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	NS	5	NS	9	NS	20	NS	30	**	40
Legumes	***	2	***	6	***	12	**	20	**	30
Interaction	NS	5	NS	15	NS	30	*	40	NS	70

density also out-yielded those at the 12 and 18 plant densities.

An interaction effect was significant ($P < 0.05$) after 105 days, MC/H/64 producing highest weights at the 6 and 24 densities and lowest yields at the 18 plant density and when alone, in contrast to Empire which was greatest at 6 and 12 plant densities and least at the 18 plant density and when alone, whereas white clover gave most when alone and with only 6 grass plants yet least with 12 and 18 grass plants.

Total yield. Differences were insignificant until the final harvest when the pots containing MC/H/64 birdsfoot trefoil and S.100 white clover out-yielded those with Empire birdsfoot trefoil (Table 3.4.3.4). At all harvests the pots with 24 grass plants tended to have higher dry weights than the other pots but the differences became insignificant, between the grass pots, at the last harvest. The results showed the expected pattern of highest yields with highest densities and a decline towards the lower densities, the legumes-only pots producing the lowest dry weights throughout establishment. There were no significant interaction effects.

Grass shoot length. No significant differences were recorded between any of the pots except at 75 days after sowing when the grasses were taller at the 6 plant density than at any of the other densities (Table 3.4.3.5).

Number of tillers per grass plant. This was greatest when only 6 grasses were competing with each other, and with the legumes, than at the greater densities. At the fourth harvest, 105 days after sowing, the grass plots with white clover had more tillers than those with the trefoil varieties but this difference was not repeated at the last harvest (Table 3.4.3.6).

Grass tiller number per pot. The highest densities had the

Table 3.4.3.4. Experiment P3. Total dry weights (g/pot)

Grass plant number/ Legume	Harvests (days after sowing)				
	60	75	90	105	120
0/MC trefoil	0.07	0.10	0.20	0.10	0.5
Empire trefoil	0.03	0.06	0.06	0.05	0.3
white clover	0.02	0.06	0.03	0.30	0.2
Mean	0.04	0.07	0.10	0.16	0.3
6/MC trefoil	1.4	4.2	2.3	12.7	20.0
Empire trefoil	1.3	3.8	2.9	12.7	15.2
white clover	1.0	4.3	3.1	12.2	19.2
Mean	1.3	4.1	2.8	12.5	18.1
12/MC trefoil	1.8	4.9	5.8	9.9	16.2
Empire trefoil	1.5	5.1	5.1	12.1	17.1
white clover	1.7	5.7	6.8	11.8	19.5
Mean	1.6	5.2	5.9	11.2	17.6
18/MC trefoil	2.2	5.3	5.8	12.8	17.6
Empire trefoil	2.6	5.8	7.0	11.1	16.8
white clover	2.8	5.5	7.0	11.9	16.9
Mean	2.5	5.5	6.6	11.9	17.1
24/MC trefoil	2.9	6.7	8.2	10.8	20.4
Empire trefoil	2.9	6.2	8.0	13.1	15.5
white clover	2.6	6.9	8.0	11.4	19.7
Mean	2.8	6.6	8.1	11.8	18.5
Legume means:-					
MC trefoil	1.7	4.2	4.5	9.3	14.9
Empire trefoil	1.7	4.2	4.6	9.8	13.0
white clover	1.6	4.5	5.0	9.5	15.1

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	***	0.20	***	0.3	***	0.6	***	0.6	***	1.1
Legumes	NS	0.07	NS	0.2	NS	0.3	NS	0.3	*	0.6
Interaction	NS	0.20	NS	0.5	NS	0.7	NS	0.7	NS	1.4

Table 3.4.3.5. Experiment F3. Mean shoot length of grasses (mm)

Grass plant number/ Legume	Harvests (days after sowing) 60	75	90	105	120
6/MC trefoil	235	460	430	530	620
Empire trefoil	241	270	410	550	610
white clover	225	460	380	510	630
Mean	234	470	410	530	620
12/MC trefoil	235	445	380	560	580
Empire trefoil	216	425	410	530	610
white clover	222	430	410	530	600
Mean	224	435	410	540	600
18/MC trefoil	235	420	410	520	580
Empire trefoil	254	425	410	510	570
white clover	248	420	410	490	580
Mean	246	420	410	510	580
24/MC trefoil	232	420	430	530	570
Empire trefoil	241	400	410	510	570
white clover	232	410	430	510	580
Mean	235	410	430	510	580
Legume means:-					
MC trefoil	234	435	410	540	580
Empire trefoil	238	430	410	520	590
white clover	232	430	410	510	600

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	NS	9.6	**	7.1	NS	8	NS	25	NS	16
Legumes	NS	5.0	NS	4.1	NS	8	NS	11	NS	10
Interaction	NS	10.0	NS	7.9	NS	13	NS	22	NS	21

Table 3.4.3.6. Experiment P3. Number of tillers per grass plant

Grass plant number/ Legume	Harvests (days after sowing) 60	75	90	105	120
6/MC trefoil	7.8	9.3	9.4	11.1	17.9
Empire trefoil	7.5	9.0	10.7	11.7	15.4
white clover	6.3	9.6	9.7	13.5	17.1
Mean	7.2	9.3	9.9	12.1	16.8
12/MC trefoil	5.4	7.9	7.6	5.7	9.1
Empire trefoil	5.1	7.4	7.0	6.8	9.0
white clover	5.3	6.8	7.4	7.3	10.2
Mean	5.3	7.4	7.3	6.6	9.4
18/MC trefoil	4.4	5.4	5.1	5.8	5.7
Empire trefoil	4.6	5.5	5.1	5.4	6.6
white clover	5.0	5.8	5.7	6.1	6.4
Mean	4.7	5.6	5.3	5.8	6.2
24/MC trefoil	4.3	4.5	4.7	3.7	5.6
Empire trefoil	4.3	4.8	4.5	4.5	5.0
white clover	4.3	4.5	4.8	4.2	5.8
Mean	4.3	4.6	4.7	4.1	5.4
Legume means:-					
MC trefoil	5.5	6.8	6.7	6.6	9.6
Empire trefoil	5.4	6.7	6.8	7.1	9.0
white clover	5.2	6.7	6.9	7.8	9.9

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	***	0.3	***	0.3	***	0.6	***	0.4	***	0.8
Legumes	NS	0.2	NS	0.2	NS	0.2	***	0.2	NS	0.4
Interaction	NS	0.3	NS	0.4	NS	0.4	NS	0.4	NS	0.7

greatest tiller numbers until the final cut when differences were insignificant. At the fourth harvest tiller number was greater in the pots containing Empire birdsfoot trefoil and S.100 white clover than in the MC/H/64 pots but this was not recorded at the other harvests (Table 3.4.3.7).

Dry weight of grasses (Table 3.4.3.8). No differences were seen except at the last harvest when yield in the Empire pots was lower than in the other pots.

3.4.4. Experiment P4 - results

The first cut was made nine weeks after date of sowing, after which the pots were allowed to recover, regular checks on herbage height being made. Within four weeks of this first cut it was noted that the legume plants were remaining static while the grasses maintained an adequate rate of recovery. The legumes cut at 2.5 and 7.5 cms showed little signs of regrowth and within another two weeks many withered and died despite constant attention. The experiment was thus discontinued.

Number of legume branches per plant. This was significantly greater in birdsfoot trefoil than in white clover, MC/H/66 being superior to both Empire and Viking (Table 3.4.4.1).

Legume dry weight yields. These are presented in Table 3.4.4.I. Yields were not significantly different, although MC/H/66 tended to be greater than S.100 white clover while Empire and Viking birdsfoot trefoils tended to be poorer. Yields of legumes cut at 2.5 cms were, as expected, greater than at 7.5 cms and 12.5 cms. There was a slight interaction effect, yields of birdsfoot trefoil varieties showing large differences between the 2.5 and 7.5 cm cutting levels while those of white clover showed little difference between these two levels.

Table 3.4.3.7. Experiment P3. Number of grass tillers per pot

Grass plant number/ Legume	Harvests (days after sowing) 60	75	90	105	120
6/MC trefoil	46	55	56	67	107
Empire trefoil	45	54	64	70	92
white clover	37	58	58	80	103
Mean	43	56	59	72	101
12/MC trefoil	64	94	91	68	110
Empire trefoil	61	90	84	82	108
white clover	64	82	88	87	123
Mean	63	89	88	79	113
18/MC trefoil	80	96	92	105	103
Empire trefoil	80	99	93	98	119
white clover	90	105	102	110	115
Mean	83	100	95	104	112
24/MC trefoil	102	108	112	89	134
Empire trefoil	104	115	110	108	120
white clover	104	109	115	103	139
Mean	103	111	112	100	131
Legume means:-					
MC trefoil	73	89	88	82	113
Empire trefoil	73	89	88	89	110
white clover	74	88	91	95	120

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	***	2	***	5	***	6	**	5	NS	9
Legumes	NS	2	NS	2	NS	3	**	2	NS	3
Interaction	NS	3	NS	4	NS	5	NS	4	NS	6

Table 3.4.3.8. Experiment P3. Dry weights of grasses (g/pot)

Grass plant number/ Legume	Harvests (days after sowing)				
	60	75	90	105	120
6/MC trefoil	1.4	4.1	2.2	12.5	19.7
Empire trefoil	1.3	3.7	2.9	12.6	15.0
white clover	1.0	4.3	3.1	12.1	19.0
Mean	1.2	4.0	2.7	12.4	17.9
12/MC trefoil	1.7	4.8	5.7	9.7	16.1
Empire trefoil	1.5	5.0	5.0	12.0	17.1
white clover	1.7	5.7	6.7	11.8	19.4
Mean	1.6	5.2	5.8	11.2	17.5
18/MC trefoil	2.1	5.2	5.7	12.6	17.5
Empire trefoil	2.5	5.8	7.0	11.1	16.8
white clover	2.7	5.5	7.0	11.9	16.8
Mean	2.5	5.5	6.5	11.9	17.0
24/MC trefoil	2.8	6.6	8.0	10.6	20.2
Empire trefoil	2.9	6.2	7.9	13.1	15.4
white clover	2.6	6.9	8.0	11.4	19.6
Mean	2.8	6.6	7.9	11.7	18.4
Legume means:-					
MC trefoil	2.0	5.2	5.4	11.4	18.5
Empire trefoil	2.1	5.2	5.7	12.2	16.1
white clover	2.0	5.6	6.2	11.8	18.7

	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±	Sign	SE±
Densities	***	0.2	***	0.26	**	0.7	NS	0.6	NS	1.1
Legumes	NS	0.1	NS	0.18	NS	0.4	NS	0.4	*	0.8
Interaction	NS	0.2	NS	0.36	NS	0.7	NS	0.8	NS	1.5

Table 3.4.4.1. Experiment P4. (a) Number of branches per legume plant; (b) Dry weights of legumes (mg/pot); (c) dry weights of grass (g/pot) at cut 1.

Cutting heights/ Legumes	Legume branch number		Legume dry weights (mg/pot)		Grass dry weights (g/pot)	
2.5 cm/						
Empire	2.9		27		2.2	
MC/H/66	3.3		61		2.2	
Viking	1.9		24		2.3	
White clover	1.0		27		2.3	
Mean	2.3		35		2.2	
7.5 cm/						
Empire	2.3		0		1.6	
MC/H/66	3.1		13		1.5	
Viking	2.5		3		1.6	
White clover	1.0		25		1.6	
Mean	2.2		10		1.6	
12.5 cm/						
Empire	2.3		0		1.0	
MC/H/66	3.1		6		0.9	
Viking	2.9		1		1.2	
White clover	1.0		0		1.1	
Mean	2.3		2		1.1	
Legume means:-						
Empire	2.5		9		1.6	
MC/H/66	3.1		27		1.6	
Viking	2.5		10		1.7	
White clover	1.0		17		1.7	
	Sign	SE±	Sign	SE±	Sign	SE±
Cutting heights	NS	0.1	**	4	***	0.05
Legumes	***	0.2	**	4	NS	0.06
Interaction	NS	0.3	*	6	NS	0.10

Grass dry weights. Highest yields were at 2.5 cms and lowest at 12.5 cms, significant differences existing between the three cutting levels (Table 3.4.4.1). There were no differences between yields of grass grown with the different legumes.

3.5. DISCUSSION OF POT EXPERIMENT RESULTS

Experiments P1 and P2

These experiments were carried out simultaneously and both received the same management under the same environmental conditions. As the trials progressed the growth of companion grasses declined in vigour while that of the legumes, especially white clover, increased respectively. The decline in grass growth was more noticeable in the hill-land species used in the second experiment than in the more vigorous lowland species, although these developed a pale green foliage which suggested deficiency of nitrogen. This effect did not become obvious until around 90 to 100 days after sowing when it was considered too late to adjust the recommended rate of nutrient application.

Another factor contributing to the decline of competitive effects on the legumes was the source of light at the base of the simulated sward where the grass plants were largely composed of shoots and stems rather than leaves. This was due to the experimental technique adopted and was corrected in the third and fourth pot experiments by placement of hardboard edging strips 30 cms high around the perimeter of the blocks of plant pots. The boards were painted with a "clover leaf" shade of emulsion paint intended to match the reflectivity of natural vegetation growing near soil level, thereby eliminating this unnatural light source. The success of the third experiment was attributed largely to this modification, and to the adjustment of nutrient supply.

White clover out-yielded birdsfoot trefoil under all main-plot treatments in trials one and two after 75 to 90 days of growth. MC/H/64 birdsfoot trefoil had superior seedling vigour, possibly due to its larger seed size, but this advantage was only short-lived under the experimental conditions; Twamley (1969) reported similar findings. Competition from the grass species reduced legume yields by about 50% in both experiments in spite of the sub-normal growth of the companion species. Within the lowland species timothy and cocksfoot offered less stress to the legumes, perennial ryegrass tending to be the most aggressive species. Sheep's fescue was the weakest competitor to the legumes among the hill species, probably because of its dwarf growth habit.

The superiority of S.100 white clover in yield could be due partly to the fact that it was bred for vigorous growth under the conditions prevailing in Britain whereas MC/H/64 was selected under different daylength and temperature conditions in Canada (Bubar 1967).

Both shoot length and branch number in the legumes were suppressed by both lowland and upland grass species. Shoot length revealed the more erect growth habit of MC/H/64 birdsfoot trefoil which grew taller than white clover at all harvests. In the lowland grass trial, significant interactions at 60, 90, and 120 days after sowing indicated some trends. MC/H/64 was tallest when growing alone but was least suppressed by association with timothy and most affected by the ryegrasses. These results are in line with findings on the capability of birdsfoot trefoil when grown with grasses in other countries, namely that timothy/trefoil mixtures are recommended, while ryegrass tends to be too aggressive (Winch 1961; Henson and Schoth 1962). White clover behaved similarly except at 90 days when it was tallest with cocksfoot and timothy yet shortest with ryegrass and when growing alone. The latter effect could have been due to shading from neighbouring main-plot pots containing grasses, as this peculiar result was not repeated in the subsequent harvest.

Branch numbers were inconsistent in both trials. In trial P1 birdsfoot trefoil had more than white clover at 60 days after sowing but fewer at 90 days yet at 120 days trefoil was once more superior in this feature. The trend was similar in trial P2 and could be attributed to the contrast in development of branches in the two legume species. Birdsfoot trefoil produces lateral branches after the first shoot has elongated whereas white clover delays production of stolons for another few weeks. This was also observed in trials carried out by Mitchell (1956).

At the period around 120 to 150 days after sowing the stolon production in white clover declines while those already formed grow longer, while birdsfoot trefoil enters a branching phase during this period. The tillering pattern of the companion grasses might also affect this same feature in the legumes and the results do show that the legumes were suppressed at the third harvest by the most vigorously tillering grasses, especially the ryegrasses. Trial P2 results indicate some contrast to this theory in that the species with the greatest tillering capacity, sheep's fescue, did not affect the pattern of branching variations in the legumes, but this is a dwarf species normally.

Contributions from the legumes affected the total dry weight figures only during the early harvests in the first trial, but right throughout experiment P2, indicating the scale of the imbalance between the vigorous white clover and the slow-growing hill grasses, a feature rarely seen under natural conditions. The lowland grasses were more vigorous in growth yet the legumes still influenced total herbage production in trial P1 as grass yields were similar when growing with both legume species, differences only being at significant levels between the grass species.

Only tentative conclusions can be drawn from experiments P1 and P2 because of the somewhat artificial conditions and trends which occurred during the trial period. Some grass species are obviously more compatible with the individual legumes than others; more reliable indications were produced from the lowland species more normally sown with legumes than the upland grasses which although often seen growing with birdsfoot trefoil and white clover, do not adversely affect the legumes when all are in the seedling phase.

Experiment P3

The modifications incorporated into the experimental technique markedly affected the results obtained in this trial. Double the quantity of fertiliser was applied to ensure that the companion grass was maintained in a vigorous state of growth. The fertiliser was applied in twice the quantity of water to avoid scorch effects on the foliage and to prevent nutrient build-up on or near the surface of vermiculite.

The edging strips used to eliminate excess light entry at the sides of the pots were not set in place until 45 days after sowing so that etiolation of seedlings was avoided.

Yields of legumes were much lower throughout this experiment than those obtained when grown with an equivalent number of Italian ryegrass plants in trial P1. This was probably due to a combination of lower light intensity and competition effects from a more vigorous grass growth both above and below the soil surface. The increased seedling vigour of MC/H/64 birdsfoot trefoil set this variety at a distinct advantage when light was plentiful and grass competition minimal, an advantage which it seems to have retained. Twamley (1969) did not concur with this theory but Qualls and Cooper (1968) reported increased yields from cultivars which had superior seedling vigour. Empire is notoriously low in seedling vigour hence its similarity to white clover once under competitive stress (Qualls and Cooper loc. cit.).

The peculiar interaction effects shown in yields of legumes at the fourth harvest indicate a possibility that MC/H/64 birdsfoot trefoil's more erect growth habit might have enabled it to survive the competition from the grass plants by obtaining a more adequate quantity of light than the more prostrate growing Empire birdsfoot trefoil and S.100 white clover. This ability for erect types of Lotus to withstand the competition of tall-growing companion species has been reported in other countries (Suckling 1965) and may be a key to its potential use under British conditions.

MC/H/64 retained this superiority over Empire, which in turn proved better than white clover in both length of shoots and in number of branches. The pattern of branch production in birdsfoot trefoil which was observed in experiments P1 and P2 was also obvious in this trial and main-plot results reflect this.

Total yield figures were influenced entirely by the performance of the companion grass, as can be seen by comparing the total yield figures with the dry weights of the grass plants. Companion grass growth was remarkably uniform throughout the trial period, except for the final harvest when grass growth was sub-normal in the pots with Empire birdsfoot trefoil. Tiller number variations were consistent, revealing a vigorous level of competition among the grass plants.

The trial revealed little information on the competitive ability of birdsfoot trefoil other than in the seedling stage. There are indications that the most promising forms of birdsfoot trefoil would be those which have high levels of seedling vigour to increase the chances of a satisfactory establishment. These conclusions are in line with reports from other countries (Winch 1961; Bubar 1967; Seaney and Henson 1970).

<u>Experiment P4</u>

The main difference between this trial and the preceding experiments was that trial P4 was intended to run beyond the initial establishment stage, the pots being allowed to recover from defoliation instead of being discarded. In theory the plants would be maintained within certain limits, the cutting treatments preventing over-development of shoots and roots. This was also the reason for the late-summer sowing, with the intention that the trial would be established by the start of the following growing season enabling several cuts to be taken at a time when this practice is normal.

The results obtained from the first cutting operation indicated that the trial would establish according to the pattern of previous trials. No conclusions can be drawn other than this as the trial subsequently failed due to non-recovery of the legumes.

It is not certain which factor, or combination of factors, was primarily responsible for the failure of the trial. The rate of fertiliser application may have been too high for autumn conditions, favouring a rapid regrowth of the companion grass to the detriment of the legumes. The high relative humidity of the microclimate within the simulated sward could have caused a disease build-up on the legumes, leading to premature death. The trial was repeated in an unheated glasshouse in the following season but with similar results, the legumes dying off before they had passed through the seedling phase. Further attempts were not therefore considered to be worthwhile and the emphasis was changed to experiments under field conditions.

A. SPACED PLANT AND CLUMP EXPERIMENTS WITH LOTUS CORNICULATUS

A.1. Experiment objectives

A preliminary classification of material of birdsfoot trefoil, obtained as seed samples from many countries, was the general aim behind a series of experiments using variations of the spaced-plant technique. Size of available seed samples and variation in age of seed precluded the use of row and sward techniques at this stage of the investigation.

A.2. Design of experiments

Experiment C1.

Specific object - to compare the behaviour of fourteen cultivars of birdsfoot trefoil with control varieties of white clover and red clover, when grown as single spaced plants.

Cultivars used:

Legume	Cultivar	Country of origin
birdsfoot trefoil	Cascade	U.S.A.
	Douglas	U.S.A.
	Empire	U.S.A.
	Fargo	U.S.A.
	Granger	U.S.A.
	Leo	Canada
	Mansfield	U.S.A.
	MC/H/66	Canada
	Morshansk	U.S.S.R.
	Viking	U.S.A.
	Wallace	Canada
	Westriver	Canada
white clover	S.100	U.K.
broad red clover	Essex	U.K.

Two additional trefoil cultivars, termed Anon 1 and Anon 2 were used in the experiment to complete the number required for the more efficient statistical design used. These were made up from spare plants of the cultivar Mansfield.

The cultivars from the United States of America were all in commercial use whereas only Leo was available to farmers in Canada. MC/B/66 is an experimental selection made by Bubar at Macdonald College, Quebec. Wallace and Westriver are selections from wild material growing in Nova Scotia, obtained from the Government Research Branch, Nappan, Nova Scotia.

Wallace is described (Langille, 1969) as a late-maturing selection in Canada and was found in a very wet field near Wallace Cumberland County, Nova Scotia. Westriver is very early maturing and selected from wild material growing on roadsides near West River, Antigonish County, Nova Scotia. Both selections were included in these trials as they were believed to be registered varieties when received. Morshansk, the Russian type used in successful Canadian breeding programmes as a source of winter hardiness features was included on the same basis although nothing is known of its commercial usage.

Statistical design - a balanced lattice square design was used incorporating five replicates of the sixteen cultivars. The four blocks within each replicate were randomised, as were the varieties within each block (Figure 4.2.1).

Experiment C2.

Specific object - to compare the performances of eleven cultivars of birdsfoot trefoil with control varieties of white and red clovers when grown as spaced aggregate clumps, each clump containing twenty plants.

Figure 4.2.1. Layout of experiment C1.

Location:- Botany plots, Apiary, Auchincruive.

4 blocks per replicate

Replicate 1

Mo	G	MC	C
F	L	Ma	WC
E	RC	A2	Wa
We	V	A1	D

Replicate 2

Wa	C	Ma	F
RC	L	A1	We
D	V	E	WC
MC	Mo	A2	G

Replicate 3

A1	V	WC	D
G	C	L	We
E	Mo	MC	F
Wa	Ma	A2	RC

Replicate 4

RC	WC	V	Ma
Mo	A1	A2	L
D	C	MC	We
E	F	G	Wa

Replicate 5

F	V	D	G
Wa	WC	RC	Ma
C	Mo	L	MC
A2	We	E	A1

Cultivars:-

C - Cascade
D - Douglas
E - Empire
F - Fargo
G - Granger
L - Leo

Ma - Mansfield
MC - MC/H/66
Mo - Morshansk
Wa - Wallace
We - Westriver

V - Viking
A1 - Anon 1
A2 - Anon 2
RC - Essex broad red clover
WC - S.100 white clover

Cultivars used - as in experiment C1 with the exception of Mansfield, Anon 1 and Anon 2.

Statistical design. An incomplete block design was used with four replicates of the thirteen cultivars. Blocks within replicates were randomised as were varieties within each block (Figure 4.2.2).

Experiment E1.

Object - to compare performances of seventeen ecotypes of *Lotus corniculatus*, *L. tenuis*, *L. pedunculatus* and interspecific hybrids when grown as spaced aggregate clumps, each clump being composed of twenty plants.

Ecotypes used:

Species	Country of origin	Source of seed
L. corniculatus	Argentina	PI 161878*
"	Bulgaria	PI 259512
"	"	PI 259513
"	"	PI 259514
"	Germany	PI 232097
" (Var. *ciliatus*)	Jugoslavia	PI 251146
"	Krasnodar SSR	USSR
"	Lithuania SSR	USSR
"	Moscow	USSR
"	Poland	PI 255176
"	Switzerland	PI 235077
"	"	PI 234806
L. tenuis	France	PI 247898
"	Jugoslavia	PI 251148
L. pedunculatus	Germany	PI 232100
L. japonicus x *L. filicaulis* (Hybrid 1)	Canada	-
L. japonicus x *L. krylovii* (Hybrid 2)	Canada	-

* Ecotypes with PI numbers were obtained from the Plant Introduction Division of the United States Department of Agriculture, Geneva, Maryland.

Figure 4.2.2. Layout of experiment C2

Location:- Botany plots, Apiary, Auchincruive.

Block 8	RC Mo	WC MC	WC F	L E	Block 1
Block 9	RC Wa	E V	G Wa	We WC	Block 2
Block 10	V G	L MC	C WC	D V	Block 3
Block 11	F Mo	We V	C RC	G F	Block 4
Block 12	E MC	C We	E D	Mo G	Block 5
Block 13	D MC	F Wa	Wa Mo	C L	Block 6
			L D	RC We	Block 7

Cultivars:-

C - Cascade
D - Douglas
E - Empire
F - Fargo
G - Granger
L - Leo
MC - MC/H/66
Mo - Morshansk
V - Viking
Wa - Wallace
We - Westriver
RC - Essex broad red clover
WC - S.100 white clover

Statistical design. Size of seed samples prevented replication of aggregate clumps so that no statistical analysis was possible. However the ecotype clumps were planted simultaneously and adjacent to the other trials and received the same treatment throughout the trial period, enabling limited comparisons to be made (Figure 4.2.3).

4.3. Investigational technique

All cultivars and ecotypes were sown on 16th August, 1967, under heated glasshouse conditions in plastic plant pots of 12.5 cms diameter containing John Innes seed compost. Seven days after sowing individual seedlings were transferred into pots to provide material for experiment C1. At the same time all pots were inoculated with effective isolates of rhizobia. It was assumed that the isolate of Rhizobium effective on birdsfoot trefoil and marsh birdsfoot trefoil was also effective on slender birdsfoot trefoil and the interspecific hybrids, and these were later found to be satisfactorily nodulated. The inoculation technique was the same as that used in the pot experiments. The pots were then arranged according to their statistical designs in the glasshouse and at 30 days after sowing date the seedling populations were reduced to 20 seedlings in experiments C2 and E1, and to one seedling in experiment C1.

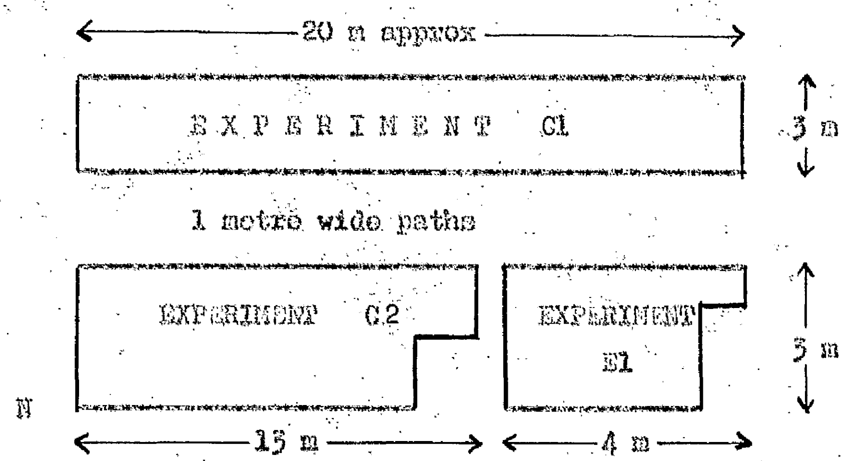
The experiments were transferred to an unheated glasshouse during mild winter conditions in January 1968 and had made enough growth by mid-April to warrant defoliation prior to planting out. A cut was taken on 23rd April leaving a stubble of 2.5 cm on the pots.

During April 1968 the trial site at the Apiary, Auchincruive, was prepared by thorough rotavation followed by raking and the

Figure 4.2.3. Layout of experiment E1

Location:- Botany plots, Apiary, Auchincruive.

Plan of cultivars and ecotypes trials area



application of a granular compound fertiliser (15% N, 15% P_2O_5 and 15% K_2O) at a rate of 375 kg/ha.

The experiments were planted out on May 7th and 8th, 1968, at 0.6 m spacing between individual plants and clumps according to the statistical designs. The experiments were planted adjacent to each other as shown in Figure 4.2.3.

Assessment of agronomic features, 1968

A visual assessment of spring growth was made on 26th February, 1968, on the cultivars involved in experiments C1 and C2. This was followed by a cut taken on 23rd April prior to planting out operations. Measurements of height and mean width were recorded for each pot before the foliage was cut to a height of 2.5 cm above soil level. The cut herbage was placed in numbered trays in an oven at 60°C overnight to obtain dry weight yields. Plants and clumps were under regular observation after planting out but only a visual assessment of growth habit was made during the period between planting and flowering.

Time of flowering was determined before the first field cut by the establishment of an arbitrary standard. Date of flowering of a spaced plant or clump was recorded as the number of days after June 1st when a minimum of five flowerheads per plant/clump showed open flowers. This feature was recorded daily and each cultivar was cut at two weeks after its mean date of flowering, within each experiment. All varieties were thus harvested at the same stage of development.

Individual records of all clumps and plants were maintained by designating each row of a trial with a letter and numbering the individuals within each row.

Prior to cutting at two weeks after date of flowering, growth habit measurements were recorded for every plant/clump. The height of the tallest branch was noted along with the mean of two width measurements - taken because the herbage growth was not circular in most cases. Growth habit could then be expressed in numerical terms by dividing the height by the width, as shown in Figure 4.3.1.

Defoliation was carried out using a one-hand lever-action garden trimmer which enabled the herbage to be held in one hand while the cut was made at 2.5 cm above soil level, and minimising dropping of branches during transference to a polythene sample bag containing a numbered label. S.100 white clover was not easily cut due to its spreading by stolons and extra caution had to be taken to ensure that no loss occurred during the cutting process.

At this first field cut in 1968 the samples were dried in an oven overnight at 60° to 70°C prior to recording dry weight yields. At all subsequent cuts the herbage samples were dried and weighed by the Chemistry Department, Auchincruive, at a temperature of 100°C for 16 hours.

During the period of regrowth between first and second field cuts of 1968 two growth habit assessments, by height and mean width measurement, were carried out - at four weeks and six weeks after the first cutting date. After the second assessment growth habit of both plants and clumps became distorted due to excessive rainfall and further assessments of this feature were postponed until the following growing season.

A second cut was taken at ten weeks after the first one. In experiment C1 actual cutting dates started on 14th September and ended on 17th October; experiment C2 was cut over the same period whereas cutting dates in experiment E1 ranged from 23rd September

Figure 4.3.1. Assessment of growth habit by height/width relationship

Designation	Height/width ratio	Side view of growth habit
Prostrate	$\frac{\text{ht. } 1}{\text{width } 4}$ (0.2-0.4)	
Semi-prostrate	$\frac{\text{ht. } 1}{\text{width } 2}$ (0.4-0.6)	
Semi-erect	$\frac{\text{ht. } 1}{\text{width } 1.25}$ (0.6-0.8)	
Erect	$\frac{\text{ht. } 1}{\text{width } 1}$ (0.8-1.1)	

to 17th October. There was little regrowth following this cut so that the plants were considered to be in a state suitable for minimum kill throughout the winter season.

Weed control was carried out manually at regular intervals. Herbicides were not used in case they affected the experiments in any way. As herbage growth gradually filled the area between the plants/clumps, weed control ceased, to prevent possibilities of damage to the legumes, but was resumed immediately after defoliation. Hoeing and raking was carried out at regular intervals during the relatively mild winter of 1968-9, no snow cover persisting for more than one day. Periods of frost occurred during December 1968 and the first three months of 1969 but these conditions were not considered to be severe, either in low temperature or in duration. Meteorological data is presented in Appendix 4.

Assessment of agronomic features, 1969

Measurement of winter kill was carried out on 9th May at the start of the second growing season, along with the first of a series of weekly recordings of growth habit, taken to obtain a more accurate assessment of the developing growth of each cultivar and ecotype. Winter kill was simply assessed by a record of numbers of plants/clumps which had died over the winter season.

Time of flowering was recorded as in the previous season and the first cut was taken at the same stage of growth. Regrowth was assessed by height and width measurements prior to a second cut taken at ten weeks after the first.

4.4. Results

4.4.1. Experiment C1

Growth habit. This was assessed by height and width recordings commencing in April 1968 when the plants were still in pots under glasshouse conditions. Measurements prior to the cut before planting out showed that a wide range of growth form was already obvious within the birdsfoot trefoil material with control variety Essex broad red clover significantly more erect than any of the *Lotus* cultivars.

At this stage Leo was the most erect form of trefoil, significantly more erect than eight of the other trefoils while Empire and Westriver were as prostrate in growth as white clover. Morshansk, the progenitor of Leo, was in the semi-prostrate range of types (Table 4.4.1.1).

The next assessment was at the first field cut two weeks after mean flowering date for each variety. These figures revealed some changes in the varietal sequence although Empire remained as low-growing as S.100 white clover. Douglas and Morshansk were the trefoil varieties remaining most erect during flowering, significantly more so than the other cultivars. Granger, Fargo and Viking were slightly more spreading. Mansfield had prostrate branches and gave a similar height-width ratio to Empire and S.100 white clover.

Two assessments in the aftermath stage did not include results for red clover, but did indicate more regular trends within birdsfoot trefoil. Empire and Fargo were significantly in the prostrate category with S.100 white clover, with Wallace and Westriver not so extreme. Douglas, Mansfield and Viking were classified as erect types according to the results of the regrowth assessments with the other cultivars in the intermediate range.

Because of winter kill after the 1968 season no further estimates of the factor were made. Table 4.4.1.1 shows the results obtained during the first season of this experiment.

Range of flowering. The 1968 results are also shown in Table 4.4.1.1. Under the conditions of the experiment S.100 white clover was one of the earliest in flower, surpassed only by Westriver birdsfoot trefoil while Essex broad red clover did not produce the required number of flowerheads until early August, in contrast to Westriver (June 22nd) and S.100 white clover (June 28th). Within the Lotus cultivars, Westriver was significantly earlier than the second earliest variety, Leo which flowered during the first week of July. After Leo the other varieties were similar in this feature, although Mansfield, Fargo and Viking proved to be significantly later than Leo.

Dry matter yield. Figures for the glasshouse cut and the two field cuts are presented in Table 4.4.1.2. Essex broad red clover out-yielded all Lotus cultivars at the glasshouse cut on April 23rd, but S.100 white clover was not significantly inferior to Essex, yet not superior to Cascade, Morshansk and Westriver trefoils. Morshansk gave significantly higher dry weights than all birdsfoot trefoil cultivars except Cascade, Westriver and Viking. Empire and Fargo were lowest yielding varieties at this cut.

Morshansk birdsfoot trefoil was significantly higher-yielding than all other legume varieties at the first field cut in July, with Leo, Empire and Fargo heading a second group of trefoil varieties which out-yielded S.100 white clover. Only Morshansk trefoil gave higher yields than Essex broad red clover which was one month later into flower than the former variety.

At the second field cut in September 1968 white clover was markedly more productive than all other legumes. Westriver,

Table A.4.1.1. Experiment C1. Growth habit (height/width ratio) and sequence of flowering (number of days after June 1st), 1968

GROWTH HABIT

Cultivars	Glasshouse cut (April)	Cut One (July)	Four weeks after Cut One	Six weeks after Cut One	Flowering time (days after June 1)
Clovers:					
S.100 white	0.4	0.2	0.1	0.2	28
Essex red	2.5	0.4	-	-	62
Birdsfoot tre-foils:					
Cascade	0.7	0.4	0.5	0.4	34
Douglas	0.6	0.7	0.8	0.6	33
Empire	0.4	0.2	0.3	0.2	37
Fargo	0.5	0.2	0.2	0.2	43
Granger	0.6	0.5	0.7	0.5	37
Leo	0.8	0.4	-	0.4	38
Mansfield	0.8	0.5	0.7	0.6	40
MC/H/66	0.7	0.3	0.5	0.5	35
Morshansk	0.5	0.4	0.6	0.5	39
Viking	0.6	0.5	0.7	0.5	36
Wallace	0.5	0.3	0.3	0.3	34
Westriver	0.4	0.5	0.4	0.3	22
Significance	***	***	***	***	***
SE±	0.1	0.01	0.04	0.03	0.8

Plates 5-8. Single spaced plants in experiment C1.

Plate 5. cv. Mansfield. This variety is typical of the erect type of growth shown by some varieties. Later in development some branches give way under weight of flowerhead and fruit.

Plate 6. cv. Westriver. This shows a prostrate growth habit typical of the cultivars suited for utilisation as grazing.

Plate 7. cv. Morshansk. This type exhibited a more spreading form of growth.

Plate 8. S.100 white clover.

Table 4.4.1.2. Experiment C1. Dry matter yields for 1968 (g/plant) and percentage of winter kill for 1968-9

Cultivars	Dry matter yields: Glasshouse cut (April)	Cut One (July/Aug.)	Cut Two (Sept./Oct.)	Percentage winter kill
Clovers:				
S.100 white	2.6	17.1	164.6	20
Essex red	3.3	28.5	16.5	40
Birdsfoot trefoils:				
Cascade	1.8	26.7	67.9	100
Douglas	0.7	25.0	48.9	80
Empire	0.3	34.8	45.3	20
Fargo	0.3	33.7	55.5	20
Granger	1.0	29.0	44.9	40
Leo	0.6	35.5	40.4	20
Mansfield	1.0	29.3	48.6	80
MC/H/66	1.0	24.9	66.2	40
Morshansk	2.0	51.2	67.9	0
Viking	1.1	26.5	68.6	100
Wallace	0.8	31.4	57.7	60
Westriver	1.7	26.3	90.3	60
Significance	***	***	***	-
SE$\bar{x}$	0.3	4.1	11.3	-

Viking, MC/H/66, Morshansk and Cascade were the highest yielding Lotus cultivars in this cut, with Leo the lowest yielding variety. Essex broad red clover was in the lowest-yielding group of legumes, with Leo, Empire and Granger.

Winter kill. A count of surviving plants was made on May 9th, 1969, when growth habit recording was resumed. These results, shown in Table 4.4.1.2, were not replicated and therefore could not be statistically analysed. The cultivars showing more than 60% kill were considered to be prone to winter kill under Scottish conditions and included Cascade, Douglas, Mansfield, Viking, Wallace and Westriver. Those varieties which suffered less than 20% losses included Morshansk, Fargo and Leo as well as S.100 white clover. Essex broad red clover had 40% kill, as did Empire, MC/H/66 and Granger birdsfoot trefoils. By the time the surviving plants reached the stage for cutting at two weeks after flowering, one of the Empire plants had recovered, reducing winter kill to 20% in this variety.

4.4.2. Experiment C2.

Start of spring growth. This feature was observed on February 26th, 1968, by a visual assessment and a height measurement when the clumps were under unheated glasshouse conditions. S.100 white clover was judged to be the most vigorous legume at this time with red clover only slightly less so. The most vigorous trefoil cultivars were Douglas, Granger and Cascade which were considered to be equal to Essex broad red clover in rate of growth and herbage production. Leo and Westriver were less vigorous than those already mentioned but were superior to the remaining ones, of which Empire, Wallace and Fargo remained almost dormant.

Growth habit. Essex broad red clover was significantly more upright than the other legumes at the glasshouse cut taken on April 23rd, 1968, whereas several trefoil varieties were as low-growing as white clover. The varieties Viking, Granger, Cascade, MC/H/66 and Douglas were all more erect than S.100 white clover at this stage (Table 4.4.2.1).

A visual estimate made on June 11th showed a similar sequence, except that Westriver was lower-growing than before. Measurements taken at the first field cut in July, also shown in Table 4.4.2.1, placed Empire and Fargo in the prostrate category while Viking was one of the most upright forms, nearly more erect than Cascade and Douglas. During the period of recovery after the first cut, S.100 white clover was more prostrate than birdsfoot trefoil, Wallace being the lowest-growing form of the latter while Viking remained the most erect and similar to Essex red clover and MC/H/66 trefoil. All these results are featured in Table 4.4.2.1.

Growth habit. During 1969 growth habit was assessed by weekly recordings of height and width of spaced clumps, a process interrupted in July by the first cut. Results obtained before this cut are presented in Table 4.4.2.2. and those obtained between first and second cuts are shown in Table 4.4.2.3.

Throughout the season S.100 white clover was significantly lower growing than any of the birdsfoot trefoil cultivars, except at the last assessment before cut one when all legumes were similar. Essex broad red clover was generally more erect in habit than the Lotus cultivars but the difference was not significant on May 9th, June 20th, August 15th and 29th.

The most erect types of birdsfoot trefoil were Douglas, Viking, MC/H/66 and Leo. Douglas was prominent from May 9th to 23rd, then Viking produced the highest height/width ratios during June although MC/H/66, along with Leo, Granger and Douglas, was similar. Leo was

Table 4.4.2.1. Experiment C2. Growth habit during 1968 (height/width ratios)

Legume variety	In glasshouse (22nd April)	Visual estimate (11th June)	Cut 1 (July/Aug.)	4 weeks after Cut 1	6 weeks after Cut 1
S.100 white clover	0.67	3	0.42	0.26	0.28
Essex broad red clover	1.73	9	0.91	0.83	-
Cascade birdsfoot trefoil	1.20	7	0.61	0.55	0.49
Douglas " "	1.31	8	0.61	0.64	0.55
Empire " "	0.66	2	0.42	0.63	0.60
Fargo " "	0.62	2	0.41	0.69	0.50
Granger " "	1.10	8	0.57	0.59	0.58
Leo " "	0.83	5	0.59	0.65	0.51
MC/E/65 " "	1.20	4	0.57	0.72	0.58
Morshansk " "	0.75	5	0.48	0.63	0.52
Viking " "	1.08	7	0.73	0.84	0.65
Wallace " "	0.62	4	0.43	0.51	0.54
Westriver " "	0.87	3	0.55	0.58	0.54
Significance	***	10 = erect	***	***	***
SE±	0.08	1 = prostrate	0.04	0.05	0.03

Table 4.4.2.2. Experiment C2. Growth habit during spring 1969 (height/width ratios)

Legume variety	May 9	May 16	May 23	June 2	June 6	June 13	June 20
	Date of assessment						
S.100 white clover	0.11	0.17	0.18	0.26	0.25	0.29	0.35
Essex broad red clover	0.75	0.63	0.88	1.00	0.99	0.87	0.65
Cascade birdsfoot trefoil	0.61	0.59	0.66	0.56	0.59	0.63	0.52
Douglas " "	0.64	0.69	0.71	0.69	0.60	0.72	0.56
Empire " "	0.44	0.62	0.54	0.66	0.65	0.63	0.48
Fargo " "	0.49	0.50	0.50	0.55	0.56	0.55	0.57
Granger " "	0.63	0.67	0.61	0.62	0.59	0.69	0.46
Leo " "	0.48	0.57	0.63	0.68	0.64	0.72	0.55
MC/E/66 " "	0.60	0.69	0.67	0.70	0.68	0.84	0.57
Morshansk " "	0.57	0.69	0.68	0.62	0.61	0.62	0.42
Viking " "	0.66	0.62	0.66	0.71	0.71	0.80	0.61
Wallace " "	0.45	0.50	0.49	0.55	0.55	0.61	0.51
Westriver " "	0.58	0.64	0.60	0.62	0.67	0.60	0.57
Significance	***	***	***	***	***	***	NS
SE±	0.06	0.05	0.05	0.05	0.06	0.05	0.06

Table 4.4.2.3. Experiment C2. Growth habit during July/August 1959 (height/width ratios)

Legume variety	July 5	August 1	August 7	August 15	August 21	August 29
	Date of assessment					
S.100 white clover	0.22	0.23	0.26	0.19	0.21	0.21
Essex broad red clover	1.02	1.09	1.33	0.89	0.94	0.65
Cascade birdsfoot trefoil	0.78	0.71	0.73	0.68	0.64	0.54
Douglas " "	0.75	0.69	0.88	0.72	0.74	0.60
Empire " "	0.33	0.52	0.71	0.64	0.63	0.51
Fargo " "	0.39	0.45	0.61	0.68	0.61	0.43
Granger " "	0.72	0.76	0.74	0.70	0.66	0.55
Leo " "	0.92	0.84	0.83	0.92	0.80	0.65
MC/H/66 " "	0.83	0.88	0.86	0.83	0.73	0.64
Morshansk " "	0.73	0.73	0.76	0.70	0.71	0.59
Viking " "	0.85	0.73	0.76	0.80	0.78	0.68
Wallace " "	0.66	0.57	0.61	0.61	0.64	0.56
Westriver " "	0.72	0.68	0.76	0.61	0.62	0.43
Significance	***	***	***	***	***	***
SE±	0.06	0.04	0.05	0.05	0.04	0.09

rather upright on 5th July just prior to the first cut and also from 15th August onwards. Westriver, MC/H/66, Granger and Leo were similarly classified as erect during early August, all having been cut only two to three weeks. Douglas, Leo, Viking and MC/H/66 remained high throughout August 1969 although by the final assessment on 29th August the range within birdsfoot trefoil was narrowing.

A similar picture emerged with those classified as prostrate or low-growing types. Empire, Fargo, Wallace and Westriver all produced lowest height/width ratios for various periods throughout the duration of the experiment. These varieties were significantly lower-growing than the upright cultivars already mentioned at most assessments. Empire was lower than Granger, Viking and Douglas on May 9th, while Fargo proved lower-growing than Douglas, Granger, MC/H/66 and Morshansk on 16th May. Fargo and Wallace were lowest within birdsfoot trefoil during the period before the July cut, and Empire was as low-growing as these two cultivars just after the cut. Towards the end of August, Fargo, Empire and Westriver produced the lowest height/width ratios although they were then in the category described as semi-prostrate in Figure 4.3.1.

<u>Sequence of flowering.</u> During 1968 S.100 white clover was significantly earlier in flowering than any of the other legumes while Essex broad red clover was correspondingly latest (Table 4.4.2.4). Earliest of the birdsfoot trefoil varieties were Granger, Westriver, Cascade and Douglas, the first two varieties being significantly earlier than Viking, Morshansk, MC/H/66 and the late-flowering types. In this first season Viking, Morshansk, MC/H/66, Fargo and Empire were all classified as late-flowering

varieties although the range of flowering within Lotus was only nine days between earliest and latest cultivars.

The 1969 results showed some similar trends with S.100 white clover earlier than all except Cascade and Granger trefoils. Essex broad red clover flowered at the same time as the early varieties of birdsfoot trefoil, at about four days after white clover, on 16th June. The birdsfoot trefoil cultivars were quite consistent, with Cascade, Granger, Westriver and Douglas early flowering varieties and Empire, Fargo, Wallace and Leo the latest into flower. Over three weeks separated earliest and latest varieties of birdsfoot trefoil.

Table 4.4.2.4. Experiment C2. Sequence of flowering during 1968 and 1969

Legume variety	No. of days to flower after June 1st	
	1968	1969
S.100 white clover	21	12
Essex broad red clover	52	16
Cascade birdsfoot trefoil	36	17
Douglas " "	36	19
Empire " "	42	39
Fargo " "	42	36
Granger " "	33	15
Leo " "	39	28
MC/H/66 " "	40	21
Morshansk " "	41	29
Viking " "	40	25
Wallace " "	39	31
Westriver " "	34	20
Significance	***	***
SE±	2.5	2.2

Dry matter yield. Marked changes were revealed as the experiment progressed. The first cut, taken under glasshouse conditions on April 23rd, 1968, showed S.100 white clover superior to all other cultivars at this stage of development. The early-flowering erect cultivars of birdsfoot trefoil were equal in yield to Essex broad red clover - Douglas and Granger, while all others were significantly lower in dry matter production. Wallace, Empire and Fargo produced the lowest weights of dry matter at this cut.

The first field cut gave dry weight figures at the full bloom stage. S.100 white clover was significantly poorer than most of the other cultivars, while Essex broad red clover, although equalled by Fargo, Empire and Morshanck birdsfoot trefoils, was higher in dry weight than the other varieties. Westriver, Douglas, Granger and Cascade trefoils were as low-yielding as white clover. The after-math cut ten weeks after the first one showed many reversals with S.100 white clover completely out-yielding the other legumes. Cascade, Granger, Douglas, Morshanck, Leo and Westriver trefoils were equally productive, all being higher than the other varieties of birdsfoot trefoil and Essex broad red clover. These latter cultivars were all similar in yield. Total dry matter yields for the 1968 season showed no significant differences between any of the thirteen cultivars involved in the trial. These results, along with those for each of the cuts taken during the first season, are presented in Table 4.4.2.5.

Table 4.4.2.5. Experiment C2. Dry matter yields, 1968 (g)

Legume variety	Glasshouse cut (April)	Cut 1 (July)	Cut 2 (Sept.)	Total
S.100 white clover	9.4	16	145	159
Essex broad red clover	6.6	85	43	128
Cascade birdsfoot trefoil	4.3	34	100	135
Douglas " "	6.3	35	85	122
Empire " "	2.3	63	37	99
Fargo " "	2.6	63	40	103
Granger " "	4.6	32	86	117
Leo " "	3.7	41	83	126
MC/H/66 " "	4.1	55	42	97
Morshanck " "	2.7	63	56	118
Viking " "	4.2	49	51	100
Wallace " "	2.2	51	44	94
Westriver " "	3.3	26	84	112
Significance	***	**	***	NS
SE$\bar{x}$	0.81	10.2	7.2	13.3

Yields from the two 1969 cuts are presented with the total season yield in Table 4.4.2.6. Morshansk and Leo birdsfoot trefoils were highest yielding varieties at the full bloom stage, the former out-yielding S.100 white clover. Essex broad red clover was significantly superseded by white clover and the two high-yielding birdsfoot trefoils whereas Douglas and Cascade were the lowest-yielding cultivars. Broad red clover was significantly highest yielding in the second cut, taken in the autumn, ten weeks after the first cut. Douglas and Morshansk were more productive than the poorest yielding varieties - Empire and Fargo, while Westriver was superior only to Fargo. There were no significant differences between the others.

Total yield figures for 1969 showed that Morshansk was superior to S.100 white clover ($P < 0.05$) as well as out-yielding Essex broad red clover and all other birdsfoot trefoils except Leo. Leo was only heavier-yielding than Granger trefoil.

Winter kill. Within the spaced clumps during the 1968-9 winter, die-off was negligible. Only one clump - one of Essex broad red clover - died during the first winter. There was not even any noticeable thinning within each clump. Clump survival after the second winter was visually recorded on 3rd June, 1970 (Table 4.4.2.6). Only five clumps were actually killed off completely although many appeared very sparse, and incapable of reasonable growth. Three of the four clumps of S.100 white clover were fully productive while Empire trefoil appeared vigorous enough in all clumps to enable further exploitation.

4.4.3. Experiment E1.

Growth habit. Assessments of this feature in the *Lotus* ecotypes started at the first field cut in 1968. Two further recordings were

Table A.4.2.6. Experiment 02. (a) Dry matter yields for 1969 (g); (b) Total dry matter yields for 1968 and 1969 (g); (c) Percentage survival, 1969-70

Cultivers	Cut One (July)	Cut Two (Sept.)	Total (1969)	Total (1968 + 1969)	Percentage Survival 1969-70
	Dry matter yields (g)				
Clovers:					
S.100 white	180	80	260	420	80
Essex red	110	160	270	420	45
Birdsfoot trefoils:					
Cascade	110	90	190	330	45
Douglas	110	100	210	340	30
Empire	160	60	220	320	55
Fargo	180	50	230	330	40
Granger	80	70	150	270	5
Leo	220	80	310	430	5
MO/H/66	150	80	230	330	10
Morshansk	280	110	390	510	25
Viking	110	80	190	300	15
Wallace	170	70	240	330	30
Westriver	120	100	220	330	25
Significance	***	***	**	**	-
SE±	25	13	34	34	-

made in the first season, at four and six weeks after cut one, although the latter assessment was not complete as prevailing weather made some clumps atypical.

At cut one and four weeks later the birdsfoot trefoil ecotypes were all similar, being spreading and semi-erect in habit. The Jugoslavian ecotype alone tended to be more prostrate at this stage. Both slender birdsfoot trefoil ecotypes were quite prostrate as was the L. japonicus x L. krylovii hybrid. The other hybrid (L. japonicus x L. filicaulis) was prostrate at the full bloom stage but more semi-erect during regrowth while the marsh birdsfoot trefoil ecotype from Germany was semi-erect at cutting but more low-growing during the aftermath period (Table 4.4.3.1).

During the second season, weekly assessments failed to reveal any extreme forms of growth habit although some trends were apparent as shown in Table 4.4.3.2. Before the first cut at full bloom, range of habit was narrow with the birdsfoot trefoil ecotypes. The Argentinian material grew relatively upright but spread outwards as flowerheads emerged. Ecotypes from Bulgaria were intermediate in form of growth and remained so until flowering. Types from Jugoslavia and Krasnodar SSR tended to be semi-prostrate whereas Lithuanian and Polish ecotypes were more semi-erect. Swiss ecotype number 235806 grew upwards at first then became spreading nearer flowering time. The German ecotype of marsh birdsfoot trefoil was low-growing at first then became more erect as vertical branches were produced, which eventually leaned outwards when flowerheads developed.

Differences were less obvious after the first cut. Most of the birdsfoot trefoil ecotypes were intermediate in growth form during the regrowth period, although Jugoslavian material produced

Table 4.4.3.1. Experiment B1. Growth habit 1968 (height/width ratios)

Ecotypes	Cut 1	4 weeks after	6 weeks after
	Height/width ratios		
L. corniculatus			
Argentina	0.69	0.75	0.55
Bulgaria 259512	0.67	0.87	0.53
Bulgaria 259513	0.63	0.66	0.56
Bulgaria 259514	0.60	0.65	-
Germany	0.61	0.74	0.42
Jugoslavia	0.43	0.48	0.36
Krasnodar SSR	0.61	0.69	0.44
Lithuania SSR	0.55	0.67	0.67
Moscow SSR	0.59	0.78	0.51
Poland	0.63	0.82	0.52
Switzerland 235077	0.62	0.40	0.31
Switzerland 235806	0.57	0.81	0.66
L. tenuis			
France	0.23	0.23	0.16
Jugoslavia	0.31	0.41	-
L. pedunculatus			
Germany	0.60	0.39	-
L. japonicus x *L. filicaulis* (Hybrid 1)	0.37	0.67	-
L. japonicus x *L. krylovii* (Hybrid 2)	0.21	0.26	0.17

Table 4.4.3.2. Experiment E1. Growth habit prior to cut 1 1969 (height/width ratios)

Ecotypes	May 9	May 16	May 23	June 2	June 6	June 13	June 20
	Height/width ratio at weekly intervals						
L. corniculatus							
Argentina	0.71	0.75	0.77	1.04	0.94	0.87	0.60
Bulgaria 259512	0.50	0.57	0.57	0.66	0.58	0.55	0.46
Bulgaria 259513	0.59	0.54	0.57	0.73	0.65	0.69	0.59
Bulgaria 259514	0.60	0.68	0.64	0.79	0.71	0.71	0.54
Germany	0.61	0.65	0.79	0.71	0.52	0.65	0.51
Jugoslavia	0.45	0.54	0.42	0.53	0.51	0.54	0.56
Krasnodar SSR	0.47	0.63	0.53	0.57	0.48	0.56	0.58
Lithuania SSR	0.55	0.92	0.78	0.93	0.84	0.49	0.42
Moscow SSR	0.48	0.48	0.60	0.63	0.57	0.65	0.51
Poland	0.68	0.86	0.93	0.71	0.74	0.67	0.48
Switzerland 235806	0.80	1.00	0.50	0.40	0.50	-	-
L. pedunculatus							
Germany	0.29	0.39	0.50	0.86	0.85	0.76	0.42

vigorous vertical growth in early August, as did the Lithuanian clump about two weeks after cutting. The marsh birdsfoot trefoil clump remained rather low-growing during July and August. Table 4.4.3.3 presents the height/width ratios during the regrowth prior to the second cut.

Sequence of flowering. Twenty-five days separated earliest and latest-flowering ecotype clumps in the first season, with slender birdsfoot trefoil from France flowering first on June 30th while the Jugoslavian ecotype of the same species was latest, not flowering until July 25th. Argentinian, German and Polish types of birdsfoot trefoil were all early-flowering on July 18th, 1968 (see Table 4.4.3.4).

Bulgarian forms of birdsfoot trefoil were the earliest of the surviving ecotypes to flower in 1969 whereas these had been relatively late the previous season, about 4 weeks later than in 1969. The Polish, German and Argentinian ecotypes were relatively early again this season whereas marsh birdsfoot trefoil from Germany was also consistently late-flowering. The 1969 results are also presented in Table 4.4.3.4.

Dry-matter yields. Results obtained in experiment E1 are shown in Table 4.4.3.5. A wide range of yields was apparent throughout the trial period with some ecotypes never reaching satisfactory levels of production while others were high-yielding before dying off. Hybrid 2 was lowest in the yield results at the first cut in 1968 and thereafter faded rapidly. The other interspecific hybrid also declined after reasonable production at cut 1. One of the Swiss ecotypes was slow in establishment then died off during winter 1968 after a promising yield at the second cut.

The highest yields in 1968 were obtained from the French and

Table 4.4.3.3. Experiment E1. Growth habit after cut 1 1969 (height/width ratios)

Ecotypes	July 21	July 25	Aug. 1	Aug. 7	Aug. 15	Aug 21	Aug. 29
L. corniculatus							
Argentina	0.82	0.75	0.79	0.82	0.71	0.66	0.50
Bulgaria 259512	0.65	0.61	0.85	0.80	0.66	0.69	0.49
Bulgaria 259513	0.74	0.56	0.61	0.78	0.61	0.71	0.47
Bulgaria 259514	0.68	0.63	0.88	0.84	0.63	0.62	0.52
Germany	0.96	0.71	0.65	0.73	0.67	0.58	0.57
Jugoslavia	-	0.40	0.60	1.00	0.86	0.83	0.55
Krasnodar SSR	0.87	0.64	0.55	0.69	0.69	0.59	0.52
Lithuania SSR	1.11	1.04	0.84	0.81	0.72	0.70	0.47
Moscow SSR	0.93	0.57	0.65	0.61	0.66	0.76	0.55
Poland	0.85	0.90	0.91	0.94	0.82	0.75	0.59
Switzerland 255806	-	0.35	0.45	0.30	0.55	0.47	0.29
L. pedunculatus							
Germany	0.46	0.44	0.42	0.71	0.47	0.49	0.41

Table 4.4.3.4. Experiment E1. Flowering sequence, 1968 and 1969

Ecotypes	Number of days after June 1st at which 5 heads show open flowers. 1968	1969
L. corniculatus		
Argentina	37	23
Bulgaria 259512	44	10
Bulgaria 259513	44	18
Bulgaria 259514	48	10
Germany	38	19
Jugoslavia	42	37
Krasnodar SSR	41	20
Lithuania SSR	45	26
Moscow SSR	42	23
Poland	38	17
Switzerland 235077	44	-
Switzerland 235806	40	17
L. tenuis		
France	30	-
Jugoslavia	55	-
L. pedunculatus		
Germany	48	31
L. japonicus x *L. filicaulis* (Hybrid 1)	48	-
L. japonicus x *L. krylovii* (Hybrid 2)	41	-

Table 4.4.3.5. Experiment E1. Dry matter yields, 1968 and 1969 (g)

Ecotypes	1968 Cut 1	1968 Cut 2	1968 Total	1969 Cut 1	1969 Cut 2	1969 Total
L. corniculatus						
Argentina	60	64	124	44	108	152
Bulgaria 259512	61	47	108	122	105	227
Bulgaria 259513	49	53	102	65	107	172
Bulgaria 259514	62	53	115	91	103	194
Germany	57	60	117	78	216	294
Jugoslavia	43	53	96	52	47	989
Krasnodar SSR	58	59	117	127	114	241
Lithuania SSR	46	33	79	72	83	155
Moscow SSR	63	55	118	167	147	314
Poland	56	56	112	122	100	222
Switzerland 235077	21	52	74	0	0	0
Switzerland 255806	45	44	89	2	4	6
L. tenuis						
France	35	103	143	0	0	0
Jugoslavia	132	1	133	0	0	0
L. pedunculatus						
Germany	62	70	132	169	143	312
L. japonicus x *L. filicaulis* (Hybrid 1)	53	1	54	0	0	0
L. japonicus x *L. krylovii* (Hybrid 2)	17	7	24	0	0	0

Jugoslavian forms of slender birdsfoot trefoil, the former being markedly high-yielding at the second cut while the latter was outstanding in July and hardly existing in September. Marsh birdsfoot trefoil was as high in dry weight as the slender birdsfoot trefoil types, its production of herbage evenly divided between the cuts. Ecotypes of birdsfoot trefoil gave satisfactory yields during the 1968 season, with the exceptions of the Swiss material and the Jugoslavian and Lithuanian ecotypes. Those types which survived the first winter were more productive during 1969. Exceptions were the remaining Swiss ecotype, which just remained viable but unproductive and the material from Jugoslavia. Some types of birdsfoot trefoil were high yielding, especially the ecotypes from Moscow, Germany and Krasnodar. The German marsh birdsfoot trefoil was one of the highest yielding clumps and emerged superior in the two-year total yield figures although the Moscow and German types of birdsfoot trefoil were nearly as productive. These figures compare favourably with the mean clump yields for the same period and obtained in experiment C2, the figures being presented alongside the ecotype yield totals in Table 4.4.3.6 to enable rough comparisons, not backed by statistical analysis, to be made.

Winter kill. The two slender birdsfoot trefoil ecotypes and the interspecific hybrids were killed off during the 1968 winter, along with the Swiss type of birdsfoot trefoil (P I 235077). The other Swiss ecotype was just viable but only a few weak branches remained. Birdsfoot trefoil from Moscow died off during the second winter season but the other clumps remained although less vigorous, especially the Argentinian material.

Table 4.4.3.6. Experiments C2 and E1. Total dry matter yields 1958 and 1959 (g per clump)

C1 Cultivars	Total Yield
S.100 white clover	429.0
Essex broad red clover	395.2
Cascade birdsfoot trefoil	331.4
Douglas birdsfoot trefoil	336.4
Empire birdsfoot trefoil	305.0
Fargo birdsfoot trefoil	337.8
Granger birdsfoot trefoil	273.1
Leo birdsfoot trefoil	427.6
NC/H/66 birdsfoot trefoil	328.8
Morshansk birdsfoot trefoil	499.1
Viking birdsfoot trefoil	296.3
Wallace birdsfoot trefoil	332.0
Westriver birdsfoot trefoil	327.8

Total Yield	E1 Ecotypes
	L. corniculatus
276.7	Argentina
335.0	Bulgaria 512
274.0	Bulgaria 513
308.4	Bulgaria 514
410.8	Germany
194.4	Jugoslavia
357.6	Krasnodar
233.1	Lithuania
431.9	Moscow
333.9	Poland
73.5	Switzerland 077
94.0	Switzerland 806
	L. tenuis
142.8	France
132.5	Jugoslavia
	L. pedunculatus
444.5	Germany
53.9	*L. japonicus* x *L. filicaulis*
25.8	*L. japonicus* x *L. krylovii*

4.5. Discussion

Seed samples of birdsfoot trefoil received from researchers in many countries were mainly in the form of cultivars, ecotypes and material of unknown pedigree. The variation in time of arrival and size of samples limited the scope of comparative studies and the range of material appeared to be so great that some preliminary classification was considered essential before more detailed agronomic experiments could be carried out.

Screening of plant material can be carried out using several techniques, generally grouped as sward trials, row trials and spaced plant trials. Each of these groups has advantages and snags and under the particular circumstances it was decided to use the spaced plant technique during this initial examination.

Spaced plant trials have been used in Britain since the technique was developed at the Welsh Plant Breeding Station, Aberystwyth, during the 1920's for use in the development of herbage plant cultivars (Williams 1927, 1931). After sowing in pots, the seedlings were planted out at approximately 0.6 to 0.7 m spacings and the plants were then generally cut twice yearly, as hay and as aftermath growth. The number of plants per variety ranged down to 100 and assessments were made for three or four seasons after which the surviving plants were used as parent material in breeding programmes. The technique has been used with little variation since this time (Hawkins 1950, 1953, 1954; Zaleski 1954; Hawkins 1958). The current technique in use at the National Institute of Agricultural Botany involves the planting-out of young material at 0.6 m spacing with 10 plants per variety and six replications, making a total of 60 plants per variety (Hawkins 1959). At Agricultural Scientific Services, East

Craigs, Edinburgh, fifty-four seedlings of each grass variety are planted out at similar spacing during the summer season (Sutton 1967); similar trials of herbage legumes have been laid out but have failed because of winter kill after the establishing season.

Zaloski (1970) also found high mortality rates especially in a wet, cold season and on heavy soils, which limited studies of distinctness, uniformity and stability on spaced plants to the year of planting.

Consideration of these factors led to the establishment of the three experiments C1, C2, and E1 as a means of preliminary study of material available at the time. Trial C1 was laid down as a spaced plant experiment, limited to only five plants of each variety. Experiment C2 was devised as an attempt to carry out a similar study for more than one season by means of aggregate clumps which enabled a total of eighty plants per variety to be tested. Such clumps had been used successfully by Rae (1967) to demonstrate the average characteristics of a herbage plant variety as opposed to spaced plants which showed the range of variation within a variety. Although inter-plant competition was vigorous within each clump, there tended to be less winter kill, the technique closely resembling that of row trials but using less material.

The third experiment, E1, included all material not classed as cultivars, and types of marsh birdsfoot trefoil and slender birdsfoot trefoil as well as interspecific hybrids. Most of these were received as small samples which excluded replication, due to low seedling numbers.

Twamley (1968) carried out an intensive study of management effects on birdsfoot trefoil variety trials and concluded that most systems of management give biased results, especially variety trials that are managed without regard to variation in the maturity of the varieties used. The management imposed in experiments C1, C2 and E1 was designed to allow the varieties and ecotypes to be compared when cut at the same stage. It was considered that factors such as performance under frequent cutting conditions should be examined in detail in future experiments incorporating the more promising material.

The study of growth habit in the birdsfoot trefoil material produced some interesting results and trends. This factor has a marked effect on the competitive ability of the legume and the trial results showed that birdsfoot trefoil varied considerably within the species as well as when compared with the clover varieties. Growth habit in the legumes was categorised in a similar manner to that of herbage grasses. Height/width ratio has been used widely by other workers (Sutton 1967) and seemed successful in the case of these experiments.

Although some varieties, including S.100 white clover, were classed as prostrate types, the use of the term was not meant to imply that the plant's stems and shoots were horizontal, but that the plant was much greater in width than it was in height. In the case of S.100 white clover, and the German ecotype of marsh birdsfoot trefoil the plants and clumps were wider due to growth of horizontal stems while the leafy branches were vertical; whereas the trefoil varieties Empire and Fergo tended to have long leafy branches which grew at a low angle and were as prostrate as the term is applied in the cases of grass varieties, typified by S.23 perennial ryegrass.

Growth habit results were similar in trials C1 and C2 although the latter revealed that the range within birdsfoot trefoil was not so great after the first season. No cultivars of Lotus were as low-growing as S.100 white clover or as erect as Essex broad red clover yet some varieties were consistent at opposite ends of the range of growth habit. The erect varieties such as Douglas and Viking behaved similarly under Scottish conditions as they did in the environment where they were bred, as did the prostrate Empire and Fargo varieties. The Russian Morshansk and related varieties Leo and MC/M/66 appeared to be more variable as they started with upright growth and gradually spread outwards as the narrow stems became top-heavy. This effect would be altered when these varieties were grown in swards with grasses as more support is given to longer branches under such circumstances.

Height/width ratios were influenced by the two component factors at the start and end of a period of growth. During early spring or just after defoliation the plants/clumps would grow vertically at first so that in birdsfoot trefoil and red clover the height/width ratio would tend to be higher than in white clover and marsh birdsfoot trefoil which retained the same width as before defoliation as the horizontal stems are not removed. After a period of growth the width of the plants and clumps was increasing at a greater rate than height, producing lower values in height/width ratio.

Sequence of flowering was broadly similar in experiments C1 and C2 during the 1966 season but there were some striking exceptions. Essex broad red clover was ten days earlier into flower as aggregate clumps than as spaced plants while clumps of Westriver trefoil were twelve days later than the spaced-plants of the same variety. In trial C2, Granger was four days earlier and Empire five days later than the corresponding material in trial C1. The 1969 results in experiment C2 showed much earlier flowering dates in the established clumps, ranging from 12th June to 9th July as opposed to 21st June to 22nd July in the previous season. Broad red clover flowered much earlier in the second year and MC/H/66 was earlier in the sequence of varieties while Wallace and Fargo were later. It was considered that these 1969 results were more reliable than those obtained in the first season as some varieties - Essex broad red clover especially - were slow in establishing as spaced plants and clumps and their subsequent performance during the first season was accordingly affected.

The flowering-time factor could be important in indicating the quality of herbage in the trefoil varieties. White clover is known to remain high in quality at the time when other herbage plants decline with increasing maturity; red clover and lucerne are stemmy as the flowering phase develops and quality therefore decreases in a similar manner to grasses (Harkess 1970). Birdsfoot trefoil would appear to be intermediate between these species as flowering stems are thinner and more succulent in appearance than those of red clover and lucerne. Winch (1969) suggested that breeding for leafiness in birdsfoot trefoil would increase herbage quality in the species so that it could be argued that the varieties which were later to flower were leafy for a longer period and therefore higher in digestibility than the earlier-flowering types. In practice it was noted that some of the varieties still maintained leaf production while flowering while others were more floriferous and not leafy. This factor should therefore be the subject of a future study with the more promising selections.

During the first season the ranking of varieties according to yield was different in trials C1 and C2 except that S.100 white clover was the highest-yielding legume in both cases, and Cascade was the most consistent high-yielding trefoil variety. Douglas, Granger and Leo trefoils ranked higher in experiment C2 whereas several varieties, including MC/H/66, Morshansk, Viking, Wallace and Westriver were less productive compared with the other varieties as spaced clumps than as single plants. Whether this was a competitive effect or not is not certain for the yields obtained from trial C2 in the second season showed no similar trends, Morshansk developing rapidly to out-yield both white and red clovers in total dry matter yield, and Wallace behaving similarly but to a lesser extent.

The yield results did reveal some promising forms of birdsfoot trefoil as regards dry-matter production. The developing productivity of Morshansk and Leo suggests that this material is worthy of more detailed study under local agricultural conditions. The 1969 results from experiment C2 produced some interesting indications of seasonal yield patterns which were not noticeable in trials C1 and C2 during the establishing season. Some cultivars produced the bulk of their herbage during the early part of the growing season, examples being S.100 white clover and the birdsfoot trefoil varieties Empire, Fargo, Leo, MC/H/66, Morshansk, and Wallace. The others had similar yields at both cuts although Essex broad red clover was higher yielding at the second cut than at the first. Bubar (1964) drew attention to the importance of seasonal yield patterns in birdsfoot trefoil and showed that the early-yielding types were more winter-hardy under temperate conditions as they became dormant earlier and thus had adequate time to store food supplies for the next season's growth. According to this theory, those early-yielding cultivars mentioned would be more suited to British grassland conditions.

Winterhardiness results in the two trials were not consistent with Bubar's theory. The C1 results do indicate that the hardier varieties were those purported to be so - S.100 white clover, Empire, Fargo, Leo and Morshansk birdsfoot trefoils. Of these varieties, however, only S.100 and Empire survived the 1969-70 winter season in experiment C2 in any reasonable manner which suggests that other factors contributed to the effect.

It was expected that variation within a particular variety would be more obvious in the spaced-plant experiment than in the aggregate clump trial but as there were variations between the replicates in both experiments the expected effect was not definitely traceable to genotypic variations. Of the two experiments the spaced-clump experiment would appear to be the superior technique under the particular circumstances as it allowed the testing of a larger number of plants for each variety than in the spaced-plant trial, and it enabled recordings to be made throughout at least two seasons which allowed more obvious trends to be more reliably assessed.

The ecotypes of birdsfoot trefoil were generally less variable in growth habit than the cultivars grown in the previous trials. None showed any results of artificial selection for extreme growth forms. The forms of slender birdsfoot trefoil and the interspecific hybrids were prostrate while they persisted but they showed a distinct lack of leafiness and did not appear to have any agricultural potential so far as Scottish conditions are concerned. The marsh birdsfoot trefoil ecotype was low-growing at first but rapidly developed an erect leafy bulk of herbage, repeating this performance after being cut.

There was a twenty-five day range of flowering date during the first season which did not alter much in the following year although the order of varieties changed. The highest yielding ecotypes of birdsfoot trefoil were about one week earlier in flowering than the equally productive marsh trefoil although the latter was visibly superior in leafiness which suggested better quality.

In terms of dry-matter yield the German, Moscow and Krasnodar ecotypes of birdsfoot trefoil matched the yields of the nearby red and white clovers in trial C2 but not even the German marsh birdsfoot trefoil reached the yield level of Morshansk until the 1970 season when it proceeded to yield about 200 g as opposed to the 62 g average of the two remaining Morshansk clumps, on the 24th June.

The rhizomatous habit of marsh birdsfoot trefoil and its increasing production of erect leafy herbage made it an obvious subject worthy of more detailed investigation. Of the birdsfoot trefoil forms tested, the variety Morshansk and its Canadian descendent Leo, the widely used American variety Empire and the Russian ecotypes from Krasnodar and Moscow regions of the Soviet Union would seem to be the material most suited to further experiments, depending on availability of seed.

5. SWARD TRIALS WITH LOTUS CORNICULATUS

5.1. Lowland Experiment L1

Object of trial - to compare the performances of three cultivars of birdsfoot trefoil with S.100 white clover and Essex broad red clover when grown with timothy under hay cropping management on the Carse of Stirling.

There are only a few special circumstances when the established species of herbage legumes are not suitable under the more intensively managed lowland grassland areas of Britain. On the flat heavy clay soils surrounding Stirling a hay-cropping system predominates based on the persistent local variety of timothy known nationally as Scots timothy. The Carse farmers have found that white clover tends to be shaded to the point of extinction by the tall hay crop while red clover's coarse stems delay the hay-curing process and increase the fibre content of the crop. This situation could be one where the more erect persistent types of birdsfoot trefoil could have potential use, its finer foliage contributing better quality to the hay, which is cut at a mature stage of growth.

Cultivars included in the experiment:

birdsfoot trefoil	-	MO/H/66
		Viking
		Empire
white clover	-	S.100
broad red clover	-	Essex

The trefoil cultivars used were selected firstly because reasonable quantities of seed were available, and also to compare early, mid-season and late cultivars of the legume. Viking has a reputation in North America for conservation purposes while

Empire is a more persistent type suited to grazing.

Experimental design. A randomised block design with five replications was used. A replicate incorporated six plots, each 5.5 m by 2.75 m, five of which contained the legume cultivars and the sixth composed of grass only. The plan of the trial is shown in Figure 5.1.1.

Figure 5.1.1. Statistical layout of Experiment L1

Location: Mains of Boquhan (Mr. D. More), Kippen, Stirling.

5.5 m; 2.75 m

	RC	EMP
Rep. 5	TIMOTHY ALONE	VIK
	MC	WC
	VIK	TIMOTHY ALONE
Rep. 4	EMP	RC
	WC	MC
	RC	MC
Rep. 3	VIK	WC
	TIMOTHY ALONE	EMP
	WC	RC
Rep. 2	TIMOTHY ALONE	EMP
	VIK	MC
	EMP	VIK
Rep. 1	MC	WC
	RC	TIMOTHY ALONE

N

Varieties:

EMP = Empire birdsfoot trefoil

VIK = Viking birdsfoot trefoil

MC = MC/H/66 birdsfoot trefoil

RC = Essex Broad Red Clover

WC = S.100 White Clover

Site of experiment. The trial was situated in a field on the farm of Mr. D. More, Mains of Boquhan, near Kippen, Stirling. The soil type was a typical Carse clay with a neutral pH level and satisfactory phosphate and potash contents, although the availability of the latter nutrients might not have been as high as the analysis suggested (see Appendix 3). The farmers in the area are usually advised to apply balanced fertilisers containing phosphate and some potash for cropping but they generally only apply sulphate of ammonia fertiliser to the grass crops.

The trial field was kept fallow throughout the growing season prior to sowing, as is the practice for weed control in the area. The usual cultivations were carried out to produce a tilth which was normal under the local conditions, but which would be classed as a coarse hard tilth unsuitable for establishment of herbage seed elsewhere in the intensive grassland areas of Britain.

Time and rates of sowing. The timothy seed was sown by the farmer on August 5th, 1967, at 14 kg/ha while the legumes were sown on August 15th, 1967, with the clover cultivars at 2 kg/ha and the birdsfoot trefoils at 5 kg/ha. The legume seed was inoculated with effective isolates of rhizobia by the milk technique (see Appendix 2) prior to being surface-sown, the hard soil preventing any raking or similar seed-covering treatment.

Management. During the trial period the management was typical of the local farming system. The sward was allowed to establish during the autumn and winter months, receiving a close mowing in February 1968 before it was rested to produce its first hay crop in late June of the same year. Approximately 80 kg/ha of nitrogen, as sulphate of ammonia, was applied each spring.

Assessment. A hay cut was taken on June 28th, 1968, just before the farmer cut the whole field. The plots were sampled using an Allen motor scythe which cut a swath 1 m wide at approximately 7 cm above soil level leaving a stubble similar to that of a hay reaper.

Before sample strips were taken from each plot a strip was cut along the borders of the plots leaving a sample area 4.5 m in length. The herbage cut in this opening process was raked off to prevent contamination with plot samples. The actual samples were then cut, care being taken to avoid mixing of different samples. A small sub-sample was removed at random along each cut sample area and placed in a labelled polythene bag for future botanical analysis, the remaining herbage being enclosed in a rope net and weighed on a spring balance. The total fresh weight was recorded before another sub-sample was removed, placed in another labelled bag and weighed, to be used for dry-matter yield determination. This procedure was repeated for all the plots.

After sampling, the remaining herbage was cut and raked off the trial area to complete the defoliation of the experiment. The dry-matter samples were dried at 100°C for 16 hours by the Chemistry Department, Auchincruive, for determination of dry matter percentage to enable dry-matter yields to be calculated. The other sub-samples were submitted to botanical analysis, separating grass, legume and weed components which were weighed to enable calculation of percentage composition.

A visual estimation of legume establishment was made at seven weeks after the hay cut on August 9th, 1968. Two individual opinions were used in this assessment in an attempt to reduce personal bias. A second hay cut was taken on 25th June, 1969, but as the legumes had virtually disappeared by this time the experiment was terminated.

Results of trial L1

The analysis of botanical samples produced legume percentages which were much lower than expected. Essex broad red clover was significantly higher than the birdsfoot trefoil cultivars and although S.100 white clover was not significantly higher than MC/H/66 it was superior to both Empire and Viking. Table 5.1.1 presents the mean legume percentages at the 1968 cut.

Table 5.1.1. Experiment L1. Mean percentages of legumes. June 1968

Legume cultivar	Percentage
S.100 white clover	1.1
Essex broad red clover	2.0
MC/H/66 birdsfoot trefoil	0.3
Empire birdsfoot trefoil	0.0
Viking birdsfoot trefoil	0.0
Significance	**
SE±	0.31

Dry matter yields obtained at the first cut are shown in Table 5.1.2. There were no significant differences between the legume plots, all of which produced high yields of around 11,000 kg/ha dry matter.

Table 5.1.2. Experiment L1. Dry matter yields of herbage, June 1968 (t/ha)

Legume cultivar	Yield (t/ha)
S.100 white clover	1.10
Essex broad red clover	1.13
MC/H/66 birdsfoot trefoil	1.05
Empire birdsfoot trefoil	1.07
Viking birdsfoot trefoil	1.10
Timothy only	1.09
Significance	NS
SE±	0.43

The visual estimation of legume establishment revealed the clovers to be more prevalent than the birdsfoot trefoil material at one year after sowing. S.100 white clover was significantly more prolific than birdsfoot trefoil whereas Essex broad red clover, although not better than MC/H/66, had established more effectively than both Empire and Viking (Table 5.1.3).

Table 5.1.3. Experiment L1. Visual estimate of legume establishment at one year after sowing

Legume cultivar	Establishment (Scale 0 to 5)*
S.100 white clover	3.8
Essex broad red clover	3.2
MC/H/66 birdsfoot trefoil	2.2
Empire birdsfoot trefoil	1.4
Viking birdsfoot trefoil	0.4
Significance	***
SE±	0.39

* The visual scale used corresponded to the following approximate percentages of legume ground cover in the aftermath sward:

5	20% legume cover	2	5% legume cover
4	15% legume cover	1	3% legume cover
3	10% legume cover	0	0% legume cover

Discussion of trial L1 results

The experiment was terminated at the time of the second hay cut in June 1969 because of the legumes' virtual disappearance by this stage. At no time was the establishment of any of the legumes considered to be satisfactory. The results obtained at the hay cut in June 1968 made the position obvious then although it was hoped that legume cover might improve by the start of the second season.

Soil analysis (see Appendix 3) revealed no abnormal levels of pH or nutrients but the application of nitrogenous fertiliser each spring may have helped to suppress the legumes and encourage a vigorous grass growth, resulting in the almost pure timothy sward. The weeds separated during the botanical analysis of sub-samples were mainly composed of bent-grass and Yorkshire fog, hardly any broad-leaved species being found. This factor suggests that the habitat was grass-dominant, at least during the period of sampling. Regular observation of the trial throughout the rest of the year did not reveal any indications of legume prominence at any time.

The botanical analysis in June 1968 indicated the superiority of the British-bred clover varieties over the trefoils although the lack of significant differences in the dry matter yields showed that the legumes contributed little to the herbage. Within the birdsfoot trefoil varieties the poor performance of Viking was surprising in view of its use in conservation swards in North America (Anon. 1961; Henson and Schoth 1962; Seaney and Henson 1970). The more promising performance of MC/H/66 may have been due to its origin in winter-hardy Russian material. Canadian selections from this material were made primarily with herbage conservation in view (Bubar 1961).

The general conclusion to be drawn from the experiment would appear to be that the particular system of management given to the sward throughout the duration of the experiment was not suitable for the maintenance of legumes in satisfactory percentages to enable them to contribute to the yield and quality of the herbage. The aim of the system is to produce a large bulk of herbage for conservation as green-cut hay. Scots timothy is one of the earliest varieties of the species in spring growth (H.M.S.O. 1966) and as the sward is rested from February onwards the legumes were probably at a distinct competitive disadvantage when they started growth in May. Under these circumstances, no herbage legume species would be suitable for inclusion in the sward.

The development of birdsfoot trefoil as a legume for conservation purposes has been successfully carried out in regions where the major herbage grass species have not proved suitable because of environmental factors such as prolonged drought, and generally poor soil conditions. In these circumstances birdsfoot trefoil has proved superior to other legumes under conservation practices (Anon. 1945; Kuprijanov 1946; Bubar 1964; Popov and Totev 1969). Such areas in Britain are not used for conservation and so the potential use of birdsfoot trefoil in this role here is low.

5.2. Upland Sward Experiments (H1 to H5)

General objectives

Experiments H1 to H5 were designed to examine the behaviour of birdsfoot trefoil, compared with that of white clover, when surface-seeded on upland pasture and subjected to various techniques used in the improvement of such types of grassland. The study was designed to span the establishment period, indicating the techniques more suitable for production of satisfactory birdsfoot trefoil stands, and also to produce some estimate of the yielding capabilities under the varying treatments applied in the trials.

The competitive factor was omitted from experiments H1 to H5 in that the legumes were sown without any companion species, other than the natural herbage, to facilitate studies of the legumes' performances during establishment. The animal factor was controlled in all the trials to the extent that the trial site was fenced and grazing by sheep and cattle was only permitted on certain occasions.

5.2.1. Designs of Experiments H1-5

Experiment H1

Specific object - to compare the performances of two cultivars of birdsfoot trefoil with S.100 white clover when surface-seeded on upland pasture under varying renovation techniques prior to sowing.

Cultivars used:

birdsfoot trefoil	-	Empire
		Viking
white clover	-	S.100.

The two birdsfoot trefoil cultivars used were selected because they were the only cultivars available in sufficient quantities of seed. Empire is described by the American literature as a persistent variety suitable for grazing purposes and thus seemed a logical choice. Viking was included to provide another standard for comparative measurement. S.100 was chosen as the control variety because of its suitability for hill land.

Renovation treatments:

(1) Chemical renovation by application of paraquat (bipyridyl)

herbicide, applied as a spray at the rate of 5.5 l/ha in 225 l/ha water one week before sowing.

(2) Rotary cultivation carried out by a Wolseley Titan Merry Tiller garden cultivator four days before sowing.

(3) Paraquat application seven days before sowing followed by rotary cultivation four days before sowing.

(4) No surface cultivation before or after sowing.

Experimental design. A split-plot randomised block design was used with the four renovation treatments as main-plots and the three legumes as sub-plots. There were five replications. Each main plot measured 15 m by 4 m, the sub-plots each being 5 m by 4 m. The plan of the experiment is shown in Figure 5.2.1.1.

Fertiliser applied. The experimental area received a dressing of ground limestone (50% CaO) at a rate of 5 t/ha and high-grade basic slag (14% P_2O_5) at 2.5 t/ha three days before sowing, after the renovation treatments had been carried out.

Sowing date and rates. The experiment was surface-seeded by hand on August 11th, 1967, when the birdsfoot trefoil cultivars were sown at 10 kg/ha and the white clover at 4 kg/ha.

Experiment H2

Specific object.- to compare the performances of two birdsfoot trefoil cultivars with S.100 white clover when surface-seeded on hill land under varying additional levels of nitrogen and potash fertiliser. A secondary object was the comparison of spring sowing of birdsfoot trefoil against the late summer sowing of experiment H1.

Cultivars used:

birdsfoot trefoil	-	Empire
		Leo
white clover	-	S.100.

Figure 5.2.1.1. Statistical layout of Experiment H1

Location: Broadshean (Mr. J. McFadzean), Kirkoswald, Ayrshire.

NORTH

Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
E | V | C P	E | C | V P + RC	E | C | V O	E | V | C RC	V | C | E P
V | E | C RC	C | E | V P	V | E | C P + RC	V | C | E O	E | C | V P + RC
C | V | E P + C	E | V | C RC	C | V | E RC	E | C | V P	V | E | C O
E | C | V O	V | E | C O	E | V | C P	V | E | C P + RC	E | C | V RC

Legume cultivars:

E - Empire birdsfoot trefoil

V - Viking birdsfoot trefoil

C - S.100 white clover

Renovation treatments:

O - no treatment

P - paraquat sprayed

RC - rotary cultivation

P + RC - rotary cultivation after paraquat spray

An adequate quality of seed of the promising Canadian cultivar Leo was received and included in this experiment in place of Viking as Leo's reported performance was more conducive with growth in Scottish upland conditions than Viking's.

Fertiliser treatments

The whole trial area was treated with ground limestone (50% CaO) at 5 t/ha and high-grade basic slag (14% P_2O_5) at 2.5 t/ha. The following additional fertiliser treatments were then applied:-

(1) nitrogen at 90 kg/ha, applied as Nitram.

(2) potassium at 125 kg/ha, applied as muriate of potash.

(3) nitrogen at 90 kg/ha with potassium at 125 kg/ha.

(4) no additional fertiliser treatment.

These fertilisers were applied prior to sowing and thereafter as an annual dressing in spring.

Experimental design. A split-plot randomised block design was used with the fertiliser treatments as main-plots and legume cultivars as sub-plots, there being five replicates. Main-plot dimensions were 15 m by 3 m while sub-plots were 5 m by 3 m. The statistical layout is shown in Figure 5.2.1.2.

Sowing date and rates. The trial was surface-seeded on 9th June, 1969, the birdsfoot trefoil cultivars at a rate of 10 kg/ha and S.100 white clover at 4 kg/ha.

Experiment H3

Specific object - to compare the performance of one cultivar of birdsfoot trefoil with that of white clover and wild white clover when surface-sown on upland pasture under varying applications of ground limestone and basic slag fertilisers. Birdsfoot trefoil is reputed to be more prolific and productive at nutrient levels too low for other herbage legumes. The aim of this trial was to

Figure 5.2.1.2. Layout of experiment H2

Location: Broadshean (Mr. J. McFadzean), Kirkoswald, Ayrshire

Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
W | L | E N + K	E | L | W O	L | W | E N + K	W | L | E K	L | E | W N
W | L | E O	L | E | W K	E | L | W N	E | L | W O	W | E | L N + K
F | W | L K	W | L | E N + K	E | W | L K	L | E | W N	E | W | L O
L | E | W N	E | W | L N	L | W | E O	W | E | L N + K	L | W | E K

NORTH

Main plots:-

O = no extra fertiliser

N = extra nitrogen fertiliser

K = extra potash fertiliser

N + K = nitrogen and potash fertiliser

Sub-plots:-

E = Empire birdsfoot trefoil

L = Leo birdsfoot trefoil

W = S.100 white clover

test this theory.

Cultivars used:

birdsfoot trefoil	-	Leo
white clover	-	S.100
wild white clover	-	S.184.

Fertiliser treatments:

(1) high-grade basic slag (14% P_2O_5) was applied at 2.5 t/ha prior to sowing, and repeated at two-yearly intervals.

(2) high grade basic slag (14% P_2O_5) was applied at 2.5 t/ha with ground limestone (50% CaO) at 5 t/ha prior to sowing and repeated at two-yearly intervals.

(3) no fertiliser applied prior to sowing.

Experimental design. The statistical design used was a split-plot randomised block-design with the fertiliser treatments as main-plots and the legumes as sub-plots. There were four replicates used in this experiment. The main-plots measured 8 m by 3 m, each sub-plot being 3 m by 2.7 m. The plan of the experiment is presented in Figure 5.2.1.3.

Figure 5.2.1.3. Layout of experiment H3

NORTH

Rep 1			Rep 2			Rep 3			Rep 4		
	SL			O			S			O	
Leo	WWC	WC	WWC	WC	Leo	WC	Leo	WWC	WWC	WC	Leo
	S			S			SL			SL	
WWC	WC	Leo	WC	WWC	Leo	Leo	WWC	WC	WWC	Leo	WC
	O			SL			O			S	
WWC	Leo	WC	Leo	WC	WWC	WC	Leo	WWC	Leo	WWC	WC

Main-plots:

O - no fertiliser

S - high grade basic slag

SL - high grade basic slag + ground limestone

Sub-plots:

Leo - Leo birdsfoot trefoil

WC - S.100 white clover

WWC - S.184 wild white clover

Date and rates of sowing. The experiment was sown on July 30th, 1969, with the birdsfoot trefoil cultivar at 10 kg/ha and the clovers at 4 kg/ha respectively.

Experiment H4

Specific object - to compare the establishment and behaviour of birdsfoot trefoil and two types of white clover when surface-sown on upland pasture with different companion grass species. This was the first sward trial investigating the competitive ability of birdsfoot trefoil when established with grasses considered suitable for marginal land improvement.

Legume cultivars used:

birdsfoot trefoil	-	Leo
white clover	-	S.100
wild white clover	-	S.184

Companion grasses used:

(1) perennial ryegrass - S.23

(2) red fescue - S.59

(3) timothy (Scots) with meadow fescue (S.53).

Experimental design. A split-plot randomised block layout was used incorporating four replicates. The companion grasses were main-plots and the legumes sub-plots. The main-plots were 12 m by 2 m and the sub-plots measured 4 m by 2 m. The actual plan is shown in Figure 5.2.1.4.

Fertiliser treatment. Five t/ha ground limestone (50% CaO) and 2.5 t/ha basic slag (14% P_2O_5) were applied to the experiment area just before surface-seeding took place. Repeat applications were to be applied at two-year intervals.

Sowing rates and date. Birdsfoot trefoil was sown at 8 kg/ha and the white clovers at 2 kg/ha. S.23 perennial ryegrass was sown at 20 kg/ha, S.59 red fescue at 15 kg/ha while the timothy/meadow fescue mixture was

Figure 5.2.1.4. Layout of experiment H4

NORTH

Rep 1	Rep 2	Rep 3	Rep 4
WC | Leo | WWC (TMF)	Leo | WWC | WC (O)	WWC | Leo | WC (PRG)	WC | WWC | Leo (RF)
WC | WWC | Leo (PRG)	WC | Leo | WWC (RF)	WC | WWC | Leo (O)	Leo | WC | WWC (TMF)
Leo | WC | WWC (RF)	WWC | WC | Leo (PRG)	Leo | WWC | WC (RF)	WC | WWC | Leo (O)
Leo | WWC | WC (O)	Leo | WC | WWC (TMF)	WWC | Leo | WC (TMF)	Leo | WWC | WC (PRG)

Main-plots:

O - no sown grass

PRG - S.23 perennial ryegrass

RF - S.59 red fescue

TMF - Scots timothy with S.53 meadow fescue

Sub-plots:

Leo - Leo birdsfoot trefoil

WC - S.100 white clover

WWC - S.184 wild white clover

sown at 5 kg/ha for Scots timothy and 20 kg/ha for S.53 meadow fescue. The experiment was sown on 30th July, 1969, the same day as the previous experiment.

Experiment H5

Specific object - to compare the performance of birdsfoot trefoil when establishing and competing with different companion grasses under varying applications of ground limestone and basic slag fertilisers.

Cultivars used:

birdsfoot trefoil	-	Leo
perennial ryegrass	-	S.23
red fescue	-	S.59
Scots timothy with S.53 meadow fescue.		

Fertiliser treatments:

(1) high-grade basic slag (14% P_2O_5) was applied at the rate of 2.5 t/ha before sowing.

(2) ground limestone (50% CaO) was applied at 5 t/ha in addition to high-grade basic slag (14% P_2O_5) at 2.5 t/ha. This treatment was to be repeated every two years.

Statistical design. A split-plot randomised block design incorporating four replicates was used, with the fertiliser treatments as main-plots and grass-legume mixtures as sub-plots. Each main-plot measured 6 m by 4 m while the sub-plots each measured 4 m by 2 m. The experimental plan is presented in Figure 5.2.1.5.

Sowing date and rates. Experiment H5 was sown on July 30th, 1969, the same day as experiments H3 and H4. The species were sown at the following seed rates:-

Figure 5.2.1.5. Layout of experiment H5

NORTH

Rep 1			Rep 2			Rep 3			Rep 4		
SL			SL			S			SL		
RF	TMF	PRG	RF	TMF	PRG	TMF	RF	PRG	TMF	RF	PRG
S			S			SL			S		
TMF	RF	PRG	PRG	RF	TMF	RF	PRG	TMF	RF	PRG	TMF

Main-plots:

S - high grade basic slag

SL - high grade basic slag + ground limestone

Sub-plots:

PRG - S.23 perennial ryegrass with Leo birdsfoot trefoil

RF - S.59 red fescue with Leo birdsfoot trefoil

TMF - Scots timothy + S.53 meadow fescue with Leo birdsfoot trefoil

birdsfoot trefoil	- 8 kg/ha	
perennial ryegrass	- 20 kg/ha	
red fescue	- 15 kg/ha	
timothy	- 5 kg/ha	applied as one mixture along with birdsfoot trefoil
meadow fescue	- 20 kg/ha	

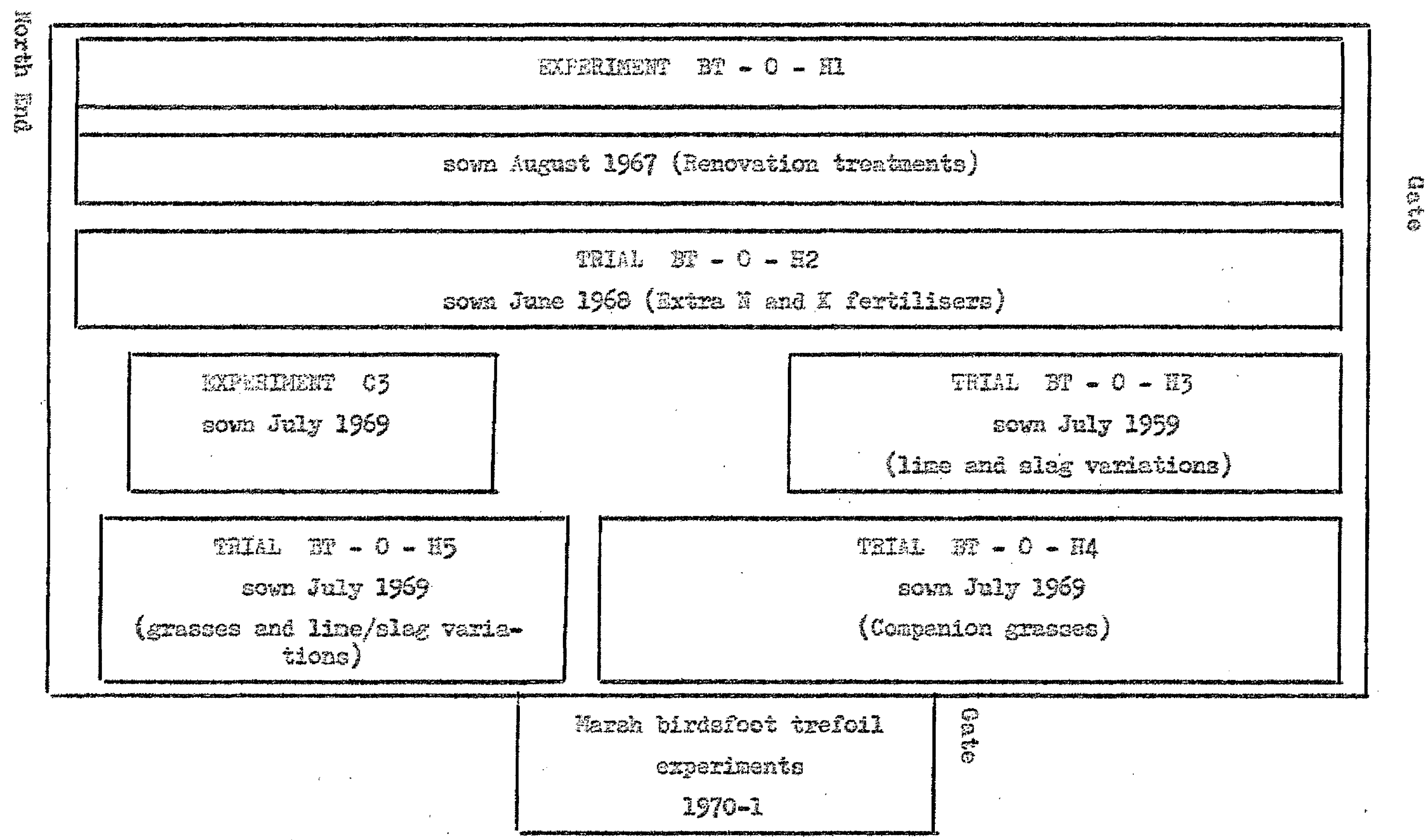
5.2.2. Investigational Technique

The site was on unimproved upland pasture on the farm of Mr. J. McFadzean, Broadshean, Kirkoswald, in south Ayrshire. Situated at 180 m above sea level, the trial area has a mean annual rainfall of approximately 1100 mm and a southerly aspect. The soil type is a moist dark peat with a pH level of around 4.5. Soil analysis figures obtained at the beginning and during the trial period are included in Appendix 3.

The selected area was fenced off before the experiments were laid down using sheep netting topped with a single strand of barbed wire. The fenced area was a rectangle 80 m x 60 m running north to south. The experimental layout is shown in Figure 5.2.2.1.

Experiment H1 was pegged out in two long strips to avoid north-south drainage ditches. One week before sowing, the chemical renovation main plots were sprayed with paraquat herbicide using an Oxford precision knapsack sprayer. Four days before sowing the rotary cultivation main plots were rotavated with a Wolseley Titan Merry Tiller rotavator. On the following day ground limestone and basic slag fertilisers were applied manually by shovels. The area to be covered by one sack of fertiliser was marked along the length of the trial area by dividing the fertiliser area by the width of the trial. This method enabled the fertiliser to be evenly distributed by hand at an accurate rate. This method was also used in the following spring when experiment H2 was laid out and in 1969

Figure 5.2.2.1. Plan of Kirkoswald trial site



when experiment H4 was started but with the other experiments where lime and slag treatments were varied, each main-plot area was fertilised separately with measured quantities. The additional fertiliser used in experiment H2 was applied separately after the lime and basic slag but before sowing.

Surface-seeding was carried out by sowing each sub-plot separately using previously weighed quantities of seed. One day before each experiment was sown, the legume seeds were inoculated with effective isolates of rhizobia using the milk technique detailed in Appendix 2. Each sub-plot seed lot was mixed with dry sand in a tin, the sand diluting the seed and effecting an even spread. The sand-seed mixture was spread at a low level to avoid any drift of seed caused by wind gusts. The grass seeds sown in experiments H4 and H5 were not mixed with the legumes but were sown separately.

Assessment of these experiments was initially carried out by visual estimates. The first of these was carried out in September 1967 at one month after sowing experiment H1, when a botanical survey of the site was made. Several pasture analysis techniques were tried, including the point quadrat method, grid methods and modifications of these techniques but the most suitable method under the particular circumstances was a square metre made of four bamboo canes tied at the corners with string.

The cane square was cast at random and a visual estimate of the percentage composition of the enclosed herbage was then made and recorded, working to the nearest 5% in the case of dominant species and to 2½% for the sporadic species. This technique was used because it produced results which were almost as accurate as those produced by more time-consuming methods. The cane square was suitable for both short and long herbage, both types being present in the trial area at the start of the experiments, and quite likely to be encountered with increasing frequency as the herbage increased in vigour due to fertiliser response. This method enabled a large number of plots to be botanically assessed within a reasonable period of time, an important consideration under the particular circumstances. Two samples per sub-plot were normally taken for experiments H1 and H2.

During the 1968 season experiment H1 was visually assessed for legume establishment and botanical composition on July 15th. The process was repeated on July 16th, 1969, when experiments H1 and H2 were assessed for legume cover and botanical composition, with emphasis on grass content, heather content and percentage of the more valuable grass species.

On October 13th, 1969, a visual estimate of legume productivity in experiments H1 and H2 was made, 3 days before a sample cut was taken. The visual method entailed the rapid movement from plot to plot, designating the herbage production of each legume cultivar by means of a scale ranging from 1 (low yield) to 10 (high yield).

For the sample cut, taken for the first time on 16th October, 1969, a wooden frame with internal measurements of 2 m by 0.25 m was used. This was cast at random within each sub-plot and the herbage within the frame cut, by means of long-handled lawn shears with horizontal blades, to approximately 3 cm above soil level. The cut herbage was then gathered by using a close-pronged hand rake 0.25 m wide, and placed in a labelled polythene bag. At this cut, two samples per sub-plot were taken from experiment H1 whereas only one sample per sub-plot was taken from experiment H2.

On return to base the legume component was separated from each herbage sample and the two portions weighed fresh. The samples were then submitted to the Chemistry Department, Auchincruive, for drying in ovens at 99 to 100°C overnight (16 hours), thus obtaining dry-matter yields.

On June 30th, 1970, another visual productivity estimate was made on experiments H1 and H2 before taking a sample cut on the same day. Only one sample cut per sub-plot was taken from both experiments at this date. The analytical procedure followed the same pattern as in October 1969.

A second assessment of productivity was made during the 1970 season, on October 6th when a visual estimate was carried out on experiments H1 and H2. In this assessment a scale of 0 to 5 was used to designate from low to high yields. At this date the first estimate of establishment in experiments H3, H4 and H5 was made, using the same method and the same arbitrary scale.

During this trial period the plots received no grazing with the following exceptions. After the visual assessment on July 16th, 1969, the fence was opened for a period of two weeks when the herbage, especially the legumes were closely grazed by sheep and cattle. The site was opened for grazing after the cut was taken in October 1969 for 4 weeks. The plots received the same treatment after the cut in June 1970. After the visual assessment on October 6th, 1970, the fence was opened and grazing stock were allowed on the trial area throughout the winter of 1970-1. The sward was closely grazed during this period, and the fence was eventually closed on 24th March, 1971.

5.2.3. Results

The results of the vegetation survey carried out in autumn 1967 are shown in Table 5.2.3.1. The natural sward was dominated

Plate 9. The square metre frame used in experiments H1 and H2. It is seen here during 1969 in a plot of Empire birdsfoot trefoil established after spraying with paraquat herbicide.

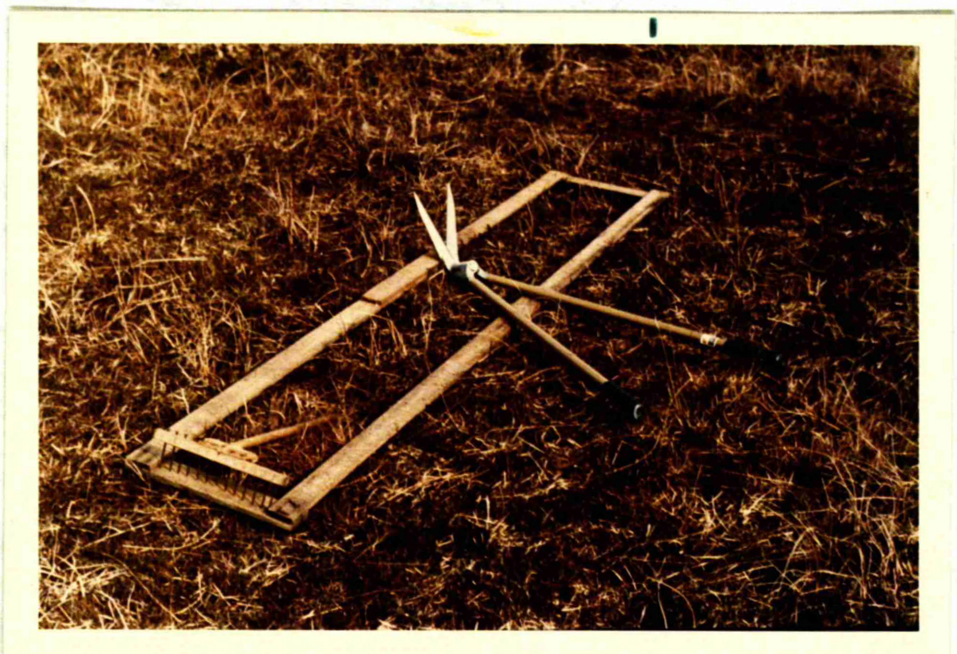


Plate 10. Equipment used to take yield samples in experiments H1 and H2. The frame was cast at random within a plot and the enclosed herbage cut with the shears. The rake then collected the cut herbage which was placed in a plastic bag.

Table 5.2.3.1. Experiments H1 to 5. Botanical composition of trial site, September 1967

Species present	Approximate percentage
Common heather	35
Purple moor-grass	24
Cross-leaved heath	13
Sedges	12
Stool bent	8
Deer's hair sedge	7

Present in small quantities:

Common rush

Tormentil

Mat-grass

Yorkshire fog

Mosses

by common heather and purple moor-grass, the drier areas having more of the former while the wetter areas contained more of the latter. Common heather was generally more frequent than cross-leaved heath, while sedges - especially drawmoss and many-headed cotton-grass - stool bent and deer's hair sedge were widespread sub-dominant species. Legume species were absent as were the more valuable hill grasses except the occasional plant of Yorkshire fog, noticeable only by a few inflorescences in one small area of the trial site.

Experiment H1

Legume establishment was shown by the results of the assessments taken in July 1968 and one year later (Tables 5.2.3.2. and 5.2.3.3). The only significant differences in these two assessments were those found between the legume cultivars. S.100 white clover was superior to birdsfoot trefoil in 1968 and 1969. Empire and Viking were similar at the first estimate but Empire was found to be superior to Viking in July 1969.

In 1968 the grass cover was found to be greater in the plots containing Viking birdsfoot trefoil than those with S.100 white clover but this difference was not significant in the next estimate in 1969. The grass cover within the area of experiment H1 was the same in 1968 despite the varying cultivations but by 1969 there was more grass in the plots which had been cultivated than there was in the other treatment plots (see Tables 5.2.3.2.and 5.2.3.3.).

A further examination of the 1968 and 1969 results revealed trends in the percentages of the more valuable hill grass species which included red fescue, sheep's fescue, bent-grasses, Yorkshire fog, annual meadow-grass. Timothy was also present, having been introduced as an impurity in the seed samples of Empire birdsfoot

Table 5.2.3.2. Experiment H1. Estimate of vegetation composition, 1968

Renovation treatment (means)	% legume	% heather	% grass	% valuable grass
R0	17.08	20.5	21.1	2.5
R1	15.33	10.8	24.8	8.2
SE±	2.01	1.78	3.5	1.77
P0	15.67	23.0	24.2	4.2
P1	17.65	16.3	21.7	6.5
SE±	2.01	1.78	3.5	1.77
Significance:-				
R	NS	***	NS	*
P	NS	*	NS	NS
R.P	NS	NS	NS	NS
Legumes (means)				
S.100	30.95	13.3	17.4	5.3
Empire	11.37	22.4	24.7	4.9
Viking	7.65	23.1	26.7	5.7
SE±	2.26	1.73	2.62	1.61
Significance	***	***	*	NS
Interactions				
Significance:-				
R.L	NS	NS	NS	NS
P.L	NS	NS	NS	NS
R.P.L	NS	NS	NS	NS

Abbreviations used:-

R0 - no rotavation
R1 - rotavation
P0 - no paraquat
P1 - paraquat
L - legumes
SE± - standard error

Table 5.2.3.3. Experiment H1. Estimate of vegetation composition, 1969

Renovation treatment (means)	% legume	% heather	% grass	% valuable grass
R0	19.60	27.4	24.1	11.3
R1	19.70	14.0	39.1	28.9
SE±	2.71	2.22	3.21	2.66
F0	18.52	23.8	29.6	17.3
F1	20.78	17.6	33.7	22.9
SE±	2.71	2.22	3.21	2.66
Significance:-				
R	NS	**	**	***
F	NS	NS	NS	NS
R.F	NS	NS	NS	NS
Legumes (means)				
S.100	33.50	14.3	31.4	24.3
Empire	17.77	22.0	31.1	17.1
Viking	7.67	25.7	32.3	18.8
SE±	2.25	1.19	2.36	2.06
Significance	***	***	NS	*
Interactions				
Significance:-				
R.L	NS	NS	NS	NS
F.L	NS	NS	NS	NS
R.F.L	NS	NS	NS	NS

trefoil. The 1968 figures showed more valuable grasses in rotavated plots than in those not rotavated before sowing. In the following year this trend was more marked yet the chemically-renovated plots were no different from those not sprayed with paraquat. More valuable grass species were recorded in plots containing S.100 white clover than in the Empire plots but differences between Viking birdsfoot trefoil plots and S.100 white clover plots were not significant.

Heather cover was visibly affected as the experiment progressed. In 1968 white clover plots contained significantly less common heather and cross-leaved heath than the birdsfoot trefoil plots, whereas in 1969 clover plots had less heather than Empire trefoil plots which in turn had less heather than Viking trefoil plots.

In 1968 main-plot differences were also significant. There was less heather in plots which had been rotavated and in those which had been sprayed with paraquat herbicide before sowing, than in untreated plots. There were no significant interactions. The heather content was similar in the sprayed and unsprayed plots by 1969 but cultivation still notably reduced the heather percentage.

Yield of legume cultivars was visually assessed in October 1969 when S.100 white clover and Empire birdsfoot trefoil appeared to be superior to Viking birdsfoot trefoil (Table 5.2.3.4). The dry weights obtained in the sample cut taken at the same time verified this conclusion and revealed no further differences between main-plot treatments. An estimate of legume percentage in the herbage by dry weight comparisons indicated that Empire was superior to S.100 white clover which was also superior to Viking. Dry-matter yields of other herbage were greater from plots containing S.100 white clover than from birdsfoot trefoil plots. The yield was

Table 5.2.3.4. Experiment H1. Legume yield, October 1969

Renovation treatment (means)	Visual estimate (1-10)	% legume by dry wts.	legume dry wt. (g)	other herbage dry wt. (g)	Total Dry wt. (g)
R0	3.03	4.44	7.60	165.5	173.1
R1	2.73	3.73	5.33	134.4	139.8
SE±	0.24	0.62	1.22	6.0	6.4
F0	2.97	4.01	6.53	150.9	157.4
F1	2.80	4.17	6.40	149.1	155.5
SE±	0.24	0.62	1.22	6.0	6.4
Significance:-					
R	NS	NS	NS	**	**
P	NS	NS	NS	NS	NS
R.P	NS	NS	NS	*	*
Legumes (means)					
S.100	3.45	4.24	7.96	177.0	185.0
Empire	3.75	6.67	9.63	143.2	152.8
Viking	1.45	1.35	1.80	129.7	131.5
SE±	0.24	0.73	1.34	9.8	9.6
Significance	***	***	***	**	**
Interactions					
Significance:-					
R.L	NS	NS	NS	NS	NS
P.L	NS	NS	NS	NS	NS
R.P.L	NS	NS	NS	NS	NS

also higher from plots not rotavated than from plots which had been rotavated. A significant interaction effect indicated that differences in yield of other herbage species were much greater when the plots were chemically renovated than when left untouched. The lowest yields were recorded on plots which had been rotavated after treatment with paraquat.

Total herbage dry-matter yields were significantly greater in S.100 white clover plots than in birdsfoot trefoil plots. Plots not rotavated before sowing gave higher dry-matter yields than those which had been rotavated. An interaction existed between rotavation and paraquat treatments in that yield differences were slight when no paraquat was applied but were great when the sward had been sprayed. Lowest yields were obtained in plots which had been sprayed then rotavated before sowing whereas highest yields were produced when the sward was only sprayed before sowing. At the cut taken in June 1970 S.100 white clover out-yielded the birdsfoot trefoil varieties (Table 5.2.3.5). However, a visual yield assessment in October 1970 suggested that Empire birdsfoot trefoil was similar to S.100 white clover, both being superior to Viking.

Legume percentages, by fresh weight comparisons, suggested that S.100 white clover gave a higher legume content than Viking, with Empire trefoil not much less than S.100 yet not significantly greater than Viking.

Highest total fresh weights of herbage were obtained from S.100 white clover plots and were significantly greater than those from birdsfoot trefoil plots.

Experiment H2

Legume establishment was assessed for the first time in July 1969 when S.100 white clover had more cover than Leo birdsfoot

Table 5.2.3.5. Experiment H1. Legume yields, 1970

Renovation treatment (means)	% legume	June 1970 Dry wt. legume (g)	Total herbage fresh wt. (g)	October 1970 Productivity (Visual 0-5)
R0	13.04	7.54	301.7	1.7
R1	8.12	4.22	280.8	1.5
SE±	1.98	1.81	14.5	0.2
P0	9.27	5.11	302.5	1.8
P1	11.89	6.66	280.0	1.3
SE±	1.98	1.81	14.5	0.2
Significance:-				
R	NS	NS	NS	NS
P	NS	NS	NS	NS
R.P	NS	NS	NS	NS
Legumes (means)				
S.100	16.59	11.51	380.5	1.9
Empire	10.69	4.27	242.1	1.9
Viking	4.46	1.86	251.1	0.9
SE±	2.47	2.36	22.8	0.2
Significance	**	*	***	**
Interactions				
Significance:-				
R.L	NS	NS	NS	NS
P.L	NS	NS	NS	NS
R.P.L	NS	NS	NS	NS

trefoil, which was significantly more prolific than Empire. Fertiliser effects were at significant levels, the legume cover being greater in plots dressed with potash than those untreated whereas cover was poorer in plots which had received nitrogenous fertiliser than in those which had had no nitrogen. The results of this assessment are shown in Table 5.2.3.6.

At this stage there were no differences in percentages of grass or of valuable hill grass species yet content of heather was visibly affected. Birdsfoot trefoil plots had a greater heather content than the plots containing white clover and those plots not receiving potash fertiliser had more heather than those treated with potash. Nitrogen fertiliser had no apparent effect on heather content.

The visual estimate of legume yield, carried out in October 1969 showed S.100 white clover out-yielding Leo trefoil which in turn out-yielded Empire (Table 5.2.3.7). Legume dry weights obtained at the same time showed no significant differences between the three legumes. Responses to fertiliser were quite dramatic. In visual and dry weight assessments, especially the latter, legume yield was considerably increased by potash fertiliser and correspondingly decreased by nitrogen fertiliser. There was a significant interaction effect between the fertiliser treatments, the potash response being much more obvious when no nitrogen was applied.

There were no significant differences between legume percentages in October 1969 although fertiliser effects were most marked and an interaction between nitrogen and potash treatments was again at a significant level.

Yields of natural herbage species were similar when growing with the different legumes but were notably increased by nitrogenous fertiliser as well as responding to dressings of potash fertiliser.

Table 5.2.3.6. Experiment H2. Estimate of vegetation composition, 1969

Fertiliser treatment (means)	% legume	% heather	% grass	% valuable grass
NO	23.48	38.3	16.2	2.1
N1	13.85	37.8	22.2	6.9
SE$\pm$	1.47	0.9	2.1	1.6
KO	16.00	40.1	18.8	3.7
K1	21.33	36.1	19.7	5.3
SE$\pm$	1.47	0.9	2.1	1.6
Significance:-				
N	***	NS	NS	NS
K	*	**	NS	NS
N.K	NS	NS	NS	NS
Legumes (means)				
S.100	28.77	32.6	17.3	5.9
Empire	8.82	42.7	21.3	4.0
Leo	18.40	38.8	19.0	3.5
SE$\pm$	1.31	1.6	1.7	1.3
Significance	***	***	NS	NS
Interactions				
Significance:-				
K.L	NS	NS	NS	NS
N.L	NS	NS	NS	NS
K.N.L	NS	NS	NS	NS

Abbreviations used:-

NO - no nitrogen
N1 - nitrogen
KO - no potash
K1 - potash
L - legumes
SE$\pm$ - standard error

Table 5.2.3.7. Experiment H2. Legume yield, October 1969

Fertiliser treatment (means)	Visual estimate (1-10)	% legume by dry wts.	Legume dry wt. (g)	Natural herbage dry wt. (g)	Total dry wt. (g)
N0	5.3	16.00	13.70	62.25	75.96
N1	3.7	5.43	5.57	94.63	100.20
SE±	0.3	1.19	1.50	2.89	3.29
K0	3.4	6.25	4.58	73.62	78.20
K1	5.6	15.18	14.70	83.26	97.96
SE±	0.3	1.19	1.50	2.89	3.29
Significance:-					
N	***	***	**	***	***
K	***	***	***	*	**
N.K	NS	*	*	NS	NS
Legume (means)					
S.100	5.3	10.80	10.00	78.22	88.22
Empire	3.7	9.15	8.60	80.12	88.72
Leo	4.5	12.16	10.31	76.98	87.29
SE±	0.3	1.22	1.56	3.05	3.70
Significance	***	NS	NS	NS	NS
Interactions					
Significance:-					
N.L	NS	NS	NS	*	NS
K.L	NS	NS	NS	*	NS
N.K.L	NS	NS	NS	NS	NS

Yields of herbage species showed a greater response to potash with Empire birdsfoot trefoil than with the other legumes, whereas the response to nitrogen was greater in birdsfoot trefoil plots than in the plots containing white clover (Table 5.2.3.8).

Table 5.2.3.8. Experiment H2. Interaction effects within dry matter yield of natural herbage, October 1969 (g)

Fertiliser treatments		Legume cultivars		
		White clover	Empire trefoil	Leo trefoil
P0	N0	65.1	53.5	51.2
	N1	89.3	83.8	98.8
P1	N0	74.7	66.2	62.9
	N1	83.7	117.0	95.0

Significance:-

N.L	*
K.L	*
N.K.L	N.S.
SE±	6.1

Yields of total herbage showed responses to potash and nitrogen but no interaction effects were significant.

In June 1970 dry weight yields of S.100 white clover and Leo trefoil were greater than those from Empire birdsfoot trefoil, as shown in Table 5.2.3.9. Potash was seen to increase legume dry weights while nitrogen depressed them. Percentages of legumes by fresh weight comparisons, revealed the same trends. Fresh weight yields of total herbage cut revealed the response to potash fertiliser and showed an interaction effect whereby the potash response was much greater with white clover than with birdsfoot trefoil (Table 5.2.3.10). The visual estimate of yield, carried out in October 1970, suggested that S.100 white clover was more productive than either Leo or Empire birdsfoot trefoils at this time. The potash response was no longer at a significant level although the decrease in yield in the plots receiving annual

Table 5.2.3.9. Experiment H2. Legume yield, 1970

Fertiliser treatment (means)	% Legume	Dry wt. legume (g)	Total herbage fresh wt. (g)	Productivity (visual 0-5)
N0	44.4	35.62	414.4	3.4
N1	17.6	11.46	360.5	2.4
SE±	4.0	4.96	30.6	0.3
K0	19.3	10.87	308.0	2.5
K1	42.7	36.21	466.8	3.3
SE±	4.0	4.96	30.6	0.3
Significance:-				
N	***	**	NS	*
K	**	**	**	NS
N.K	NS	NS	NS	NS
Legumes (means)				
S.100	36.4	31.10	443.5	3.9
Empire	20.4	10.78	350.1	2.4
Leo	36.2	28.73	368.7	2.3
SE±	3.5	3.56	30.7	0.2
Significance	**	***	NS	***
Interactions				
Significance:-				
N.L	NS	NS	NS	NS
K.L	NS	NS	*	NS
N.K.L	NS	NS	NS	NS

dressing of nitrogen was significant.

Table 5.2.3.10. Experiment H2. Interaction effects within total herbage fresh yields (g). June 1970

Fertiliser treatments		Legume cultivars		
		White clover	Empire trefoil	Leo trefoil
PO	NO	350	280	310
	N1	240	320	340
P1	NO	670	370	500
	N1	500	430	330

Significance:-

N.L	NS
K.L	*
N.K.L	NS
SE±	61

Experiment H3

The first estimate of legume establishment in experiment H3 was made on October 6th, 1970. The results of this visual assessment, presented in Table 5.2.3.11, indicated that S.184 wild white clover and Leo birdsfoot trefoil had established more satisfactorily than S.100 white clover. Legume establishment was significantly poorer in the sward which received no fertiliser than in the areas which had been treated with basic slag and with ground limestone and basic slag. A significant interaction effect indicated that S.100 white clover's establishment was as poor under the basic slag treatment as it was when both lime and slag were applied, whereas S.184 wild white clover and Leo birdsfoot trefoil plants were more numerous when ground limestone was applied in addition to basic slag.

Experiment H4

The visual estimate in October 1970 showed S.184 wild white clover had established better than Leo birdsfoot trefoil which was better than S.100 white clover. The legume establishment in competition with the different grass species was similar (Table

Table 5.2.3.11. Experiment H3. Legume establishment, 1970

Fertiliser treatments	Visual estimate (0-5)
No fertiliser	0.3
Basic slag	2.0
Lime and basic slag	2.8
SE±	0.34
Significance	**

Legumes	
S.100 white clover	1.2
S.184 wild white clover	1.9
Leo birdsfoot trefoil	1.9
SE±	0.2
Significance	*

Interaction (Fertiliser x legumes)

	S.100	S.184	Leo
Control	0.3	0.3	0.3
Basic slag	1.7	2.2	2.0
Lime and basic slag	1.7	3.2	3.5

SE± 0.34
Significance *

Plate 11. Response to potash fertiliser in experiment H2. To the left of the photograph are plots which received no potash fertiliser whereas those on the right were given annual applications.

5.2.3.12). The grass establishment was very low, especially in S.23 perennial ryegrass. The mixture of Scots timothy with S.53 meadow fescue fared little better whereas the S.59 red fescue was more obvious than the other grass cultivars, but still only sporadic in appearance.

Table 5.2.3.12. Experiment H4. Legume establishment, 1970

Companion grasses	Visual estimate (0-5)
None	2.4
Perennial ryegrass	2.0
Timothy/meadow fescue	2.3
Red fescue	2.6
SE±	0.029
Significance	NS
Legumes	
S.100 white clover	1.69
S.184 wild white clover	2.88
Leo birdsfoot trefoil	2.38
SE±	0.334
Significance:-	
Legumes	***
Interaction	NS

Experiment H5

Establishment of Leo birdsfoot trefoil was again low in this trial and only slightly better in the sward receiving both lime and slag than in the plots receiving slag only (Table 5.2.3.13). Grass establishment was worse, the only trace being in the red fescue main-plots which had been treated with lime and basic slag.

Table 5.2.3.13. Experiment H5. Legume establishment, 1970

Fertiliser treatments	Visual estimate (0-5)
Basic slag only	2.0
Lime and basic slag	2.3
SE±	0.34
Significance	NS
Companion grasses	
Perennial ryegrass	2.13
Timothy/meadow fescue	2.13
Red fescue	2.13
SE±	0.00
Significance:-	
Companion grasses	NS
Interaction	NS

5.2.4. Discussion

Pasture establishment by surface-sowing methods has been comprehensively reviewed by Charles (1962) in which the essential steps are summarised as:

(a) the correction of soil mineral deficiencies;

(b) the elimination of the old natural sward;

(c) placing the seed in contact with the soil, and

(d) suitable management thereafter.

Surface-sowing has been developed over a period of several years and has now evolved, within Britain, into three main techniques.

One technique is known in Scotland as the Muirfad system, and was developed by Mr. Alexander Allan of Muirfad, Newton Stewart, Kirkcudbrightshire (Gardner et al, 1954); this involves the application of ground limestone and basic slag on wet peats with swards containing little grass followed by surface-sowing in early spring, the hooves of grazing livestock achieving the successful contact of seed with the soil.

Where low-yielding grasses dominate the upland sward, the methods of sward regeneration or chemical renovation may be used. The former technique employs a surface treatment of harrowing or disc-harrowing to expose the soil through the grass mat and the application of a compound fertiliser containing nitrogen, phosphate and potash. Surface-sowing is followed by further harrowing and heavily controlled stocking to ensure that the seed contacts the soil. Chemical renovation is relatively new, involving the use of herbicides such as dalapon or paraquat to check the growth of the existing herbage long enough to allow the sown seed to establish.

These three methods have been used successfully many times under a wide range of conditions. Charles (loc. cit.) concluded that they were not as reliable as the more conventional methods involving ploughing and sowing. Nevertheless, these methods provide the main hope of improvement in marginal and hill land in Britain and it is under these conditions that birdsfoot trefoil has potential use.

Establishment was satisfactory in experiments H1 and H2 but poor in experiments H3, H4, and H5. Birdsfoot trefoil material persisted at a satisfactory level in experiments H1 and H2, probably because the sward received light grazing pressure. Under heavier stocking rates, birdsfoot trefoil may well have disappeared, as it did in experiments in Wales (Davies 1969).

The slower establishment rate of birdsfoot trefoil in experiment H1 was hardly surprising as these cultivars are known to have low establishment vigour (Twamley 1967a; 1967b). S.100 white clover had little competition from the natural herbage and thus spread vigorously. The natural establishment of grass, especially of the more valuable species such as bent-grass, fescue and Yorkshire fog was observed with interest. The more rapid increase in the rotary cultivated plots was considered to be normal under the circumstances but the higher content of the better grasses in the clover plots in July 1969 suggested the first signs of a response to legume nitrogen.

Reduction in heather content was considered to be a usual trend after application of calcium-based fertilisers. The lower content in the clover plots could well have been a visual effect only, as clover's extensive canopy of horizontally-aligned leaves could conceal a proportion of the natural vegetation. Reduction of heather in rotavated and chemically-treated plots would also be considered a typical trend after such a disturbance (Frame 1971).

The results obtained in both yield estimates carried out during

October 1969 were in accordance with each other as differences were clearly visible at this stage, Viking's lower yield being most obvious throughout all replicates.

The lower percentage of S.100 white clover was a reflection of the significant increase in dry matter yield of herbage from the natural species, another indication of a stimulation of the natural herbage by nitrogenous enrichment of the sward due to the clover. This trend was shown by the total herbage yield figures which also echoed the greater yields from the non-rotavated plots than from those which had been rotavated.

The interaction effect between paraquat-treated plots and rotavated areas could point to the theory that the combined treatment is too drastic a change in this environment, except when vigorous species are sown after the cultivation treatment. The non-legume herbage was composed largely of material which probably would not have been consumed by grazing animals, especially on areas where no cultivation had been given prior to sowing. The lower yields from the rotary-cultivated plots could have been caused by the removal of this valueless herbage and replacement by more leafy palatable material.

Legumes are never aggressive competitors. The species used in experiment H1 are normally prone to invasion by other species and this was certainly noticeable in this case. In the wetter parts of the trial area the invading species were led by drawmoss and rushes while the more valuable grasses, especially fescue and Yorkshire fog were primary colonisers in the drier areas.

These changes in the balance of the other species must receive secondary consideration. The object of the experiment was to test the ability of birdsfoot trefoil to establish under the trial conditions and in this aspect, Empire birdsfoot trefoil showed promise, under all four renovation treatments. This performance was again observed in the 1970 results, although white clover was increasing its superiority under the conditions prevailing at this trial site. These conclusions are in agreement with reports from other countries that birdsfoot trefoil can be established readily under conditions of low fertility (Kolar 1956; Winch 1961; Henson and Schoth 1962). The problem of its persistence under sustained grazing pressure is another matter.

Experiment H2 was again successful in the testing of birdsfoot trefoil establishment, which was much more satisfactory after the spring sowing than after the autumn sowing of experiment H1. The poor establishment of trials H3, H4 and H5 were mainly due to the winter conditions since there was a promising establishment in the autumn.

Although S.100 white clover was superior in plant cover by July 1969 the Canadian cultivar Leo was seen to be a most promising improvement over Empire birdsfoot trefoil. Leo retained its increased vigour and productivity throughout the trial and would appear to be an obvious choice for inclusion in future British trials on well-drained upland pasture.

The main feature of the results obtained from experiment H2 was the response to the applications of additional fertilisers. The increased growth of legumes in areas treated with potash was obvious from the early stages and reached dramatic levels in 1969 and 1970, the visual effect being most obvious, even from a distance. This response of legumes to potash where this nutrient is deficient has been reported elsewhere (H.M.S.O. 1966; Harkess 1970) and is not considered unusual. The extraordinary feature of this particular response was the high level of available potash in the peat soil. The soil potash must be in a form not readily available to the herbage plants which thus respond to applications of potassic fertiliser. This effect has been reported occurring in peat soils (Hunt 1971) although the actual reason for the anomaly has yet to be explained (Golightly 1971).

Depression of legume yield by nitrogenous fertiliser was noticeable from 1969 onwards. This is also a well-known effect (H.M.S.O. 1966), and birdsfoot trefoil behaved similarly to white clover in this respect. There was a possibility that nitrogen fixation by birdsfoot trefoil was at a lower rate than in S.100 white clover, as the response of the natural herbage species to nitrogen was greater in the birdsfoot trefoil plots in October 1969. Lynch and Sears (1951) reported that certain rhizobial isolates from birdsfoot trefoil fixed higher amounts of nitrogen in potassium-deficient plants than did others better adapted to well-nourished plants. No such effect was noticed in experiment H2.

An unusual interaction effect was recorded in the cut taken in June 1970 when potash response of fresh weights of total herbage was much greater from the S.100 white clover plots than from the plots containing birdsfoot trefoil, despite the effect of fertiliser nitrogen being non-significant. This result was produced by the high content of legume in the total herbage, the percentage reaching the 50 to 75% level in the potash-treated areas.

In experiment H3 birdsfoot trefoil failed to reveal any superiority it may have over white clover at lower levels of fertility. This feature has been reported by several workers, notably Robinson (1934) and MacDonald (1946). It may be more obvious under conditions more extreme than those experienced in experiment H3.

Nevertheless Leo birdsfoot trefoil was similar to S.184 wild white clover in establishment and significantly superior to S.100 white clover by October 1970 and the latter, unlike the others, failed to respond to the addition of ground limestone.

The effects of vigorous companion grasses were not seen in experiments H4 and H5 owing to the marked failure of the grasses to establish. Only red fescue reached a noticeable level in these experiments and this may have been due to stimulation of natural material by the application of ground limestone and basic slag.

5.3. Other Upland Sward Trials

5.3.1. Experiment C3

Object of trial - to compare the performance of nine cultivars and two ecotypes of *L. corniculatus* with S.100 white clover and S.184 wild white clover during the establishment phase under upland pasture conditions.

Material used:

		Origin
white clover	- S.100	U.K.
wild white clover	- S.184	U.K.
birdsfoot trefoil cultivars	- Empire	U.S.A.
	Fargo	U.S.A.
	Leo	Canada
	MC/H/66	Canada
	Morshansk	U.S.S.R.
	Taborsky	Czechoslovakia
	Trebicsky	Czechoslovakia
	Viking	U.S.A.
	Wallace	Canada
birdsfoot trefoil ecotypes	- Bulgaria	U.S.D.A.
	Russia	U.S.S.R.

The cultivars used in this experiment were selected because of reasonable size of seed sample. MC/H/66 and Wallace, although not actual cultivars, were placed in this category as they were the products of recurrent selection. The Bulgarian ecotype was a composite of

U.S.D.A. Plant Introduction Numbers 259512, 259513 and 259514 whereas the Russian ecotype was a composite of the material collected in Krasnodar, Lithuania and Moscow regions. Both ecotypes had been used in the spaced-clump experiment E1.

Site of experiment. The trial was laid out adjacent to experiment H1 to H5, within the same enclosed area, as shown in Figure 5.2.2.1.

Design of experiment. A randomised block design was used with two replications of each cultivar/ecotype. Each plot measured 3 m by 1 m. Replication was limited due to lack of space within the enclosed area at the trial site. The actual plan is shown in Figure 5.3.1.1.

Figure 5.3.1.1. Layout of experiment C3

3 m; 1 m

Rep 1	Rep 2
Fargo (U.S.A.)	Taborsky (Czech.)
Russia	Empire (U.S.A.
Leo (Canada)	MC/H/66 (Canada)
Viking (U.S.A.)	S.184 WWC
S.100 WC	Bulgaria
Morshansk (U.S.S.R.)	Russia
Trebicsky (Czech.)	Leo (Canada)
Wallace (Canada)	Fargo (U.S.A.)
MC/H/66 (Canada)	Trebicsky (Czech.)
Taborsky (Czech.)	Viking (U.S.A.)
Bulgaria	S.100 WC
Empire (U.S.A.)	Morshansk (U.S.S.R.)
S.184 WWC	Wallace (Canada)

North

Fertiliser treatment. All plots received basic slag (14% P_2O_5) at 2.5 t/ha which was manually spread one week before sowing.

Sowing date and rates. The birdsfoot trefoil cultivars and ecotypes were sown at 15 kg/ha while the clovers were sown at 4 kg/ha. The trial area was surface-seeded on July 30th, 1969. The legume seed was inoculated with effective isolates of rhizobia one day before sowing, using the milk technique described in Appendix 2.

Management during the experimental period. This was essentially the same as in experiments H1 to H5 in that the whole of the trial area was opened for grazing during the periods previously specified.

Assessment. A count of establishing seedlings was made on 13th October, 1969. A hollow wooden square with internal dimensions of 0.25 m by 0.25 m was cast at random four times within each plot.

The number of legume seedlings within the sample area was then recorded. A germination test had been carried out on the seed samples at the start of the trial period, by the licensed seed testing station of McGill & Smith Ltd., Ayr, as it was considered that a check on the effect of germination capacity on the legumes' establishment should be made. No further assessments were carried out until October 6th, 1970, when a visual estimate of the legume plant numbers was made using an arbitrary scale of 0 to 5 to indicate low to high legume content.

Results 1969-1970

When the results of the germination test were obtained, a wide range of germination capacity was revealed. The following table shows the range of germination within the material used, and the year the sample was received.

Table 5.3.1.1. Experiment C3. Percentage germination and hard seeds

Legumes	% Germination	% Hard seeds	Year of receipt
S.100 white clover	96	4	1969
S.184 wild white clover	85	11	1969
Empire birdsfoot trefoil	75	11	1967
Fargo	26	2	1966
Leo	64	24	1968
MC/H/66	58	25	1967
Morshansk	37	23	1963
Taborsky	67	22	1968
Trebicsky	72	6	1968
Viking	13	6	1967
Wallace	55	40	1967
Bulgaria	13	73	1963
Russia	40	8	1963

Viking and Bulgarian birdsfoot trefoil had the lowest germination percentage and the former's hard seed content was also low. The Bulgarian material had the highest hard seed content of all the samples. The oldest seed samples all tended to have low germination levels whereas the more recently received material had lower hard seed levels. Germination was highest in the two clover varieties and in Empire and the two Czechoslovakian trefoils, Taborsky and Trebicsky.

The October seedling count produced some notable contrasts, as seen in Table 5.3.1.2.

Table 5.3.1.2. Experiment C3. Seedling numbers (1969) and plant numbers (1970)

Legumes	Mean no. seedlings per 25 cm x 25 cm (1969)	Plant numbers (1970) (visual scale)
S.100 white clover	4	1.5
S.184 wild white clover	7	2.0
Empire birdsfoot trefoil	22	3.0
Fargo	22	2.0
Leo	24	2.0
MC/H/66	21	1.0
Morshansk	21	2.5
Taborsky	17	1.5
Trebicsky	31	3.0
Viking	3	1.0
Wallace	26	3.5
Bulgaria	19	2.0
Russia	24	2.0
Significance	**	NS
SE±	1.4	0.3

The two clovers and Viking birdsfoot trefoil had the lowest recorded numbers of seedlings, while Trebicsky was highest with an average of over thirty seedlings per sample area. Most of the birdsfoot trefoils were close to each other, varying from 19 to 26 seedlings per sample area.

The only trefoil to have a low germination capacity and a low seedling number was Viking. The other trefoils which had low germination capacities were satisfactory in seedling numbers in the actual sward.

By October 1970 legume plant numbers were at a low level (also shown in Table 5.3.1.2).

The highest plant numbers were evident in plots of Empire, Trebicsky and Wallace birdsfoot trefoils while MC/H/66, Viking, Taborsky and S.100 white clover plots were rather scantily populated.

Discussion

Seedling numbers in October 1969 showed little relationship to the germination test results with the exception of Viking birdsfoot trefoil which appeared to be a poor quality sample of seed. When the seedling counts were made it was noticed that there was an uneven distribution of seedlings within every plot, depending largely upon the growth habit of the native species. The largest seedling numbers were found on areas which had been severely trampled by grazing livestock, causing the soil to be exposed. In mossy situations the seedlings were growing but were rather chlorotic in appearance and many looked as though they would die. Tussocks of stool bent were too great a barrier for surface-seeding operations and no seedlings were found growing in the tufts of closely-matted vegetation.

These observations point to the need for some form of sward disturbance to enable the sown seed come into contact with the soil surface and thus give it a reasonable opportunity of establishing. The disturbance can be produced by livestock treading or by some form of mechanical cultivation but it is obvious that it is necessary for success in surface-seeding of upland pasture.

The difference in seed rate between the clovers and the trefoils had a marked effect on seedling numbers. The use of these high seed rates of birdsfoot trefoil was not practicable in any way and had little effect on subsequent plant numbers as shown in the results of the October 1970 survey.

After one year's enclosure the natural herbage became rank and coarse, offering a relatively high competitive effect against the legume plants. This trial was therefore not considered to be a fair test of the birdsfoot trefoil material. Such a comparison would require well-drained conditions where close grazing with intermittent rest periods is the general practice. These circumstances are widespread in the West of Scotland as 'machair' common grazing land which is currently undergoing intensification under an apportionment scheme (Bruce 1968).

5.3.2. Experiment C4

Object of trial - to compare the establishment and performances of nine herbage legume cultivars when surface-seeded on wet peat land open to grazing by livestock. This experiment was carried out in co-operation with the Grassland Husbandry Department at the West of Scotland Agricultural College as part of a programme of experiments on upland improvement. It was sown at the same time as, and adjacent to a trial comparing twenty-seven cultivars of sown perennial grasses in an attempt to discover which cultivars were most productive and persistent under the extreme conditions.

Location of experiment. Experiment C4 was laid down at Greenfield, farmed by Mr. R. Gibb at Eaglesham, Renfrewshire. The site lies at 260 metres above sea level and has an annual rainfall of approximately 1500 mm. The soil is a boggy acidic peat (see analysis in Appendix 3) and supports a vegetation dominated by sedges and mosses.

Legume species and cultivars used

Species	Cultivar	Country of origin
white clover	S.100	Wales
	S.184	Wales
	Pajbjerg	Denmark
birdsfoot trefoil	Empire	U.S.A.
	Leo	Canada
	MC/H/64	Canada
	Viking	U.S.A.
	Wallace	Canada
marsh birdsfoot trefoil	S.335	New Zealand

S.184, S.100 and Pajbjerg white clovers were chosen as typical forms of small, medium and medium-large leaved cultivars respectively, each with different patterns of yield and persistence. The birdsfoot trefoils were selected as representing a cross-section of available material while S.335 marsh birdsfoot trefoil was included as it was reported to have great potential on similar sward types in New Zealand (Barclay 1960).

Design of experiment. The trial was laid down as a non-replicated randomised block experiment with each plot measuring 4 m by 2 m. The plot layout is shown in Figure 5.3.2.1.

Figure 5.3.2.1. Layout of experiment C4, Eaglesham

Location:- Greenfield (Mr. R. Gibb), Eaglesham, Renfrewshire.

Pajbjerg white clover	MC/H/64 birdsfoot trefoil	Leo birdsfoot trefoil
S.335 marsh birdsfoot trefoil	Viking birdsfoot trefoil	S.100 white clover
Wallace birdsfoot trefoil	S.184 wild white clover	Empire birdsfoot trefoil

4m

2m

North

Grass cultivar trial

(Grassland Husbandry Department)

Fertiliser treatment. All plots received 5 t/ha ground limestone (52% CaO) and 2.5 t/ha basic slag (9% P_2O_5) on the day before sowing and then at two year intervals.

Sowing. The trial area was surface-sown on August 5th, 1966, with birdsfoot trefoil at 10 kg/ha and white clover at 4 kg/ha. The seed was not inoculated with effective rhizobia prior to sowing and sheep had access to this trial and the nearby grass variety trial throughout the experimental period.

Management during the trial period. Experiment C4 was located in an area of the farm comprising about eighty hectares, which supports sixty to eighty ewes. The trial was open to grazing at all times and the legumes were always found to be closely grazed, several sheep being present on the legume and grass trials on every occasion the site was visited.

Assessment. During 1967, 1968 and 1969 the legume trial was visited regularly and assessed by visual and photographic comparisons. On May 28th, 1970, heavy metal grazing cages measuring approximately 3 m by 1 m were placed on plots containing S.535 marsh birdsfoot trefoil, S.100 white clover and Leo birdsfoot trefoil respectively to enable yield comparisons to be made. A sample area of $0.5 m^2$ was cut from under each cage using long-handled lawn shears which cut the herbage at about 3 cm above surface level. The samples were separated into legume and non-legume components, weighed fresh and then submitted to the Chemistry Department of the West of Scotland Agricultural College where they were dried at 99 to 100°C for 16 hours before re-weighing to obtain dry-matter yields. The remainder of the herbage enclosed by the grazing cages was cut to a similar level after the samples had been removed.

A second cut was taken, using the same methods, on September 17th, 1970, when the cages were removed from the trial for the winter period.

Results 1966-1970

Legume establishment had reached satisfactory proportions by June 1967 with the exception of Viking birdsfoot trefoil which was very sparse and visibly inferior to the other cultivars. The other trefoil cultivars had populated the areas between the denser tufts of vegetation. The marsh birdsfoot trefoil seedlings were no more numerous than the common birdsfoot trefoil cultivars but they were larger and more vigorous. S.100 white clover had the largest leaves of the clovers and appeared superior to S.184 and Pajbjerg at this stage.

In 1968 the birdsfoot trefoil cultivars decreased in population, Viking, Wallace and MC/H/64 almost disappearing from the sward.

In autumn 1968 the most productive legumes were S.335 marsh birdsfoot trefoil and S.100 white clover, the former developing more herbage from a smaller number of foci whereas the latter was more widespread in the sward but with smaller and finer leaves.

Three years after sowing, only traces of Empire, Leo and MC/H/64 birdsfoot trefoil remained whereas S.335 marsh birdsfoot trefoil had produced a vigorous cover of closely-grazed herbage. The plants of this cultivar were seen to be grazed to the basal crowns which were composed of numerous branches. Nodulation in marsh birdsfoot trefoil appeared excellent, the plants bearing large nodules which contained pink colouration indicating effectiveness, even in the surface area of the soil. The rhizomatous habit of marsh birdsfoot trefoil was evident and the plants were apparently colonising the dense vegetation tufts more than the stolons of the white clover cultivars. The latter were in the form of a fine cover with very small leaves. The following table presents the dry-matter yields obtained in the two sample cuts taken during the 1970 growing season.

Table 5.3.2.1. Experiment C4. Legume dry-matter yield (kg/ha), 1970

Legume cultivar	Cut 1 (16.7.70)	Cut 2 (17.9.70)	Total Yield
S.100 white clover	250	320	570
S.335 marsh birdsfoot trefoil	1150	1030	2180

Plate 12. Experiment C4. Growth of marsh birdsfoot trefoil during 1970. The lower half of the photograph shows growth after seven weeks under a grazing cage whereas the upper half shows the remainder of the plot which was closely grazed during this period.

These results showed that there was almost four times the yield of herbage from the marsh birdsfoot trefoil than was obtained from S.100 white clover. Legume content in the sample cuts averaged 58% for S.335 marsh trefoil and 62% for S.100 white clover. Only two small plants of Leo birdsfoot trefoil were seen within the caged area and so this was not included in the results.

Discussion

Experiment C4 was laid out as a pilot trial to see if any of the *Lotus* material available at the time would persist under the adverse conditions experienced in such areas. Any innovation which could make the improvement of this type of pasture a more economic prospect is desirable. A herbage legume showing promise under these conditions is worthy of investigation. In the results obtained in this experiment, marsh birdsfoot trefoil showed such potential that it warranted further detailed studies.

The experiment was not replicated, but the trial results echoed indications shown in other experiments. The spaced-clump experiment E1 also indicated that marsh birdsfoot trefoil could produce large quantities of leafy herbage after the establishment phase was passed.

Davies (1969) reported promising results from marsh birdsfoot trefoil until winter conditions reduced the promising start to an insignificant development. If the Welsh trials had been sown in spring instead of late summer then the results might conceivably have been different.

The legume cultivars in experiment C4 were sown in early August and many more seedlings were seen to develop during the months before winter than in the following spring. The legumes recovered from the winter's effects probably by the germination of hard seeds.

The gradual disappearance of the L. corniculatus cultivars from the sward after two or three years was possibly due to a combination of two main factors. The species may not be able to withstand these particular environmental conditions, especially the high moisture content, although other workers, notably Stapledon (1925), Chevrotte and Gauthier (1957) reported its tolerance of water-logged conditions. It is more likely that birdsfoot trefoil does not persist under grazing systems where no rest period is allowed. Evidence from Welsh hill trials (Thomas 1936; Davies 1969) and from other countires (Washko 1961) supports this conclusion.

It is not easy to estimate the exact level of grazing pressure applied to the legumes in this trial. The number of sheep per hectare can be used as a standard when the pasture is uniform throughout the area but the legume trial and the neighbouring grass variety trial were always subjected to overgrazing. The sheep concentrated on the more palatable herbage produced in these trials in preference to the surrounding area and thus the stocking rate would actually be considerably higher than the livestock numbers suggest.

This situation arises in the "mosaic" system of rough pasture improvement described by Nicholson et al (1968) and Davies (1970) but in the case of this system grazing pressure is controlled to enhance the capacity of the improved pasture for future production. Nevertheless, as S.535 marsh birdsfoot trefoil withstood the treatment imposed in experiment C4 so well, it is evident that the potential value of this species lies in this direction. These conclusions led to the examination of the species in greater detail.

6. EXPERIMENTS WITH LOTUS PEDUNCULATUS ECOTYPES

The logical method of assessing the potential of marsh birdsfoot trefoil as a herbage legume in upland pasture was by a process of elimination. It was decided to carry out preliminary studies on material obtained from as many different countries as possible to isolate material more suitable for use in Scotland. This was then followed by basic experiments with cultivars, the most promising of these to be examined in competition studies before being subjected to grazing trials.

The general objective of the ecotype experiments E2 and E3 was to establish parameters within the species with which to judge more promising material in future experiments.

Material used in experiments E2 and E3. Fifty ecotypes of marsh birdsfoot trefoil were obtained from the United States Department of Agriculture Plant Introduction Division, Geneva, New York, in 1969. These original ecotypes were converted to composite ecotypes by mixing seed from similar countries of origin. In some cases the ecotypes from several neighbouring countries with similar climatic conditions were mixed. This reduced the number of ecotypes from fifty to twelve and at the same time resulted in more satisfactory quantities of seed per ecotype, thus enabling further replication. Table 6.1 shows the composition of the composite ecotypes.

Table 6.1. Composition of ecotypes used in Experiments E2 and E3

USDA P.I. No.	Country of origin	Composite ecotype
190349	Australia	
316274	Australia (ex. New Zealand)	Australia
316273	Australia (ex. Portugal)	
229905	Belgium	BENE
237188	Netherlands	
202383	Chile	
282128	"	Chile One
282129	"	
282130	"	
282131	Chile	
282132	"	
282133	"	Chile Two
282134	"	
282135	"	
282136	Chile	
282137	"	
282138	"	Chile Three
282139	"	
282140	"	
239940	Denmark	
235526	"	
235115	"	DES
235114	"	
235102	Sweden	
23938	France	
162562	"	
91983	"	FRIPO
235529	Italy	
210321	Portugal	
210322	"	
235531	Great Britain	
239939	" "	Great Britain
235530	" "	
232099	Germany	
232100	"	Germany
239937	"	
235528	"	
223997	New Zealand	
189113	" "	New Zealand
190633	" "	
78636	" "	
234812	Switzerland	
251829	Austria	
239936	"	SACH
308037	Czechoslovakia	
180172	"	
235527	Hungary	
253442	Yugoslavia	
251529	"	Yugoslavia
251178	"	

These composite ecotypes were used in experiments E2 and E3 along with Kyle, a local wild ecotype collected from roadsides near Ayr, and control varieties of clovers.

6.1. Outlines of Experiments E2 and E3

Experiment E2

Object - to compare the performances of twelve ecotypes of marsh birdsfoot trefoil with broad red clover as spaced aggregate clumps under lowland arable conditions.

Location of experiment. This trial was carried out at the Botany Department plots at the Apiary, Auchincruive, on land adjacent to experiments C1, C2 and E1 already dealt with.

Ecotypes and cultivars used:

red clover	-	Essex broad red	
marsh birdsfoot trefoils	-	Australia;	BENE;
		Chile Two;	Chile Three;
		DES;	FRIPO;
		Great Britain;	Germany;
		Kyle;	New Zealand;
		SACH;	Yugoslavia

Experimental design. An incomplete block design was used as in experiment C2, with four replications of the thirteen ecotypes. Blocks within replicates were randomised, as were varieties within each block. The plan of experiment E2 is shown in figure 6.1.1.

Experiment E3

Specific object - to compare the performances of thirteen ecotypes of marsh birdsfoot trefoil with three control cultivars of clover as spaced aggregate clumps under upland pasture conditions. As this experiment was established at the same time and in the same manner as experiment E2 it was also intended to compare the development of the ecotypes in their contrasting environments.

Location of experiment. Experiment E3 was carried out at the upland

Figure 6.1.1. Experiment E2 layout, Auchincruive

Block 12	Block 4	Block 11	Block 6	Block 10	Block 3
DES A	NZ BRC	BRC BEME	BRC AYR	C3 A	GER SACH
C2 GER	GB A	C3 GER	SACH C2	SACH YU	GB FIP

Block 1	Block 9	Block 2	Block 8	Block 13	Block 5	Block 7
GB C2	NZ YU	NZ C3	DES GB	AYR A	BEME NZ	BRC FIP
YU BEME	GER AYR	FIP C2	C3 AYR	BEME FIP	SACH DES	YU DES

NORTH

Ecotypes:

BRC	-	Essex red clover	GB	-	Great Britain
A	-	Australia marsh trefoil	GER	-	Germany
BEME	-	BEME	NZ	-	New Zealand
C2 & 3	-	Chile Two and Three	SACH	-	SACH
DES	-	DES	YU	-	Yugoslavia
FIP	-	FRIPO	AYR	-	Kyle

trial site, Broadshean, Kirkoswald, Ayrshire, on land next to the sward experiments H1 to 5, already dealt with in the previous section.

Ecotypes and cultivars used:

red clover	-	Essex broad red	
white clover	-	S.100	
wild white clover	-	S.184	
marsh birdsfoot trefoil	-	Australia;	BENE;
		Chile One;	Chile Two;
		Chile Three;	DES;
		FRIPO;	Great Britain;
		Germany;	Kyle;
		New Zealand;	SACH;
		Yugoslavia.	

Experimental design. A balanced lattice square design was used in experiment E3 as had been used in the *L. corniculatus* spaced-plant experiment C1, incorporating five replicates of the sixteen legumes. The four blocks within each replicate were randomised, as were the legumes within each block. The actual layout is shown in Figure 6.1.2.

6.2. Investigational Technique

All the legumes were sown on September 24th, 1969, under heated glasshouse conditions, in 12.5 cm diameter plastic plant pots containing John Innes seed compost. The seeds were then covered with 1 cm depth of vermiculite. Inoculation with a rhizobial isolate effective on marsh birdsfoot trefoil was carried out on September 29th using the contents of six culture tubes distributed in 3.2 l of quarter-strength Ringer's solution. Each pot received 25 ml of the inoculum. The pots were then arranged according to the statistical designs of experiments E2 and E3.

At one month after sowing the seedling populations were reduced to twenty per pot in all pots. On March 10th, 1970, the foliage on

Figure 6.1.2. Layout of experiment E3, Kirkoswald

Location:- Broadsheen (Mr. J. MacFadzean), Kirkoswald, Ayrshire.

Rep 1				Rep 2				Rep 3				Rep 4				Rep 5			
SACH	A	FIP	WC	A	BRC	YU	WWC	DES	SACH	GER	YU	NZ	WWC	DES	FIP	SACH	WWC	C3	AYR
BRC	BENE	C3	DES	C3	FIP	GER	C2	WC	WWC	C2	BENE	AYR	A	BENE	GER	YU	GB	FIP	BENE
GER	GB	C1	WWC	AYR	WC	DES	GB	NZ	A	C3	GB	C2	SACH	GB	BRC	BRC	NZ	GER	WC
AYR	NZ	C2	YU	NZ	BENE	SACH	C1	AYR	FIP	BRC	C1	WC	C1	C3	YU	A	C2	C1	DES

NORTH

Ecotypes:-

BRC	-	Essex red clover	DES	-	DES
WC	-	S.100 white clover	FIP	-	FRIPO
WWC	-	S.184 wild white clover	GB	-	Great Britain
A	-	Australia trefoil	GER	-	Germany
BENE	-	BENE	NZ	-	New Zealand
C1 to 3	-	Chile One to Three	SACH	-	SACH
			YU	-	Yugoslavia
			AYR	-	Kyle

every pot was trimmed to approximately 3 cm above soil level and the pots were transferred to an unheated glasshouse for hardening off prior to planting out.

Planting out of experiment E2 took place at the Apiary, Auchincruive, on 8th May, 1970, when the clumps were carefully planted on a prepared site at 90 cm spacings. The trial site was rotavated, raked and treated with a granular compound fertiliser (15% N, 15% P and 15% K) at a rate of 350 kg/ha, one week before sowing.

Experiment E3 was planted out at the same spacing as E2 on 12th May, 1970, at the upland trial site at Broadshean, Kirkoswald, Ayrshire, in a separately fenced and wire-netted enclosure adjacent to the birdsfoot trefoil sward experiments. On the day before this experiment was planted out the trial area was closely mown using a 'Flymo Professional' rotary mower. Pegs were then inserted at the positions of the aggregate clumps and a turf 40 cm square and 15 cm deep was cut at each peg using spades. Each turf was lifted and carefully replaced upside down, leaving a vegetation-free square of peat. The bare squares were then fertilised with ground limestone (50% CaO) at a rate of 5 t/ha and high-grade basic slag (14% P_2O_5) at a rate equivalent to 2.5 t/ha.

The planting operation then consisted of cutting a hole of approximately 12.5 cm diameter in the centre of each inverted turf and carefully inserting the contents of each pot into the hole.

Assessment. Important agronomic features were assessed by using the same methods as in the *L. corniculatus* spaced clump/plant experiments. Only one estimate of growth habit by height and mean width measurements was made during 1970, carried out on June 20th in experiment E2 and on June 21st in experiment E3.

Plate 13. Experiment E3. Clumps of marsh birdsfoot trefoil planted out at Kirkoswald in May 1970.
At each position a square of turf was overturned and given a standard application of ground limestone and basic slag before the trefoil clump was planted in the prepared hole in the middle of the turf.

The range of flowering was recorded by observing the number of days after June 1st at which a clump was bearing five flower-heads containing open florets. The aggregate clumps were then cut for the first time at two weeks after mean flowering date, and for the second time at ten weeks after cut one in experiment E2, and eight weeks after cut one in experiment E3.

At the cuts each clump was defoliated to 2.5 cm above soil level using hand-operated lawn trimmers; the cut herbage was collected and placed in labelled plastic bags. Samples were dried by the Chemistry Department of the West of Scotland Agricultural College at 99 to 100°C for 16 hours, to obtain dry matter figures.

6.3. Results

The statistical analyses of the results obtained from experiments E2 and E3 during 1970 were carried out using two methods. A randomised block analysis was used in addition to a balanced incomplete block analysis, as a greater efficiency was obtained with some variates with one system than with the other. Because the experiments were carried out simultaneously and analysed by the same methods it is considered appropriate to examine the results of trials E2 and E3 together with the aim of revealing trends in relative behaviour at the two trial sites.

Growth habit. The estimate of growth habit carried out in June 1970 showed that marsh birdsfoot trefoil was generally a low-growing species. In both experiments Essex broad red clover was much more erect than any of the *Lotus* ecotypes, whereas in experiment E3 seven of the ecotypes were not significantly different from white clover and wild white clover. Range of height/width ratios was similar at both sites. At Auchincruive the Great Britain and Australia ecotypes were significantly more erect than the two most prostrate types BENE and Kyle. Under upland conditions the Yugoslavian ecotype had a greater height/width ratio than the other ecotypes of marsh trefoil. This ecotype, along with SACH, FRIPO, DES, Australian and German ecotypes, was more erect than S.100 white clover. Table 6.3.1 shows height/width ratios as recorded in June 1970 in both experiments E2 and E3.

Time of flowering. At the upland trial site S.184 wild white clover and S.100 white clover were earlier in flowering than all the ecotypes of marsh birdsfoot trefoil. The Australian L. pedunculatus was the earliest flowering ecotype in trial E3 with FRIPO and New Zealand ecotypes almost as early. At Auchincruive, Australia was earlier than all the ecotypes and red clover with the exception of FRIPO, New Zealand being significantly later than Australia but similar to FRIPO. Kyle was later than all legumes at the lowland site and was later than many of the ecotypes at Broadshean, while Chile Three was almost as late-flowering as Kyle. BENE and Great Britain were also late blooming at the upland site whereas SACH was later than all except Chile Three and Kyle in trial E2 (Table 6.3.1).

Table 6.3.1. Experiments E2 and E3. Development of clumps, 1970

	Growth habit (ht/width) June		Flowering date (days after June 1st)	
	E2	E3	E2	E3
Clovers				
Essex broad red	1.1	0.9	26	36
S.100 white	-	0.2	-	27
S.184 wild white	-	0.2	-	25
Marsh birdsfoot trefoil				
Australia	0.5	0.4	17	37
BENE	0.3	0.3	27	56
Chile One	-	0.2	-	50
Chile Two	0.3	0.3	27	52
Chile Three	0.3	0.3	32	50
DES	0.4	0.4	26	49
FRIPO	0.4	0.4	20	40
Great Britain	0.5	0.3	26	56
Germany	0.4	0.5	27	48
Kyle	0.2	0.3	45	62
New Zealand	0.4	0.3	25	43
SACH	0.3	0.4	38	54
Yugoslavia	0.4	0.6	26	47
Significance	***	***	***	***
SE±	0.1	0.1	2	3

Dry matter yield. Table 6.3.2 shows the total dry weights obtained in the first cut taken from trials E2 and E3 during 1970, at two weeks after mean date of flowering. Under upland conditions many of the *Lotus* ecotypes out-yielded the white clovers, only Kyle, Australia and FRIPO yielding at the same level. Seven ecotypes which out-yielded Essex broad red clover at the same site included the Chile ecotypes and material from Great Britain, Germany, Belgium and the Netherlands. At the lowland site only two ecotypes, Chile Three and SACH were significantly greater than Essex broad red clover, SACH out-yielding all others. However only the Australian material gave poorer dry yields than the red clover, other ecotypes being just as productive at this stage of development.

At the second cut of experiment E2, Chile Three again out-yielded Essex broad red clover and all others except Australia and Chile Two. None of the Lotus ecotypes was lower yielding than Essex broad red clover.

The hill trial was cut again at eight weeks after the first cut and again showed Chile Three marsh birdsfoot trefoil to be superior to all other legumes in the experiment. This ecotype and the New Zealand material both out-yielded S.100 white clover while seven ecotypes out-yielded S.104 wild white clover. The only ecotype which S.100 white clover exceeded at this cut was Great Britain.

Table 6.3.2. Experiments E2 and E3. Clump yield, 1970 (g)

	Cut One		Cut Two		Total yield	
	E2	E3	E2	E3	E2	E3
Clovers						
Essex red	39.0	22.3	113.7	26.3	153.9	48.2
S.100 white	-	17.8	-	18.3	-	36.1
S.104 white	-	18.3	-	13.0	-	31.7
Marsh birdsfoot trefoil						
Australia	22.5	22.5	116.1	17.0	140.1	39.0
BRNE	41.7	30.8	103.5	20.4	144.3	50.3
Chile One	-	32.1	-	19.7	-	51.5
Chile Two	42.5	34.8	127.3	22.3	168.7	57.1
Chile Three	54.4	37.2	144.8	31.6	199.7	68.9
DES	37.2	36.1	97.0	14.8	134.1	51.1
FRIPO	28.1	21.1	87.6	20.1	117.1	41.0
Great Britain	43.2	46.2	93.5	12.0	134.6	59.0
Germany	45.0	34.4	111.0	13.9	155.0	48.5
Kyle	50.8	25.5	106.7	13.5	157.4	39.4
New Zealand	37.3	25.9	112.7	25.3	149.1	52.0
SACH	73.4	28.4	99.3	19.2	175.8	47.3
Yugoslavia	33.8	29.5	84.2	17.8	118.3	47.2
Significance	***	***	*	***	**	***
SE±	4.8	2.6	10.2	1.8	13.2	3.5

Total dry matter yields from both 1970 cuts are also shown in Table 6.3.2. Under the more testing upland conditions Chile

Three was the most productive *Lotus* ecotype; it out-yielded all except Great Britain. All ecotypes, except FRIFO, Kyle and Australia, out-yielded S.100 white clover during the establishment season and the three ecotypes mentioned were just as productive as S.100 and S.184. The British material was also high in dry matter yield although its local counterpart Kyle was significantly less productive.

Chile Three was the highest yielding ecotype in the lowland experiment E2, exceeding all but SACH and Chile Two. No ecotypes were lower yielding than Essex broad red clover under the trial conditions.

6.4. Discussion

The development of marsh birdsfoot trefoil as a sown herbage plant is not as advanced as that of birdsfoot trefoil. Only in the United States of America and New Zealand have cultivars been produced although some European countries do have what appear to be local varieties. The lack of available cultivars of marsh birdsfoot trefoil delayed the straightforward extension of experiment C4 (described in section 5.3.2). A more fundamental approach was made possible by the offer of fifty worldwide ecotypes of *L. pedunculatus* from the United States Department of Agriculture's Plant Introduction Service, enabling an assessment of the range of material available within the species.

The spaced clump technique used in the trials of birdsfoot trefoil material had proved a useful means of evaluation under the particular circumstances and there seemed no reason why the same technique should not be applied for assessment of the marsh birdsfoot trefoil ecotypes. The assessment was extended by attempting a duplicate trial at the Kirkoswald upland site as well

Plate 14. Experiment E2. Rhizomatous habit of marsh birdsfoot trefoil. The rhizomes emerge at the surface at a short distance from the clump centre and produce more herbage.

as at Auchincruive. Although failure was possible due to the additional exposure it was hoped that at least one season's results would be obtained under the more realistic environment. The mild winter of 1970-1 failed to kill off any of the clumps at either site thus enabling future assessment during the 1971 season.

The white clover types were included in the upland trial E5 as well as Essex broad red clover, the latter being the only control variety in the lowland trial E2. Chile One was also omitted at Auchincruive to enable the use of a balanced incomplete block design, thereby obtaining a greater level of efficiency in the analysis of results.

Differences between the ecotypes were noticeable even during the establishment of the clumps in the glasshouse. By March 1970 when the pots were transferred to hardening-off quarters, the Chilean, Mediterranean and Australasian ecotypes were producing vigorous, large-leaved foliage whereas BENE, Great Britain and Kyle were small-leaved and slow-growing. Subsequent observation in the field during 1970 reflected these trends. Suckling (1965) reported the introduction of Portuguese material into New Zealand to improve winter production of marsh birdsfoot trefoil. The early growth of ecotypes from New Zealand and similar climatic regions did demonstrate the influence of this valuable characteristic.

Other features were noted which proved relatively consistent at both trial sites. Growth habit in marsh birdsfoot trefoil was quite distinct from that of red clover yet more akin to that of white clover as the trefoil's rhizomes behaved in a similar manner to the stolons of white clover. Trefoil foliage grew vertically, only tilting outwards when the weight of flowers and fruit exerted their influence. This did not occur with white clover as its foliage never extended as much as marsh birdsfoot trefoil's. Both species could however be classed as low-growing rather than prostrate as when the term is applied to grass growth habit. Some marsh trefoil ecotypes produced taller shoots than others and consequently their height/width ratios were greater. Material of this type has proved useful in New Zealand for enticing grazing livestock on to rush and scrub areas, obliterating those weeds by trampling and thereby opening the land to further improvement (Suckling 1965).

General development in the two trials was relative, the upland clumps growing to 50 cm wide and 10 to 15 cm high while the lowland clumps measured up to 100 cm wide by 25 cm high when the second cut was taken in September 1970. Planting the E3 clumps on upturned turves seemed to be a successful technique which enabled the clumps to spread undisturbed during the first season while minimal control of weeds and ungrazed natural vegetation was needed.

The relative proportions of leaf and stem were not specifically recorded during the first season but left for more detailed investigation as the material develops. The usual pattern of early-flowering types being stemmy while later types are leafy was evident but exceptions were noticed and will be followed up during 1971, with comparison for quality by <u>in-vitro</u> digestibility analysis.

Flowering sequence was in accordance with expected variations, due to geographic origin of material. The sub-tropical FRIPO and the Australasian ecotypes, purported to contain Mediterranean genotypes by Harris (1970) were earliest while temperate material from northern and southern hemispheres tended to be late-flowering. The character was affected by the cooler upland conditions which delayed the development of some clumps during the season of establishment.

Yield comparisons during 1970 showed considerable promise for marsh birdsfoot trefoil, especially under the upland conditions in which it is intended to be utilised. Further results will be obtained from a system of more frequent defoliation in 1971.

It is hoped that these experiments will eventually point to the ecotypes more suitable for use in Scottish upland pasture. This material would then be examined and tested in greater detail by using the original ecotypes supplied by the United States Department of Agriculture as separate units. In the meantime the examination of marsh birdsfoot trefoil cultivars available for use was considered to be a justifiable measure.

7. EXPERIMENTS WITH CULTIVARS OF LOTUS PEDUNCULATUS

Assessment of recently produced New Zealand cultivars of marsh birdsfoot trefoil was initiated in spring 1970 by the establishment of a spaced aggregate clump experiment (code number C5) under upland pasture conditions and two row trials (code numbers R1 and R2), the first sown under lowland arable conditions at Auchincruive and the second at the same upland site as experiment C5. The main object of these experiments was to make a comparative study of the performances of the *Lotus* cultivars and local material, including a control variety of clover, under the particular environmental conditions.

7.1. Outlines of Experiments C5, R1 and R2

Experiment C5

Location. This trial was laid out at the upland experiment site at Broadshean, Kirkoswald, Ayrshire, in a separate enclosure adjacent to the sward experiments already described. The soil analysis is included in Appendix 3.

Cultivars used:

red clover	-	Essex broad red
marsh birdsfoot trefoil	-	Grasslands 4703 diploid Grasslands 4704 diploid Grasslands 4705 tetraploid Kyle (local ecotype)

Experimental design. A randomised block design was used with four replications of the five legumes. The layout is shown in Figure 7.1.1.

Figure 7.1.1. Experiment C5 layout, Kirkoswald

Kyle	Essex red clover	Grasslands 4704	Grasslands 4703	Grasslands 4705	Rep 1
Grasslands 4705	Grasslands 4704	Essex red clover	Kyle	Grasslands 4703	Rep 2
Grasslands 4704	Kyle	Grasslands 4703	Grasslands 4505	Essex red clover	Rep 3
Grasslands 4703	Grasslands 4705	Grasslands 4704	Essex red clover	Kyle	Rep 4

NORTH

Experiments R1 and R2

Locations. R1 was sown out at the Botany Department plot area at the Apiary, Auchincruive, next to the ecotypes trial E2 whereas experiment R2 was sown at the upland site, Broadshean, Kirkoswald, Ayrshire, in the enclosed area containing the other ecotypes trial E3.

Cultivars used:

red clover	-	Essex broad red
marsh birdsfoot trefoil	-	Grasslands 4703 diploid Grasslands 4704 diploid Grasslands 4705 tetraploid Kyle (local ecotype)

Experimental design. A randomised block design was used with four replications of the five legumes. An identical layout was used for both experiments, shown in Figure 7.1.2. Each row measured 1 m in length and 20 cm in width, having an area of 0.20 m^2. The rows were arranged parallel to each other with an interval of 70 cm between the edges of adjacent rows areas as explained in Figure 7.1.2.

experiments with an effective rhizobial isolate at one week after sowing. The plant numbers were reduced to twenty per pot after one month's growth. The aggregate clumps were planted out at the Broadsheen site on 2nd July, 1970, the delay being due to prolonged drought conditions which would probably have adversely affected the establishment of the clumps after the transplanting process. The clumps were spaced at intervals of 90 cm both ways, on overturned turves, prepared and fertilised in the same manner as in experiment E3.

The legume seed used in the row trials R1 and R2 was inoculated with effective isolates of rhizobia using the milk technique described in Appendix 2, on May 5th. The rows were sown with the aid of a wood frame which had internal measurements of 1 m by 20 cm. The frame was placed with the row peg on the inside at one end and a measured quantity of seed was carefully sown within the frame.

The lowland site for experiment R1 was prepared in the same manner as in the ecotype experiment E2 whereas the upland site for R2 was closely mown with the rotary mower at the same time as for experiment E3. Each row in experiment R2 was given a dressing of ground limestone (50% CaO) and high-grade basic slag (14% P_2O_5) at the rates used in previous upland experiments, just before the seed was surface-sown.

Assessment of experiment C5. A germination test was carried out under the conditions specified for the species by the International Seed Testing Association during April 1970. Two petri-dishes, each containing 50 seeds on moistened filter paper, were used for each cultivar, the first count being made after four days and the final count after twelve days.

The only assessment carried out on the aggregate clumps during the 1970 growing season was a cut taken on September 24th, 1970, when each clump was cut with lawn shears to a level of 3 cm above soil level. The herbage samples were dried in ovens and re-weighed for dry-matter yields by the Chemistry Department of the West of Scotland Agricultural College, using the methods already described for previous trials.

Assessment of experiments R1 and R2. Measurements started on August 7th, 1970, in the case of R1 and on October 6th, 1970, in the case of R2, the delay being due to a slow establishment caused by prolonged drought in May and June.

The number of plants per row was recorded in trial R1 on 7th August before the rows were cut to 3 cm above soil level, the samples being dried at 75°C for 16 hours to obtain dry weights. A second cut was taken from this experiment six weeks after the first cut, on September 17th, when dry weight figures were obtained by the same process.

Plant number per row was recorded in trial R2 on October 6th, 1970, and a separate estimate of the number of established plants in each row was made. No cut was taken as the material was not considered to be adequately developed at this time.

7.3. Results of Trials C5, R1 and R2

The results of the germination test carried out at the beginning of the trial period are presented in the following table.

Table 7.3.1. Germination capacity and hard seed content of red clover and marsh birdsfoot trefoil cultivars used in experiments C5, R1 and R2

Legume	Germination	Hard seed content	Year of harvest
Essex broad red clover	60%	9%	1967
Grasslands 4703	32	38	1966
Grasslands 4704	13	70	1965
Grasslands 4705	73	27	1969
Kyle	17	79	1969

The seed of Kyle, collected locally to Auchincruive in autumn 1969 was mainly composed of hard seeds whereas the tetraploid 4705 cultivar had the highest germination capacity with the remaining seeds in the hard state. The diploid marsh trefoils 4703 and 4704 were low in content of germinable seeds, 4703 also containing 30% non-viable seeds. Red clover's germination was reasonable and surpassed only by 4705 marsh trefoil. At the end of the germination test period seedling vigour was notably highest in the tetraploid marsh birdsfoot trefoil with seedlings up to 4 cm long bearing a dense growth of root hairs. Red clover seedlings were only 2-3 cm long and had no root hairs.

Results of experiment C5

Dry weights obtained in the cut taken on September 24th, 1970, are presented in Table 7.3.2.

Table 7.3.2. Experiment C5. Dry weight means 1970 (g)

Legume cultivar	Dry weight (g)
Essex broad red clover	12.5
Kyle marsh birdsfoot trefoil	11.0
Grasslands 4703	26.3
Grasslands 4704	24.7
Grasslands 4705	31.5
Mean	21.2
Significance	*
SE±	4.0

Grasslands 4705 and 4703 marsh birdsfoot trefoils were greater yielding than Essex red clover and Kyle marsh trefoil. 4704 showed a similar trend being significantly greater than Kyle but the difference between Essex red clover and 4704 was just below the level of significance. Visual observations made at the time of the cut indicated that the tetraploid 4705 cultivar was the leafiest of the marsh trefoils and was also considered to be the most succulent in appearance, having an abundance of soft leafy foliage.

The Kyle ecotype was noted to be very prostrate in growth habit compared with the other cultivars.

Results of experiment R1

Exceptional drought conditions during the latter part of May and most of June 1970 had a marked effect on the establishment of this trial, but by August the plant numbers in the rows were significantly higher with the New Zealand cultivars than with Essex broad red clover and Kyle marsh birdsfoot trefoil. Of the three Grasslands cultivars 4703 had fewer plants than 4704 with the tetraploid 4705 intermediate. The latter showed the most satisfactory development with a large number of vigorous plants as well as some late-developing seedlings whereas 4703 and 4704 both had a smaller number of established plants but a large number of growing seedlings. Kyle had only produced a small number of plants with low vigour, no developing seedlings being visible as in the other trefoils. In contrast Essex broad red clover was composed of a few large plants with no evidence of emerging seedlings.

The dry weight figures obtained in the August cut showed that Grasslands 4705 marsh birdsfoot trefoil and Essex broad red clover were the highest yielding legumes, both out-yielding the other trefoil cultivars. The high-yielding group and the lower-yielding group did not differ significantly within each group (Table 7.3.3).

Table 7.3.3. Experiment R1. Plant numbers and yield, 1970

Legume	No. of plants per row	Dry-matter yield (g) Cut One	Cut Two	Total
Essex broad red clover	9.5	20.25	38.55	58.80
Grasslands 4703 marsh trefoil	52.0	7.02	33.27	40.30
Grasslands 4704 " "	66.5	6.57	27.67	34.25
Grasslands 4705 " "	59.7	21.47	49.80	71.27
Kyle " "	14.7	3.75	20.30	24.05
Significance	***	**	*	**
SE±	4.4	3.09	5.26	7.66

At the second cut on September 17th, Grasslands 4705 remained the highest yielding cultivar of marsh birdsfoot trefoil, significantly out-yielding the other types. 4703 and 4704 yielded dry weights similar to that of Essex broad red clover which out-yielded only the Kyle ecotype of trefoil. The total dry-matter yields of herbage produced in experiment R1 in the establishing season are also shown in Table 7.3.3. Of the trefoils, the tetraploid 4705 was most productive at this stage, as high yielding as Essex broad red clover. The diploid cultivar 4703, although similar to Essex clover in total dry weight was significantly less productive than 4705. 4704 and Kyle were both out-yielded by Essex broad red clover but these trefoil varieties did not differ significantly from 4703.

Results of Experiment R2

The effects of the drought conditions had a more obvious effect on the establishment of this experiment. Replicates 3 and 4 were situated on a drier area than replicates 1 and 2 and the young seedlings were almost totally killed off during the month of June. Despite this effect Grasslands 4705 showed a greater number of plants per row on October 6th, 1970, than did 4703, Kyle and Essex broad red clover. 4704 was similar to 4705 in this feature, as were 4703, 4704 and Essex red clover (Table 7.3.4). A separate estimate of the numbers of established plants, excluding seedlings, showed no significant differences between the legumes although 4705 and 4704 were highest, 4703 and Essex broad red clover similar, and Kyle lowest.

Table 7.3.4. Experiment R2. Plant numbers 1970

Legume	No. of plants/ row	No. of established plants/row
Essex broad red clover	9.0	6.0
Grasslands 4703 marsh birdsfoot trefoil	9.2	6.2
Grasslands 4704 marsh birdsfoot trefoil	23.0	14.0
Grasslands 4705 marsh birdsfoot trefoil	30.2	13.2
Kyle marsh birdsfoot trefoil	3.2	1.0
Significance	*	NS
SE$\pm$	6.06	4.51

7.4. Discussion

The principle of preliminary examination of unknown material by means of spaced trials as opposed to sward trials was again applied in the case of the New Zealand cultivars of marsh birdsfoot trefoil. Use of the row trial method enabled the study of the cultivars' development from a natural establishment while the spaced clump experiment was used to examine the cultivars in the same manner as the other material had been tested. The clump experiment was also an insurance against possible failure of the row trials, a precaution taken when the variable results were obtained in the April germination test on the seed samples. This precaution was fully justified by successive events.

An unusually prolonged spell of dry weather started just as the legume seedlings were at a sensitive stage of development, about 2 to 3 cm high. The dry weather persisted for about six weeks and markedly upset the establishment of the row trials, many of the seedlings succumbing due to lack of water.

Experiment R1 was watered on two occasions by means of a hose-pipe and thus fared better than the upland experiment R2. The latter was badly affected in replicates 3 and 4 as this area was

<u>Plate 15. Experiment R1. Polyploidy in marsh birdsfoot trefoil</u>. To the left is the artificially-induced tetraploid variety Grasslands 4705 from New Zealand, and to the right normal diploid material of Grasslands 4703.

raised further above the water table than the other end of the trial area. The peat soil dried out considerably and took longer to return to normal when the rainfall resumed.

Hard seed content played a major role in the subsequent establishment of the row trials so far as the New Zealand cultivars were concerned, but Kyle failed to respond in the same way. This factor has usually been considered an undesirable feature in legumes but it could well have value in the case of establishment under adverse conditions. Indeed, this is considered to be one of the species' main virtues in areas of New Zealand where marsh birdsfoot trefoil has been established for a long period, allowing large quantities of hard seed to build up in the soil (Suckling 1965). Whenever an area of scrub is burnt, a rapid germination of marsh trefoil seed ensures a rapid recovery.

The marsh birdsfoot trefoil cultivars have shown considerable promise in the results so far obtained. The performance of the tetraploid cultivar Grasslands 4705 looks especially promising so far as establishment, yield and quality are concerned. This cultivar was seen to produce high yields of herbage which was judged to be of high quality by having a greater proportion of leafy herbage than the other cultivars. The induction of polyploidy is known to increase the digestibility of herbage plants (Harkess 1970). Further investigations must endeavour to determine if this is so in this particular case.

Evaluation of these three marsh trefoil cultivars in New Zealand is under way (Barclay and Lambert 1970; Harris 1970). Trials in both islands have shown considerable promise when the varieties have been compared with Grasslands Huia white clover under both rotational and set-stocking systems of livestock grazing

(Barclay and Lambert, loc. cit.). The denser diploid varieties 4703 and 4704 are favoured under set-stocking, whereas the more open, thick-stemmed tetraploid variety 4705, was at its most productive phase when oversown and when grazing pressure was low. Harris (1970) concluded that, from the aspect of yield, 4705 was a distinct improvement on the diploid 4703, which in turn surpassed 4704, possibly because of the latter's higher content of Portuguese genetic material. The slower rate of establishment in marsh birdsfoot trefoil, compared with white clover, was suggested as a limit to the use of the species in situations where white clover was of little use (Harris, loc. cit.).

8. HERBAGE QUALITY

An examination of this important aspect was initiated in 1970 by carrying out the first in a series of proposed experiments (coded Q) comparing the quality of birdsfoot trefoil herbage with that of clovers under varying agronomic conditions.

Experiment Q1

The object of the first experiment was to compare the quality, as measured by the *in-vitro* digestibility technique of analysis, of birdsfoot trefoil, marsh birdsfoot trefoil, white clover and red clover by regular sampling during the first flush of spring growth, from the vegetative to the flowering stages.

Location of experiment. Q1 was laid out next to the ecotypes trial (E2) and the row trial of marsh birdsfoot trefoil cultivars (R1) at the Apiary, Auchincruive, the site being prepared in the usual method already described.

Species and cultivars used:

Birdsfoot trefoil	-	Leo
Marsh birdsfoot trefoil	-	British material
White clover	-	S.100
Red clover	-	Essex broad red

The marsh trefoil material used was the Kyle ecotype mixed with the Great Britain ecotype used in the experiments E2 and E3, the latter being composed of the U.S.D.A. Plant Introductions numbered 235531, 239939 and 235530. All seed samples used in this experiment were from 1968 or 1969 harvests.

Treatment imposed. The four legume species were planted out as spaced aggregate clumps with eight clumps of each species per replicate, one clump being cut every week from the early vegetation phase through to the flowering period.

Experimental design. A split-plot randomised block design was used with three replications. The eight weekly harvests were used as main-plots while the four legume species were sub-plots. The trial plan is shown in Figure 8.1.

Figure 8.1. Experiment 01 layout, Auchincruive

Harvest No.:-	4	3	8	7	1	6	2	5
Rep 1	MBT	WC	BT	MBT	BT	BRC	BRC	WC
	BRC	BRC	WC	WC	MBT	WC	MBT	BT
	WC	MBT	BRC	BT	BRC	BT	BT	MBT
	BT	BT	MBT	BRC	WC	MBT	WC	BRC

Harvest No.:-	6	7	1	4	5	3	2	8
Rep 2	MBT	BT	WC	BRC	BRC	WC	BT	MBT
	WC	BRC	MBT	BT	BT	BRC	MBT	BT
	BRC	WC	BRC	WC	MBT	MBT	WC	BRC
	BT	MBT	BT	MBT	WC	BT	BRC	WC

Harvest No.:-	7	3	2	6	8	5	1	4
Rep 3	BRC	MBT	BT	WC	WC	BRC	MBT	WC
	WC	BRC	BRC	MBT	MBT	BT	BRC	BT
	BT	WC	MBT	BRC	BT	MBT	WC	MBT
	MBT	BT	WC	BT	BRC	WC	BT	BRC

NORTH

Legumes:-

BRC - Essex broad red clover
WC - S.100 white clover
BT - Leo birdsfoot trefoil
MBT - British marsh birdsfoot trefoil

8.1. Experimental technique

The legume species were sown under heated glasshouse conditions on November 14th, 1969, in 12.5 cm diameter plastic plant pots containing John Innes seed compost. Germination was rapid and the pots were inoculated with effective rhizobial isolates diluted in quarter-strength Ringer's solution on November 25th. At one month after sowing the number of plants per pot was reduced to twenty. The pots were then left to develop under these conditions until March 10th, 1970, when the foliage was trimmed to 3 cm above soil level and the pots transferred to an unheated glasshouse at the Apiary, Auchincruive, for hardening off prior to planting out in the field.

The process of planting out the spaced aggregate clumps took place on May 8th, 1970, the trial site having been rotavated, raked and given the same application of granular fertiliser as in previous experiments at the same site. The clumps were spaced at 75 cm intervals both ways, the contents of each pot being carefully placed in a 12.5 cm hole and then firmly consolidated. The area between the clumps was subsequently kept in a weed-free condition by regular hoeing.

The first harvest was taken on June 3rd, 1970, when the clumps were in the early vegetation phase of growth. The designated clumps were cut, using hand-operated lawn shears, to 3 cm above soil level and the herbage was collected and placed in a labelled bag taking care to avoid contamination with soil. The samples were then passed to the Chemistry Department for dry weight determination, in the manner previously described and analysis for quality by the <u>in-vitro</u> digestibility technique (Alexander and McGowan 1966). Successive harvests were carried out at weekly intervals until July 22nd, 1970, when the surviving clumps were all in full bloom.

8.2. Results

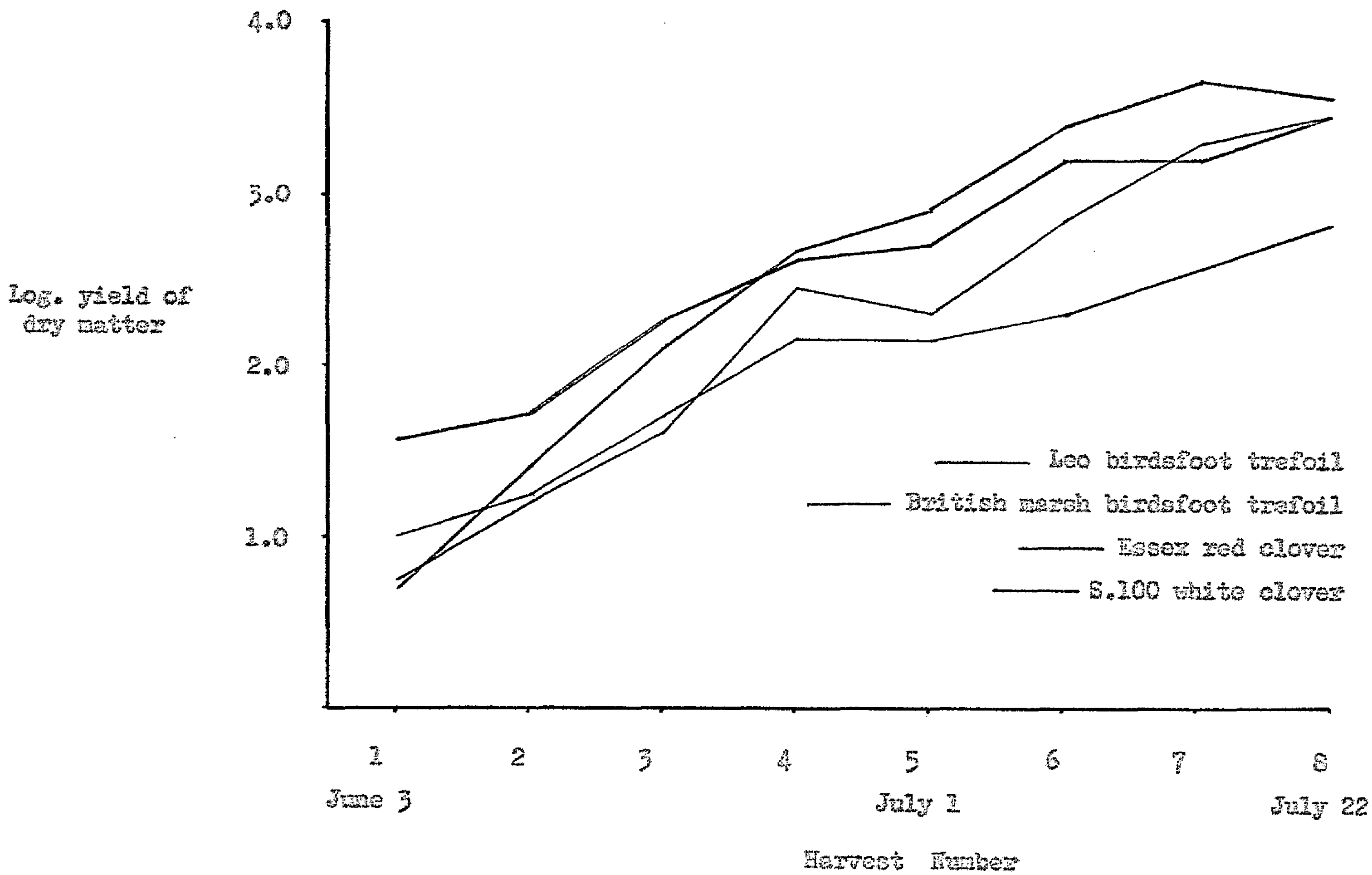
The figures obtained underwent computer analysis as a split-plot randomised block design. The coefficients of variation for the yield variates proved to be very high with the routine analysis as the replications in the first three harvests had to be bulked in order that an adequate sample could be obtained for <u>in-vitro</u> analysis. These variates were therefore log-normalised to obtain a more efficient analysis.

<u>Total dry weights.</u> These were highest in birdsfoot trefoil and red clover. These species out-yielded marsh birdsfoot trefoil which in turn out-yielded white clover. Dry matter yield increased with successive harvests although the fourth and fifth cuts were not significantly different, and neither were harvests seven and eight. Table 8.2.1 and figure 8.2.1 summarise the results.

<u>Table 8.2.1. Experiment Q1. Logarithms of yield</u>

Legumes	Yield of dry matter	Yield of digestible organic matter
Red clover	2.5870	2.0462
White clover	1.9863	1.6011
Birdsfoot trefoil	2.5310	2.0675
Marsh birdsfoot trefoil	2.2262	1.5259
Significance	***	***
SE±	0.0547	0.0556
Harvests		
1 (June 3)	1.0114	0.5617
2 (June 10)	1.3729	0.9016
3 (June 17)	1.9127	1.4357
4 (June 24)	2.4548	1.8185
5 (July 1)	2.5134	1.9626
6 (July 8)	2.9195	2.3376
7 (July 15)	3.1734	2.6769
8 (July 22)	3.3029	2.7869
Significance	***	***
SE±	0.0795	0.0827
Interaction		
Significance	**	*
SE±	0.1547	0.1572

Figure 8.2.1. Experiment Q1. Log. yield of dry matter (g)



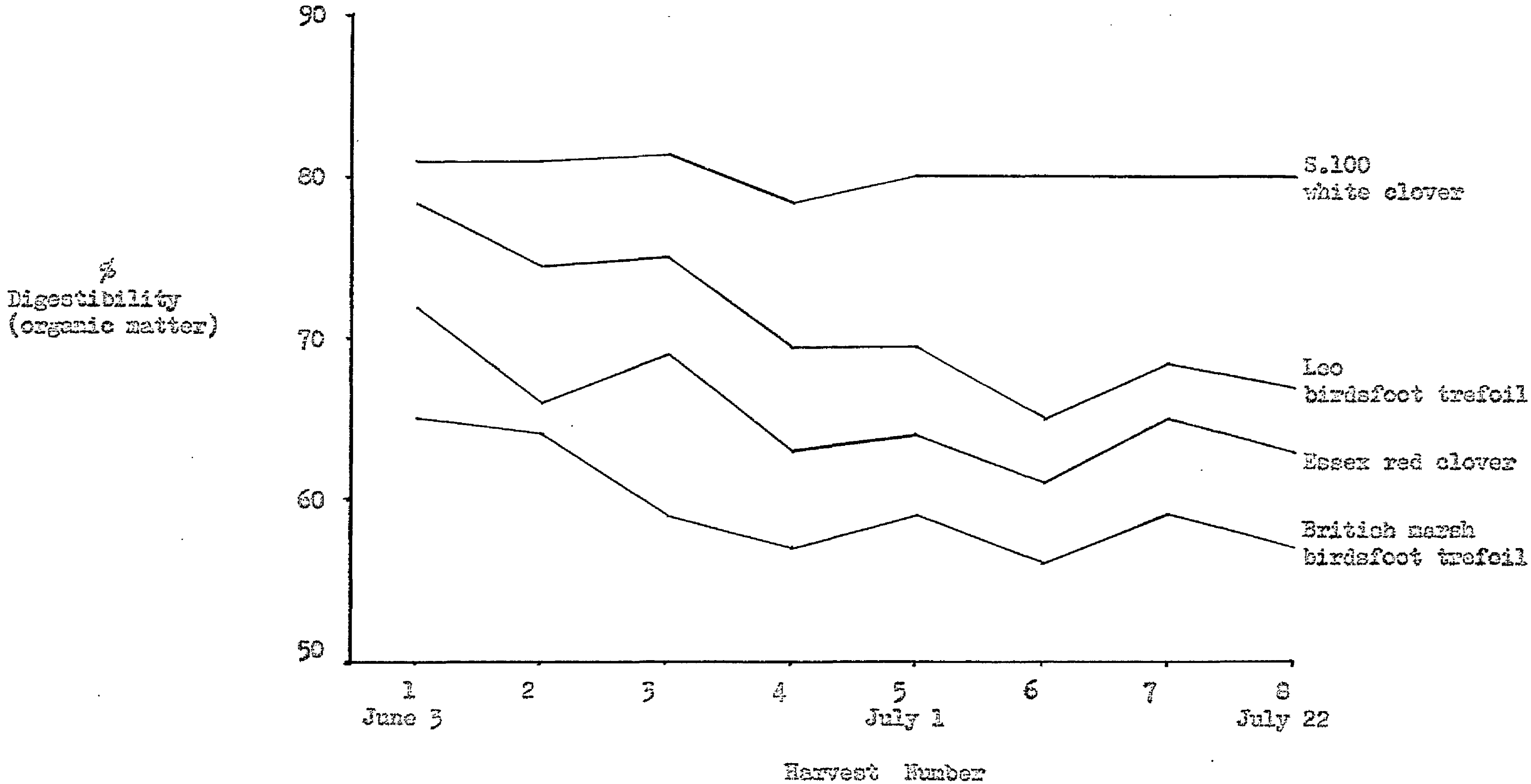
Percentage digestibility (organic matter). This factor was significantly different, both between legume species and between harvest and the interaction of these factors was at a significant level (Table 8.2.2 and figure 8.2.2). White clover was the legume with the highest digestibility percentage of 80, higher than birdsfoot trefoil at 71, which was higher than red clover at 65%. Marsh birdsfoot trefoil was the lowest in this feature, at 60%. Harvest one showed the highest percentage with a gradual decline to harvest four but thereafter the level fluctuated, except in white clover which remained constant at 80%.

Table 8.2.2. Experiment Q1. Percentage digestibility (organic matter)

Legumes	% digestibility
Red clover	65
White clover	80
Birdsfoot trefoil	71
Marsh birdsfoot trefoil	60
Significance	***
SE±	0.3
Harvests	
1 (June 3)	74
2 (June 10)	71
3 (June 17)	71
4 (June 24)	67
5 (July 1)	68
6 (July 8)	65
7 (July 15)	68
8 (July 22)	67
Significance	***
SE±	0.4
Interaction	
Significance	***
SE±	0.8

Yield of digestible organic matter. A similar level was recorded in red clover and birdsfoot trefoil and also with marsh birdsfoot trefoil and white clover, the latter pair being significantly lower than the former species. There was a gradual increase in this

Figure 8.2.2. Experiment Q1. Percentage Digestibility (organic matter)



factor as the clumps developed although harvests four and five were similar, as were harvests seven and eight (Table 8.2.1 and figure 8.2.3).

Relative rates of development. During the sampling period stage of growth was visually estimated; table 8.2.3 indicates the recorded trends. White clover and birdsfoot trefoil had similar rates of development, reaching the bud stage by the third harvest (17th June) and flowering from the fourth harvest onwards. Red clover reached the bud stage at the same time but the opening of florets was delayed by about one week in this species. The wild material of marsh birdsfoot trefoil was by far the slowest in development reaching bud stage by July 1st, two weeks later than the other species, and blooming after a similar delay.

Table 8.2.3. Experiment 01. Relative rates of legume development, 1970 (visual estimate of growth stages)

	Legume species			
Sampling date	Birdsfoot trefoil	Marsh birdsfoot trefoil	White clover	Red clover
June 3	EV	EV	EV	EV
10	V	V	V	V
17	Bud	V	Bud	Bud
24	EB	E bud	EB	EB
July 1	B	Bud	B	B
8	B	EB	B	B
15	LB	B	B	LB
22	LB	B	LB	LB

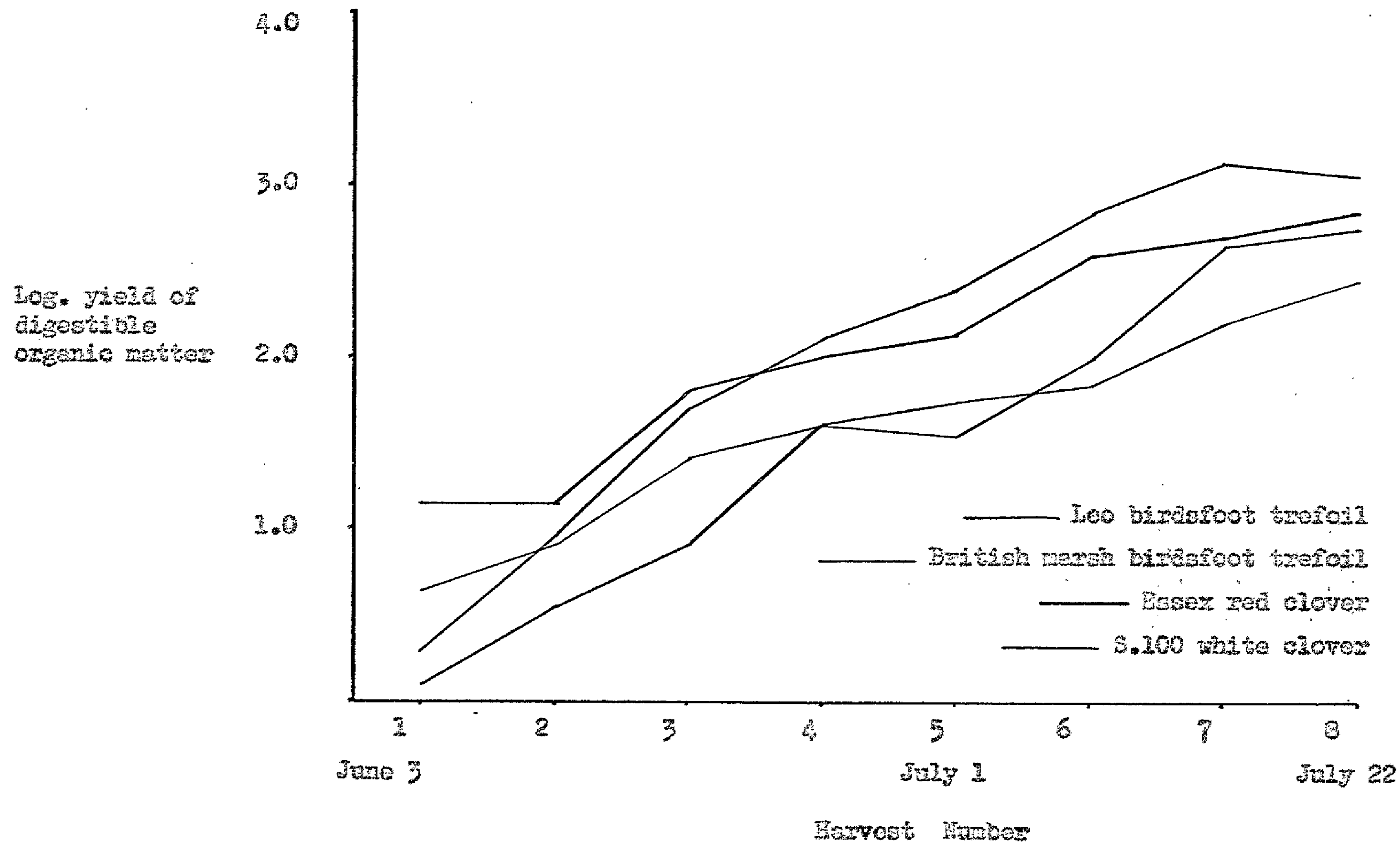
Abbreviations

EV - early vegetation
V - vegetation
E Bud - early bud
EB - early bloom
LB - late bloom

8.3. Discussion

Perhaps the most important role of herbage legumes in the improvement of upland pastures is their ability to raise the summer nutrition of livestock to an adequate level (Eadie 1967). Munro

Figure 8.2.3. Experiment Q1. Log yield of digestible organic matter (g)



(1969) presented some evidence obtained in Welsh experiments to back this hypothesis, and found that white clover, when surface-sown in mixtures with grass species, largely prevented the mid-summer depression of digestibility which occurred in pure grass swards. Clearly, if birdsfoot trefoil is to be used in a similar manner to clover in hill-land then it too must reach certain standards of quality as well as yield and persistency.

The earlier review of published literature included a section on herbage quality studies in birdsfoot trefoil carried out in other countries. There is no record of any British work on birdsfoot trefoil and no information from any source has been traced relating to the digestibility of marsh birdsfoot trefoil. The first examination of this aspect was therefore carried out at the species level, to obtain some basic parameters on which to base further studies within birdsfoot trefoil and especially marsh birdsfoot trefoil.

The spaced-clump technique was considered to be the most suitable under the existing circumstances, small legume plots tending to be readily invaded by weeds. The only drawback with this technique was the low dry-matter yield per clump obtained in the first three harvests, requiring the replicates to be bulked in order that an adequate sample was obtained for the <u>in-vitro</u> digestibility analysis. This was overcome during statistical analysis by log-normalising these figures.

Birdsfoot trefoil has been shown to give satisfactory yields of good quality herbage in American and Canadian trials (Winch 1969); its similarity to red clover in yields of digestible organic matter help to explain its popularity abroad (Ingalls <u>et al</u> 1965, 1966).

The marsh birdsfoot trefoil material proved disappointing throughout the experimental period; it was seen to be slow to develop, was low in yield, and its very appearance forecast the lower level of digestibility compared with the other legumes. It is obvious that the use of wild material was not a fair test of this species when compared with selected cultivars of birdsfoot trefoil and the clovers.

Henson and Schoth (1962) mentioned indications that the trefoils are somewhat less palatable than other commonly used legumes but concluded that animals readily consume *Lotus* herbage once they are accustomed to it. The quality of marsh birdsfoot trefoil was considered to be suspect due to high tannin content in the foliage, a feature which indicates low palatability (Henson and Schoth, *loc. cit.*). The tannin content in *Lotus* is also suggested to be the reason for its non-bloating ability, a valuable asset in a herbage legume (Kendall 1966).

Copeman and Roberts (1960) reported its rejection by livestock after establishment under water-logged conditions but experience in New Zealand suggests that marsh birdsfoot trefoil has no drawbacks, so far as quality is concerned, in the circumstances where the legume has proved valuable. Suckling (1965) reported that livestock search for and graze marsh birdsfoot trefoil in scrub land, thereby obliterating ferns and rushes and allowing the introduction of more productive species. There was no sign of livestock refusing to graze it in experiment C4; marsh trefoil was as closely grazed as the other legumes at all times. In this situation its quality was probably much higher than that of the natural vegetation and it is in this context that it must be judged.

Further experiments are warranted to study the quality of marsh birdsfoot trefoil. During 1971, Experiment Q2 is being established at Auchincruive. This trial includes spaced clumps of New Zealand and North American cultivars of marsh birdsfoot trefoil for yield and quality comparisons with white clover during the vegetative and flowering phases of development. The ecotypes in Experiment E2 are also undergoing analysis for yield and digestibility during this season. In this manner it is hoped to obtain a more accurate picture of herbage quality within this promising species.

9. CONCLUDING DISCUSSION

9.1. The experiments

The general objective of the project was an assessment of the potential value of members of the genus *Lotus* as herbage legumes in British grassland. The particular circumstances existing throughout the period of experimentation limited the scope of the study to an examination of the agronomic characteristics of the more promising species from a fundamental standpoint, and precluded studies of the behaviour of improved *Lotus* material under actual systems of utilisation. An abundance of diverse material of unknown characteristics under British conditions indicated that the logical approach to the exercise would be a preliminary screening of this material followed by a more detailed examination of the forms showing potential value.

There was little information available on the behaviour of birdsfoot trefoils under British conditions when the project was started, so samples of *Lotus* were obtained from as many different sources as possible. The generous response from abroad led to the spaced-clump experiments involving ecotypes and cultivars of birdsfoot trefoil and marsh birdsfoot trefoil. Sward trials were carried out when size of seed sample was adequate. The pot experiments under glasshouse conditions attempted to assess competition and management factors. It is intended to carry out a more fruitful examination of these factors when more information is collected on the basic features of the types within the species and on the conditions in which they are most productive.

The idea behind the screening of material at the lowland Auchincruive site using spaced aggregate clumps was the same principle as is used in germination testing of seed samples. If a type proves promising under near ideal conditions then it may have a greater chance of success at the site of intended use. This principle has been applied with success in the development of other herbage species but it has yet to be confirmed with the birdsfoot trefoils.

The initial screening process was satisfactory in that it produced some useful information on the range within several basic agronomic features from a wide selection of different genotypes. It proved a more reliable method than the use of single spaced plants which succumbed under relatively mild conditions after only one season's growth. Bringing on the seedling clumps in a glasshouse before planting out saved time and ensured a good establishment - factors which can mar row experiments. The space required for the trial was minimal and weed control and other maintenance operations were less onerous. Nevertheless, the trial conditions were near those experienced under systems of grassland utilisation. Experiments E3, C5 and R2 at the Kirkoswald hill site were attempts to simulate more realistic circumstances but the results obtained must be classed as preliminary compared with testing under grazing conditions.

The sward experiments were more realistic from the agronomic aspect but the material used was of unknown quantity at the time and the sites chosen and management applied were not ideal, with the exception of New Zealand marsh birdsfoot trefoil at the Eaglesham site.

Results of the agronomic evaluation of thirty-four introductions of Lotus in Wales were published while this present project was under way (Davies 1969). Lotus material was compared with control varieties of clover but the trials were conducted at sites where white clover performed well. A more revealing test of the species would have been obtained if the legumes had been compared in situations where white clover is not satisfactory, i.e. in areas where moisture is deficient or in excess.

The material tested in Wales originated mainly in latitudes to the south of Britain, with a few exceptions. The more promising types emerging from the results of the present project have originated in countries at northern latitudes - Russia, Canada and from the southern hemisphere, Chile and New Zealand. The inclusion of these types and cultivars not available at the time of the Welsh studies accounts for the differing conclusions from the two projects.

9.2. The species

9.2.1. Birdsfoot trefoil

Birdsfoot trefoil showed a wide range of variation within its major agronomic features while under trial at Auchincruive. Patterns of growth were different from those in clovers yet herbage production was just as high in several forms and even greater than white clover in some instances, seen in the results of experiments C1, C2 and E1.

Establishment. This has been a problem in the development of the species as a herbage plant in some countries but workers in the United States and Canada have investigated the seedling vigour of birdsfoot trefoil and increased it by breeding improved cultivars (Henson and Tayman 1961; Draper and Wilsie 1965; Twamley 1967b). Sowing methods for trefoil on dry soils would be variations of techniques already found successful under these circumstances, involving surface-seeding or methods, such as sod-seeding, which involve a minimum of surface cultivation before the sowing operation.

Heddle and Herriott (1968) have already reported on the success of such methods in the establishment of legumes in Scottish upland pastures. Where wind erosion would jeopardise success, the use of chemical herbicides such as paraquat or dalapon would check the growth of the existing sward until the sown species had established. This method would be more effective on sandy soils such as the 'machair' grasslands in the West of Scotland where birdsfoot trefoil is one of the main natural legumes in the existing sward.

Seed rate would require to be higher in birdsfoot trefoil than in white clover as only the latter spreads by stolons. It could be argued that the self-seeding ability of trefoil would permit lower seed rates but it would be safer to use more seed to ensure a satisfactory establishment and then rely on the self-sown seed to maintain the species and possibly spread it to surrounding areas. This hypothesis is backed by evidence published in North America (Winch 1961; Henson and Schoth 1962; Seaney and Henson 1970).

MacDonald (1946) concluded that, while birdsfoot trefoil tends to produce better yields than other legumes on normally poor soils, soil fertility requirements did not differ from those of other commonly used legumes. This would seem to be the case in Britain; the successful establishment of the species would include fertiliser application at a similar rate to that for clover. Once the sown species were established then fertiliser treatment could be carried out less frequently than with clover. Fertiliser treatment would be dictated more by the companion grasses sown with the trefoil.

Drought resistance. The notable feature of *L. corniculatus* which suggests its high potential value on dry soils is its tolerance of drought conditions. It has greater persistence than other legumes in poor sandy soils because of its root distribution; roots grow nearly as deep as lucerne yet have more extensive development in the upper soil (MacDonald 1946). It is this character which may place it at an advantage over other legumes in the northern regions of Britain where lucerne is unsatisfactory, enabling it to grow during the dry periods in early summer while clovers fail to be productive during these periods. Additional features such as its reputation for not causing bloat in animals grazing it and its ability to spread by self-seeding justify further investigations into the potential of birdsfoot trefoil under these specific conditions.

Companion species. On the well-drained natural pastures in the West of Scotland major companion grass species include perennial ryegrass, timothy and cocksfoot as well as the potential species tall fescue and smooth-stalked meadow-grass. The glasshouse experiment F1 examined the growth of birdsfoot trefoil when accompanied by some of these species. Timothy and cocksfoot were generally more compatible species whereas perennial ryegrass was the most aggressive competitor. Even with good grazing management, drought restricts the growth of perennial ryegrass in these areas during summer and autumn so that it would not provide aggressive competition to birdsfoot trefoil when the latter was in full growth. Establishment of cocksfoot is good on drier land but rarely does it form an ideal sward for sheep. Better utilisation of this species is possible where more cattle are kept and the cultivar S.143 has given good results in these conditions (Copeman and Roberts 1960). Mixtures of birdsfoot trefoil and cocksfoot have been productive over a long period in the United States (Parsons and Davis 1964). There seems no reason to prevent the use of such mixtures on machair land under the more intensive management imposed by fencing and apportionment of this land, being carried out at present under a government scheme (Bruce 1968).

Timothy is rapidly grazed out by the selective grazing sheep although the more persistent varieties such as S.48 are worthy of inclusion. Tall fescue and smooth-stalked meadow-grass are drought-tolerant species which have proved of value on similar land in other countries (Frame 1969; Dawson 1971); they could prove to be good companion species for birdsfoot trefoil in these circumstances.

Utilisation. This type of grassland would be used mainly for grazing so that cultivars of birdsfoot trefoil selected for use would be those more tolerant of this form of exploitation. Even with these forms, a rotational system of grazing would be required, or alternatively a lax system of more continual stocking to ensure that the legume persisted. Persistence of legume is valuable on this land for maintenance of herbage quality. Birdsfoot trefoil is satisfactory from the quality aspect having a yield of digestible organic matter which may often exceed that of white clover, as shown in experiment Q1.

Cultivars of possible value include the prostrate Empire and Dawn and hardy genotypes Leo, Morshansk and other Russian forms, yet to be tested for use under British conditions. Any future studies involving birdsfoot trefoil on dry areas should include these types in preference to others less suited to British conditions.

9.2.2. Marsh birdsfoot trefoil

Marsh birdsfoot trefoil has shown considerable potential in the preliminary studies reported in this thesis. These results are in line with findings under similar circumstances in other countries where the species has been successfully developed (Jackson et al 1964; Barclay and Lambert 1970). It is similar to white clover in form of growth, spreading by means of horizontal stems between the coarse tufts of vegetation so common on wet peat land. The vegetation is taller than white clover, enabling it to persist in swards dominated by tall species (Suckling 1965). Establishment. Copeman and Roberts (1960) and several other workers have reported its slow rate of establishment under water-logged conditions. Rate of establishment has been improved in New Zealand by the production of cultivars with good seedling vigour; the use of these or forms selected from them would largely alleviate the establishment problem, coupled with spring seeding. Seed rates for marsh birdsfoot trefoil could be the same as for white clover due to similar seed size and growth habit; productive swards have been established in New Zealand which involved the sowing of diploid marsh birdsfoot trefoil and white clover at about 2 kg/ha in mixtures with companion grasses (Barclay and Lambert 1970).

Companion grasses would not offer formidable competition stresses under the adverse conditions experienced in bog areas. The use of persistent cultivars such as S.23 perennial ryegrass, S.143 cocksfoot, S.215 and S.53 meadow fescue, S.170 tall fescue, smooth-stalked meadow-grass, S.59 red fescue and Yorkshire fog should not present problems when sown with marsh trefoil in reasonable proportions. New Zealand experiments involved the sowing of marsh birdsfoot trefoil in mixtures with bred varieties of perennial ryegrass and cocksfoot (Barclay and Lambert 1970), without any problems being encountered from the competitive aspect. The varieties mentioned above performed well in the trial sown adjacent to experiment C4 at the Eaglesham site (Hunt 1971).

The only method of sowing on peat bog land is surface-seeding. The natural vegetation in such areas is rarely dominated by grasses other than purple moor-grass and therefore the seed can best be brought into contact with the soil by heavy stocking with grazing animals. The grazing stock themselves could be used to disseminate the seed of marsh birdsfoot trefoil. Suckling (1965) reported studies which showed that approximately 11 kg/ha of viable legume seed passed through cattle in an undamaged condition. This did not include ripe seed heads which were not grazed and were therefore an additional source of seed for use in following seasons. Experiments revealed that it is mainly the hard seed which survives the passage through the animal. The feeding of hay containing a high legume seed content - which is usually of the hard type of seed - was considered a more promising practice than the feeding of commercial seed in bran or other media, as the commercial seed is mostly digested. The sowing of seed in this way would have the added advantage of suitable fertiliser placement along with the seed.

Fertiliser requirements. These would require to be at normal levels to ensure a satisfactory establishment of the sown mixture. The application of ground limestone and basic slag or some alternative source of phosphorus should be carried out at the recommended levels before sowing time; addition of potash fertiliser would seem essential on peat land despite levels apparently adequate in soil analysis figures (as apparent in experiment H2), and would repay the outlay by encouraging the production of trefoil foliage thereby providing a valuable source of protein in the herbage.

Time of sowing. Spring sowing on these wet areas would appear to be advocated to ensure a vigorous establishment of legume and grass. In the Welsh experiments, Davies (1969) reported outstanding initial growth of marsh birdsfoot trefoil after sowing in July, followed by a severe check in the winter after which the material never regained any degree of prominence. In the surface-seeding trial established in 1966 by the present author, the marsh trefoil appeared as numerous seedlings after sowing in early August, many of which failed to survive the winter; they were replaced by more seedlings - possibly from germination of hard seed - in the following spring and proceeded to establish a sward which has increased in production every successive season. Despite these contrasting results the sowing of seeds in early spring would provide the species with the greatest opportunity of a rapid and successful establishment. The poor establishment obtained in the author's experiment R2 was due to exceptional drought conditions.

Choice of genotypes. Examination of marsh birdsfoot trefoil is not advanced enough to permit a recommendation regarding the material suitable for use in this country. At some point in the selection of suitable *Lotus* types a choice will need to be made between forms having a high natural seeding capability and those which produce herbage of high quality. The most valuable material would combine these features with high yield and may be already available. The performance of material from Chile was most promising in experiments E2 and E3 during the 1970 season but trials of longer duration will be necessary. As the use of New Zealand-bred cultivars is already widespread in Britain it is rather obvious that the Grasslands varieties already produced would be likely contenders for the purpose. Yet the presence of Portuguese genes in these varieties might render them unsuitable for use in Scotland due to lack of hardiness. The cultivar S.335 used in experiment C4 was composed solely of New Zealand material and cannot be taken as an advance indication of the performance of the other New Zealand varieties. Harris (1970) mentioned the inferior performance of Grasslands 4704 possibly due to its higher content of Portuguese genes. Further studies will clarify the position of these apparently promising varieties.

The use of marsh birdsfoot trefoil in British natural pasture will depend on the future of these New Zealand cultivars to a large extent. It is more likely that seed for Britain would be imported from New Zealand seed producers rather than be produced in this country. If New Zealand marsh trefoil is not made available then it would be difficult to see another source of suitable material.

Natural reseeding. Perhaps the greatest asset of the species is the seed producer's problem - the ability of marsh birdsfoot trefoil to dehisce like its relative birdsfoot trefoil. In New Zealand the real purpose of surface-seeding is realised by building up a thin establishment into a vigorous stand by allowing natural reseeding to take place. In parts of the country where marsh trefoil has been established for a long period, large amounts of buried hard seed have been built up in the soil. Wherever an area of scrub is burnt, large numbers of trefoil seedlings appear, thereby ensuring a rapid recovery of valuable herbage (Suckling 1965).

9.2.3. Use of trefoils in pasture improvement techniques

Results obtained so far in the experimental programme indicate that birdsfoot trefoil and marsh birdsfoot trefoil have potential value as pioneer species in the improvement of natural pastures in Britain. Use of trefoils and white clover should be complementary in this role with the former species for the poorer areas. Birdsfoot trefoil has features which could raise its value beyond that of a pioneer species on the drier soil types as improvement in these circumstances does not result in the removal of the drought effects which occur at the height of grassland productivity.

As the potential value of birdsfoot trefoil lies in different situations from that of marsh birdsfoot trefoil, the establishment and subsequent management of the two species must be considered separately.

Birdsfoot trefoil could well be established with other herbage species by using the chemical renovation technique already mentioned. The natural reseeding ability of both trefoils could be used to a greatest advantage in the 'mosaic' system of pasture improvement described by Nicholson *et al* (1968) and Davies (1970). About 20% of a large enclosed area is improved in patches which are left unfenced. Natural reseeding and spread via livestock droppings improves the surrounding area. The patches of improved land have proved adequate as an *in situ* pasture supplement to provide high enough dietary quality (Nicholson *et al*, *loc. cit.*).

It is under these circumstances that the species of *Lotus* may well be of greatest potential value in Britain.

10. SUMMARY

1. A series of experiments was carried out at the West of Scotland Agricultural College over the period 1966-1971 with the object of assessing the potential value of birdsfoot trefoils (Lotus species) in Northern British grassland farming.

2. Pot experiments under glasshouse conditions indicated that some grass species are more compatible with birdsfoot trefoil than others; cultivars with good seedling vigour appeared better equipped to withstand competition from companion grasses during the establishment phase.

3. A wide range of ecotypes and cultivars of birdsfoot trefoil were compared with each other and with clover control varieties in spaced-plant and spaced-clump experiments during 1968 and 1969, revealing broad differences in the major agronomic features. Erect and low-growing forms, early and late-flowering types were recorded. In terms of productivity the Russian cultivar Morshansk and its Canadian selection Leo were most promising while the behaviour of a German ecotype of marsh birdsfoot trefoil indicated the need for further investigation of this rhizomatous species.

4. A sward experiment involving the testing of birdsfoot trefoil cultivars along with clovers under a lowland hay-cropping system failed to produce any suggestions of potential use in this aspect of grass farming.

5. A series of hill sward experiments in which birdsfoot trefoil was surface-sown under variations of renovation treatment, fertiliser practice and companion grass species was carried out at an upland site in south Ayrshire from 1967 onwards. The American cultivar Empire showed promise in that it established successfully

under all renovation treatments applied but its persistence under continuous grazing pressure on this soil type was in doubt. A marked yield response to potash fertiliser and a depressing effect caused by nitrogen fertiliser were obtained. The cultivar Leo was as productive as white clover under the lax grazing system imposed.

6. A sward variety evaluation experiment comparing several cultivars of birdsfoot trefoil was surface-sown at the Ayrshire site in 1969 and several types, notably Russian material, Leo and some North American cultivars appeared to have potential during the autumn after sowing. Subsequent unfavourable sward conditions caused a deterioration in all varieties of trefoil and clover. The material was considered to be worthy of re-examination at different types of site.

7. A non-replicated trial of birdsfoot trefoil and marsh birdsfoot trefoil cultivars established satisfactorily after being surface-sown in 1966 at an unfenced wet upland site near Eaglesham, Renfrewshire. The birdsfoot trefoil cultivars gradually disappeared under constant grazing pressure but a New Zealand cultivar of marsh birdsfoot trefoil developed a vigorous, productive growth, despite close-grazing and was found to out-yield S.100 white clover by a ratio of almost 4 to 1 during the fourth season of growth in 1970, when grazing cages were applied to obtain yield figures.

8. Accordingly, a world-wide collection of marsh birdsfoot trefoil ecotypes was examined in spaced aggregate-clump experiments at Auchincruive and at the south Ayrshire trial site from 1970 onwards. During the first season some ecotypes showed considerable promise from the aspect of yield at both sites. Material from Chile was outstanding at this stage although many other ecotypes

also out-yielded white clover; only one ecotype, a local wild form was less productive.

9. Cultivars of marsh birdsfoot trefoil produced in New Zealand were compared with red clover and local wild marsh trefoil in a spaced-clump experiment at the Ayrshire upland site, and two row trials, one at Auchincruive and the other at the Ayrshire upland site. During the 1970 season, establishment was impeded by a prolonged spell of drought shortly after sowing but the New Zealand cultivars showed good potential, especially an induced tetraploid cultivar, Grasslands 4705.

10. Herbage quality investigations commenced in 1970 with a spaced-clump experiment which compared the birdsfoot trefoils with red and white clovers during the primary growth phase. Leo birdsfoot trefoil produced a satisfactory yield of digestible organic matter when compared with the clovers but the wild material of marsh birdsfoot trefoil was significantly lower in digestibility percentage. During 1971 the ecotypes of marsh birdsfoot trefoil are being examined for this feature and an experiment including New Zealand and North American cultivars has been initiated to investigate the effects of artificial selection and induced tetraploidy on this vital characteristic.

11. These preliminary results indicate that birdsfoot trefoil and marsh birdsfoot trefoil have potential value as pioneer legumes in British natural pastures. Birdsfoot trefoil shows more promise on poor dry areas and marsh birdsfoot trefoil on wet peat soils; they offer a good alternative to white clover as the most suitable legume in these situations.

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1365.

Appendix 1. List of common and scientific names of grasses, legumes and other plants mentioned in the thesis.

Common names	Scientific names
LEGUMES:	
Birdsfoot trefoil	*Lotus corniculatus* L.
Marsh birdsfoot trefoil	*L. pedunculatus* Cav.
Slender birdsfoot trefoil	*L. tenuis* Waldst. & Kit. ex Willd.
Alsike clover	*Trifolium hybridum* L.
Crown vetch	*Coronilla varia* L.
Hop trefoil	*T. campestre* Schreb.
Kidney vetch	*Anthyllis vulneraria* L.
Lucerne	*Medicago sativa* L.
Red clover	*T. pratense* L.
Sainfoin	*Onobrychis sativa* Lam.
Subterranean clover	*T. subterraneum* L.
White (Ladino) clover	*T. repens* L.
Yellow trefoil	*M. lupulina* L.
GRASSES:	
Annual meadow-grass	*Poa annua* L.
Brome-grass	*Bromus inermis* Leyss.
Browntop bent	*Agrostis tenuis* Sibth.
Carpet-grass	*Axonopus compressos* L.
Cocksfoot	*Dactylis glomerata* L.
Creeping bent	*A. stolonifera* L.
Crested wheat-grass	*Agropyron cristatum* L.
Golden oat-grass	*Trisetum flavescens* (L.) Beauv.
Italian ryegrass	*Lolium multiflorum* Lam.
Mat-grass	*Nardus stricta* L.
Meadow fescue	*Festuca pratensis* Huds.

Common names	Scientific names
Perennial ryegrass	*L. perenne* L.
Purple moor-grass	*Molinia caerulea* (L.) Moench.
Red fescue	*Festuca rubra* L.
Sheep's fescue	*F. ovina* L.
Smooth-stalked meadow-grass	*P. pratensis* L.
Soft brome-grass	*B. mollis* L.
Swamp meadow-grass	*P. palustris* L.
Tall fescue	*F. arundinacea* Schreb.
Tall oat-grass	*Arrhenatherum elatius* (L.) Beauv. ex J. & C. Presl.
Timothy	*Phleum pratense* L.
Yorkshire fog	*Holcus lanatus* L.
OTHER PLANTS:	
Common heather	*Calluna vulgaris* (L.) Hull
Cross-leaved heath	*Erica tetralix* L.
Deer's hair sedge	*Trichophorum cespitosum* (L.) Hartm.
Drawmoss	*Eriophorum vaginatum* L.
Many-headed cotton-grass	*E. angustifolium* Honck.
Stool bent	*Juncus squarrosus* L.
Common rush	*J. effusus* L.
True sedges	*Carex* species L.
Tormentil	*Potentilla erecta* (L.) Hausch.

Appendix 2. The milk technique of legume seed inoculation used in the surface-sown experiments

This technique was devised by Thornton (1931) but with some slight modifications.

The following isolates of *Rhizobium* were sub-cultured on yeast mannitol agar in tubes:-

3E011 isolate - effective on *L. corniculatus* (U.S.A.)

3E0b5 " " " *L. pedunculatus* (U.S.A.)

V.157 " " " *Trifolium spp.* (Australia)

A 0.1% solution of calcium phosphate in milk was prepared and approximately 200 ml of this solution was used to wash the rhizobia from the culture tubes (two tubes for each species of legume to be inoculated). The seed was then poured into the *Rhizobium*/milk solution and thoroughly mixed to ensure that every seed was coated. The seed was then spread out thinly on newspapers and allowed to dry in a shaded position. No weighing of seed samples was carried out until the seed was thoroughly dry.

The seed was sown at the experimental site within one or two days of inoculation to prevent death of bacteria.

Appendix 3. Soil analyses at experimental sites

Site	Loss on ignition (% oven-dried soil)	pH (water)	Available P_2O_5 (mg/100 g)	Available K_2O (mg/100 g)	pC
Experiment L1					
Kippen, Stirling (1968)	12.2	6.9	9.0	9.0	3.7
Spaced-clump trials					
Apiary, Auchincruive (1970)	7.3	5.6	4.0	12.0	4.1
Experiments H1-5					
Kirkoswald (1968):					
natural	23.0	4.4	3.0	14.0	3.7
after lime and basic slag	22.2	5.1	21.0	13.0	3.7
Kirkoswald (1969):					
natural	17.2	4.8	2.0	6.0	4.0
fertilised	18.0	5.0	3.0	6.0	4.0
Experiments E3, R2, C5					
Kirkoswald (1971)					
natural	25.0	4.5	2.0	8.0	4.1
Experiment C4					
Eaglesham (1971)	84.6	4.6	15.0	23.0	3.6

Appendix 4. Meteorological data during the experimental period

Glasshouse experiments. Mean monthly temperatures (°C) and relative humidity (%)

Experiments P1 and P2, 1966

	temperature
May	14.5
June	20.0
July	20.0
August	17.2
September	17.2
maximum	24.0
minimum	10.0

Experiment P3, 1967

	temperature	humidity
April	14.0	55
May	15.5	50
June	18.3	45
July	21.0	45
maximum	24.0	-
minimum	9.0	-
mean humidity		50

Experiment P4, 1967

	temperature
October	10.3
November	18.3
December	15.5
maximum	20
minimum	15
mean humidity	45

Auchincruive-spaced plant/clump/row experiments. Air temperature (°C at 1 m) and soil temperature (°C at 30 cm)

	1968		1969		1970		1971
	Air	Soil	Air	Soil	Air	Soil	Air
January	4	4	5	5	4	4	5
February	1	3	1	3	2	3	6
March	6	5	2	3	4	4	5
April	8	7	7	6	6	6	
May	8	9	10	10	11	10	
June	13	13	13	13	15	14	
July	13	14	14	14	13	15	
August	15	14	15	15	15	15	
September	12	11	13	14	13	13	
October	11	11	12	12	10	11	
November	5	7	4	7	7	8	
December	3	5	4	5	5	6	

Kirkoswald, Ayrshire - sward/clump/row experiments. Air temperature (°C at 10 cm) and soil temperature (°C at 10 cm)

	1968		1969		1970	
	Air	Soil	Air	Soil	Air	Soil
January	4	4	6	3	3	4
February	1	3	1	2	1	3
March	6	5	3	4	6	4
April	15	7	10	7	12	6
May	14	9	13	11	17	10
June	18	15	16	15	24	14
July	15	14	17	14	19	13
August	16	13	18	14	22	15
September	14	12	17	12	17	13
October	10	10	17	12	13	11
November	5	7	10	7	8	8
December	3	5	8	6	3	6

Appendix 5. Paper presented at the 4th General Meeting of the European Grassland Federation, Lausanne, Switzerland, on 14th-19th June, 1971 (Section 5 Improvement of natural grassland)

THE POTENTIAL VALUE OF LOTUS SPECIES IN THE IMPROVEMENT OF NATURAL GRASSLAND IN SCOTLAND

Summary

A wide range of types within Lotus corniculatus L. and L. pedunculatus Cav. has been evaluated for agronomic use in Scottish natural pastures. Variety trials, row trials and sward experiments were conducted at various sites. Results to date show that L. corniculatus is promising on poor dry areas and L. pedunculatus on wet peat soils. They offer a good alternative to Trifolium repens on these areas as the most suitable legume. Preliminary findings indicate that further investigations, including grazing trials, are warranted.

Introduction

Two-thirds of Scotland is covered by a type of natural grassland which falls far short of its potential output due to adverse climatic factors and deficiencies of lime, phosphate, nitrogen and other essential nutrients. Application of fertilizers such as ground limestone and basic slag rectify some of the soil nutrient deficiencies, but the herbage legume is becoming increasingly important as a cheap source of nitrogen.

The main legumes suitable for this role are the small-leaved wild white clover and the larger-leaved form typified by S.100 white clover. Recent years have seen the development of Lotus species for rough-land improvement, particularly in North America (1, 2), South America (3), Europe (4, 5) and New Zealand (6). Of the 200 species within this genus only common birdsfoot trefoil

(*Lotus corniculatus* L.) and marsh birdsfoot trefoil (*L. pedunculatus* Cav.) have been of widespread value. Both species are common perennials on Scottish hills. The former prefers well-drained sites whereas *L. pedunculatus* thrives in wet, grassy places, yet neither are in commercial use in this country. This situation warranted further investigation, so seed samples were obtained from sources in several countries to evaluate the potentiality of *Lotus* species for hill-land improvement.

Trials with *Lotus corniculatus*

Spaced-clump trials

The size of available seed samples limited the study of eleven cultivars of *L. corniculatus* in a replicated spaced-clump design, each clump being an aggregate of twenty plants. Varieties were sown in pots in autumn 1967 and inoculated with an effective strain of *Rhizobium* obtained from North America. The clumps were established over winter in an unheated glasshouse and planted out at Auchincruive in spring 1968. This lowland site lies at an altitude of 30 metres above sea level with an annual rainfall averaging 950 mm. The soil is a neutral heavy arable loam. Major agronomic characteristics were assessed during two seasons using S.100 white clover and Essex broad red clover as control varieties for dual comparison.

Growth habit. Height-width recordings taken at intervals prior to flowering showed that no trefoil variety was as prostrate as white clover or as erect as red clover. Nevertheless habits varied from semi-erect types such as Viking, Granger and Cascade to prostrate types such as Empire and Fargo.

Time of flowering. Both clovers were earlier flowering than the earliest trefoils which bloomed four weeks before the latest trefoils. This feature was consistent in both seasons and no distinct grouping was observed. In general the semi-erect Granger, Cascade and Douglas (USA) were early, coming into full bloom around June 18th, Leo (Canada) and Morshansk 528 (USSR) were intermediate (about June 28th) while the prostrate American pasture types Empire and Fargo were late, blooming about July 8th.

Yield. The clumps were cut at flowering and aftermath stages to compare seasonal distribution of dry matter production and dry matter yield. Despite a slow start white clover out-yielded all other varieties in the first season, but was surpassed by the Russian Morshansk 528 and its Canadian selection Leo, and equalled by all except Granger, Cascade and Viking in the second harvest year. Yield patterns - probably more typical in the second season - resembled white clover with a higher proportion of forage produced during June and July and growth falling off in early autumn.

Winter hardiness. All the trefoil varieties and white clover survived winter 1968-9 in a satisfactory condition while red clover suffered some damage.

Sward trials. The more readily available varieties were established in sward trials within a fenced area at hill site A using variations of hill-land improvement techniques. This site, at 180 metres above sea level, has a mean annual rainfall of 1100 mm. The water table is high in winter and low in dry summer spells and the soil is a dark peat with a pH of about 4.5. The trial site has a southerly aspect.

The first experiment was autumn-sown after a normal application of lime and basic slag followed by combinations of paraquat and rotavation treatment. Empire and Viking trefoils were sown on the heather dominant sward at 11 kg/ha while S.100 white clover was sown at 4.5 kg/ha. Both species were inoculated with effective rhizobial strains. Establishment was slow but successful and after one year the white clover was significantly superior to both trefoils. The area remained untouched during establishment except for one week in July and two weeks in late autumn when sheep were allowed access.

A cut taken after two years showed Empire to be as productive as white clover with Viking markedly inferior. Surface-seeding without any paraquat or rotavation proved just as successful as any of the other combinations, in terms of legume establishment and growth, although rotavation reduced heather cover and encouraged grass growth.

A second trial was spring-sown and compared the effects of additional applications of nitrogen (90 kg/ha) and/or potash (125 kg/ha) as annual spring dressings. The spring sowing greatly improved legume establishment and a sample cut taken in the following season showed no difference in yield between Empire and Leo birdsfoot trefoils and the control S.100 white clover. There was a marked response to potash dressings whereas nitrogen depressed legume growth, more probably by stimulation of the natural herbage than by affecting nodulation.

Trials with *Lotus pedunculatus*

Clump trials

Ecotypes from many countries were compared with red and white clovers in two spaced-clump trials, planted out in spring 1970 at the lowland Auchincruive site and hill site A. The species in these trials and in all others, were inoculated with effective strains of *Rhizobium*. Agronomic features were studied throughout the 1970 season.

Growth habit. Range of growth form within the marsh trefoil ecotypes was not great with most clumps rather prostrate due to the characteristic spreading by stolons. The foliage was taller than in white clover but rate of horizontal spread was similar, the lowland clumps developing to one metre in diameter while those planted at hill site A reached 0.5 metre by autumn.

Time of flowering. Six weeks separated the earliest and the latest ecotypes at Auchincruive and only one week less on the hill. Results were consistent at both sites, Australian material being earliest and local Kyle material latest. Although similar to the earliest trefoils at the lowland site, the clovers were earlier at the hill site.

Yield. When cut at flowering, all ecotypes out-yielded white clover and some were also better than red clover, especially at hill site A. In the aftermath cut, all marsh trefoils were as productive as white clover at the hill site. Chilean and New Zealand ecotypes were more productive than white clover on the hill and one ecotype from Chile out-yielded red clover at both sites.

Total yield figures showed all ecotypes to be better than S.100 white clover at the hill site, some markedly so (Table 1).

Table 1. Total legume dry matter yields of hay and aftermath cuts (expressed as percentage of control varieties) at lowland and hill sites, 1970

	Auchincruive site (means of 4 replicates)	Hill site A (means of 5 replicates)	
Clovers			
Essex red clover	100 (153.9)*	100 (49.4)*	139
S.100 white clover	-	72	100 (31.0)*
S.184 wild white clover	-	63	87
Marsh trefoil ecotypes			
Chile 1 (4) **	-	102	142
Chile 2 (5)	110	112	156
Chile 3 (5)	130	138	192
Australia (3)	91	83	115
New Zealand (4)	97	103	144
Germany (4)	101	100	139
SACH (6)	114	98	137
DES (5)	87	102	142
FRIPO (6)	76	83	116
Jugoslavia (3)	77	97	135
BENE (2)	94	109	152
Great Britain (3)	87	116	161
Kyle (1)	102	78	108
S.E. of actual yield	± 13.55	± 3.48	

* Actual total dry matter yield per clump of control variety (g).

** The ecotypes are actually the author's composites of United States Department of Agriculture Plant Introduction ecotypes. The number in brackets indicates the number of ecotypes per composite. SACH is a composite of ecotypes from Switzerland, Austria, Czechoslovakia and Hungary; DES - from Denmark and Sweden; FRIPO - from France, Italy and Portugal; BENE - from Belgium and the Netherlands, and Kyle is an ecotype collected near Auchincruive.

A spaced-clump trial containing three New Zealand cultivars of *L. pedunculatus* along with the local Kyle ecotype and Essex broad red clover was planted out in spring 1970 at hill site A and was cut once during the growing season. The tetraploid variety Grasslands 4705 out-yielded red clover and Kyle, while the normal diploid varieties Grasslands 4703 and 4704 were superior to Kyle (Table 2).

Row trials. The New Zealand varieties, Kyle marsh trefoil and Essex broad red clover were also sown in row trials on both sites. An unusually prolonged spell of drought after seedling emergence affected establishment although the lowland trial recovered enough to allow two sample cuts.

Grasslands 4705 showed an increased vigour and leafiness over the normal diploid varieties and it equalled red clover in dry matter yield, both being more productive than the diploids Grasslands 4703 and 4704, and Kyle.

Table 2. Legume dry matter yields (g) at lowland and hill sites, 1970

	Row trial - Auchincruive			Clump trial - hill site A
	Cut 1	Cut 2	Total	Cut 1
Clover				
Essex red clover	20.1	38.6	58.6	12.5
Marsh trefoil				
Kyle	3.8	20.3	24.1	11.0
Grasslands 4703	7.0	33.3	40.3	26.3
Grasslands 4704	6.6	27.7	34.3	24.7
Grasslands 4705 (tetraploid)	21.5	49.8	71.3	31.5
S.E. means	± 4.69	±5.26	± 7.65	± 3.99

Sward trials. New Zealand S.335 marsh birdsfoot trefoil was compared with five *L. corniculatus* and three *Trifolium repens* varieties in a sward trial sown in August 1966 at hill site B on boggy acidic peat (pH 4.0). This site is 260 metres above sea level and receives approximately 1500 mm of rainfall annually.

Normal dressings of lime and basic slag were applied prior to sowing the inoculated seed at 10 kg/ha for the trefoils and 4 kg/ha for the clovers. The small seed samples prevented replication.

This unfenced trial was subjected to stocking rates of more than one ewe per hectare and after three seasons only S.335 marsh trefoil and S.100 white clover remained productive. Sample cuts were taken within grazing cages during the fourth year (Table 3). Dry matter yields of the marsh trefoil were considerably greater than those of S.100 white clover.

Table 3. Legume dry matter yields (kg/ha) during fourth season of set stocking at hill site B, 1970

Legume	Cut 1 (16.7.70)	Cut 2 (17.9.70)	Total yield
S.100 white clover	250	324	574
S.335 New Zealand marsh trefoil	1154	1028	2182

Discussion

The results from the *L. corniculatus* clump trial indicate that there may be a case for the use of this species as an alternative to white clover on the drier areas of Scotland's natural grassland. Indigenous types of this species are widespread in such areas of low grazing pressure and, provided that spring sowing is carried out, it would appear that the species' drought resistance might help it to contribute more than white clover.

Subsequent trial results suggest that *Lotus pedunculatus* has more immediate economic importance in Scotland. The results obtained so far are in line with findings under similar circumstances in other countries (6, 10). Production from marsh birdsfoot trefoil in the 1966 hill trial (Table 3) was so much greater than from S.100 white clover. The quality of the herbage, as judged by leafiness, appeared to be similar in both varieties.

Ellis-Davies (8) concluded that *Lotus* species appeared to be unable to recover from heavy grazing. Washko (9) found that in North America heavy continuous grazing will even kill off so-called pasture varieties of *L. corniculatus* such as Empire, yet the species continued to be developed successfully despite this feature, by using it under farming systems where the grazing pressure was relatively low or intermittent as opposed to continuous.

Seed rates for L. pedunculatus could be about the same as for white clover. In a New Zealand grazing trial (6) diploid marsh trefoil and white clover were both sown at 2.2 kg/ha while tetraploid marsh trefoil was sown at 4.4 kg/ha. Results show that all Lotus varieties were significantly better than white clover in both summer and winter herbage production.

In Canada, Bubar (7) used Russian material to develop the L. corniculatus variety Leo which has better winter hardiness than other North American varieties. The yields of Leo and the Russian Morshansk 528 in the second season of the clump trial did indicate their higher resistance to winter kill. The performance of S.335 marsh trefoil in the sward trial at site B suggests that winter hardiness will not be a problem in ecotypes from the temperate regions.

The conclusions drawn from the L. pedunculatus clump trials are of a preliminary nature covering only one season of growth and with no winter survival results. Despite this, the species has some attractive features. The general habit of growth suits the potential use of the species in the short dense natural sward. Leafiness does not seem to be associated with time of flowering, a feature to be assessed more closely next season. Flowering may have a marked effect on herbage quality although Canadian results (11) indicate that in-vitro digestibility of L. corniculatus is similar to that of clover.

A fairly wide range of Lotus material has been evaluated, as far as seed supplies permit, for agronomic use in the natural grasslands of Scotland. Preliminary results show promise for certain types and in certain locations so that use of Lotus and white clover may be complimentary, with the former for the poorer areas. This work, together with results from other countries, suggests that further assessment of these species should be carried out in Britain. Plans are in hand at this station to continue the studies and to widen the scope of investigations to include the animal factor where possible, and to assess herbage quality by in-vitro digestibility determinations.

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Appendix 6. Presentation of results

Mean values are presented in the body of the thesis as tables, together with the results of statistical examination by analyses of variance where relevant. Certain conventional statistical abbreviations are used as follows:-

Mean = mean value for specified characters.

Sign = levels of significance for the treatment differences

* or $P < 0.05$ = significance at 5% level

** or $P < 0.01$ = significance at 1% level

*** or $P < 0.001$ = significance at 0.1% level

NS = not significance at the 5% level.

SE± = Standard error of difference between means. This is given for the main treatment effects whether they are significant or not.

THE AGRICULTURAL VALUE OF BIRDSFOOT TREFOILS IN SCOTLAND

by

JOHN FREDERIC LIVINGSTONE CHARLTON

Ph.D. THESIS SUMMARY

The herbage legume is the cheapest actual and potential source of nitrogen and high protein herbage within the large area of natural grassland in Britain. A major economic improvement could be achieved by encouraging legumes to grow and spread in these regions. The development of birdsfoot trefoil and marsh birdsfoot trefoil as legumes for use on poor areas has taken place in many countries during recent years. Birdsfoot trefoil is distributed throughout the British Isles on well-drained poor soils whereas marsh birdsfoot trefoil is prevalent in wet acidic areas. A series of experiments was therefore carried out at the West of Scotland Agricultural College from 1966 onwards to determine the potential value of these species under British conditions.

Pot experiments with birdsfoot trefoil under glasshouse conditions indicated some trends in the species' competitive abilities when grown with major species of companion grass during the establishment phase. A range of ecotypes and cultivars of this species was evaluated in spaced-plant and spaced-clump experiments at the College; some promising material was recorded, notably genotypes of Russian origin and an ecotype of marsh birdsfoot trefoil. A sward experiment failed to show any promise for birdsfoot trefoil under a hay-cropping system in Stirlingshire but a series of upland sward experiments revealed some notable features concerning the management of birdsfoot trefoil in renovation

practices. The need for spring sowing after normal applications of lime and basic slag fertilisers was evident, as was a requirement for extra potash fertiliser under peaty conditions. In one experiment birdsfoot trefoil cultivars gradually disappeared under close-grazing treatments, whereas a New Zealand cultivar of marsh birdsfoot trefoil remained vigorous and considerably out-yielded white clover when samples were taken in the fourth year of growth.

Accordingly, a world-wide collection of marsh birdsfoot trefoil ecotypes was examined in spaced-clump experiments at lowland and upland sites from 1970 onwards. During the first season most ecotypes out-yielded white clover in flowering and aftermath cuts, material from Chile being outstanding in yield of dry matter. New Zealand cultivars, especially an induced tetraploid, showed considerable potential when compared with red clover in spaced-clump and row experiments.

Studies of herbage quality in the birdsfoot trefoils started in 1970 with an experiment comparing the two species with red and white clovers. Birdsfoot trefoil repeated its promising performance shown in foreign trials but wild British material of marsh birdsfoot trefoil was lower in digestibility than the other legumes. A further experiment including the New Zealand cultivars, along with two selections from North America, has been sown out to study the effects of selection and polyploidy on this feature.

These preliminary results suggest that Lotus species have potential value in the improvement of British natural grassland. Birdsfoot trefoil shows more promise on poor dry areas where its tolerance of drought conditions and self-seeding abilities place it at an advantage over white clover. Marsh birdsfoot trefoil is particularly suitable on the wet peat areas of upland pasture where white clover is not so productive; it can spread by rhizomes and by self-seeding, and appears to be able to withstand close grazing, providing protein essential to improve the diet of livestock grazing on such pasture. Both trefoils might be used in mosaic improvement of rough pasture where their natural re-seeding capabilities could be exploited to best advantage.