

THE POTENTIAL OF *LUPINUS ANGUSTIFOLIUS*
CV. UNIHARVEST, IN CANTERBURY,
AS A SUMMER GREENFEED FOR LAMBS

A thesis
submitted in partial fulfilment
of the requirements for the degree
of
Master of Agricultural Science
in the
University of Canterbury

by

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Lincoln College

1981

Abstract of a thesis
submitted in partial fulfilment of the requirements
for the Degree of M.Agr.Sc.

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Two trials using *Lupinus angustifolius* cv. Uniharvest were conducted in the summer of 1978-1979 at Lincoln College, Canterbury.

From the first trial, designed to measure dry matter accumulation and changing nutritive value of lupins with time, a maximum dry matter yield of just under 990 kg ha⁻¹ was obtained 150 days after sowing. Peak digestibility was 65.0 per cent and was recorded at 125 days after sowing. Protein concentration was highest in the young plant (28.75 per cent at 45 days after sowing) and declined after this, but highest total nitrogen yield coincided with peak dry matter accumulation.

In the second trial, lupins at 60 and 100 plants m⁻² were grazed with weaned lambs at each of four successive stages of the plants' growth - pre-flower, primary flower, secondary flower and green pod (post-flower). Highest dry matter accumulation, at just under 1 000 g m⁻², occurred at the green pod

stage, and peak protein concentration of 23.7 per cent at the pre-flower stage (lower density). Digestibility was highest at the pre-flower stage (higher density) and the metabolizable energy concentration was also highest in the pre-flower high density plots.

Regrowth of lupins following grazing occurred in plots which had been grazed at the pre- and primary flower stage. Maximum total dry matter accumulation from the first grazing combined with the regrowth was $1\ 350\ \text{g m}^{-2}$. Digestibility, protein and metabolizable energy concentration of the regrowth was at acceptable levels for animal growth.

From the results obtained, and those of other workers, both in New Zealand and overseas, it is suggested that lupins may have considerable potential as a high quality summer forage crop for grazing of young lambs.

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INTRODUCTION

Lupins have been grown over many centuries for a variety of reasons, but their use as a forage has been somewhat limited. Grazing of the bitter cultivars was practised on a small scale in several countries including New Zealand, but when sweet (low alkaloid) cultivars became available in the mid 1930's, interest was increased. Various problems have since limited their widespread acceptance as a forage crop.

In the first part of Chapter One, the history of lupins as a forage crop in several areas of the world (Europe, North America, South Africa, Australia and New Zealand) is considered, and the yield and nutritive value of the four main species (*Lupinus albus*, *L. angustifolius*, *L. cosentinii* and *L. luteus*) that have been used, together with the problems associated with their use as a forage, are reviewed.

The second part of Chapter One reviews briefly the methods used for chemical analysis and both *in vivo* and *in vitro* evaluation of forage quality, in terms of their accuracy and practicability.

In New Zealand, lupins were grown in the 1930's and 1940's as a summer feed for lamb fattening, but serious problems with both bitter and sweet cultivars, together with the increasing importance of other greenfeeds, especially lucerne, led to their decline. Most recent interest has been in lupins as a seed crop, but with diseases and pests becoming more of a problem in lucerne, the possibility of an annual legume, such as lupins, being used as a sheep feed, has once again been raised. Preliminary work at Lincoln College (Clarke, unpub.) suggested

that as well as having a high protein concentration, lupin forage is highly digestible, and other trials (Herbert, 1977a) have demonstrated that high dry matter yields are also obtainable.

Two trials conducted at Lincoln College in the summer of 1978-79 are described in Chapters Two and Three. The first of these was designed to measure dry matter accumulation and changing nutritive value, in terms of nitrogen (and protein) concentration, digestibility and energy value, in a lupin crop throughout its life. The second was a grazing trial, in which a lupin crop was grazed by weaned lambs at four alternative stages of growth, in an attempt to determine the stage at which it would be best grazed, from a quality aspect, and the level of utilization to be aimed at to make most economic use of the crop.

As regrowth occurred after grazing, in some treatments in Experiment 3, further investigations were carried out, and these results and their effect on the potential use of the crop are discussed in Chapter Four.

Chapter Five summarizes the findings of the two trials, and attempts to define the potential of this crop as a lamb fattening feed for Canterbury conditions.

CHAPTER ONE

REVIEW OF THE LITERATURE

1.1 LUPINS AS A FORAGE CROP

1.1.1 Introduction

The genus *Lupinus* has been grown for centuries in many parts of the world as a source of food for both humans and animals (Heiser, 1973, cited by Hudson *et al.*, 1976). Zhukovsky (1929, cited by Gladstones, 1970d) stated that the seeds of *Lupinus albus* (syn. *L. termis*) were found by Schiaparelli in 1868 in the Egyptian tombs of the 12th Dynasty (about 2000 B.C.). Although there is some doubt about the genus being present in Egypt at that time (Hanelt, 1960, cited by Gladstones, 1976), it seems certain that lupins were well established in Europe in classical Greek and Roman times (Gladstones, 1970d; Hudson *et al.*, 1976) and were used by the Romans as a green manuring crop for improving soils (van Vuuren, 1962; Anon., 1972).

Green manuring seems to have been one of the more common uses of the plant (Henson and Stephens, 1964), although types of the Mediterranean white lupin, *L. albus*, were partially developed and used as a subsistence crop in Europe. Likewise, the Pearl lupin, *L. mutabilis*, has been grown for many centuries in the Andean Highlands of South America (Gladstones, 1975a). However, forage lupins occupy the unique position of being the only crop developed for agricultural

purposes during the early part of the twentieth century (Edwardson and Corbett, 1959). One of the major problems with the plant, from a fodder point of view, was the high alkaloid content, making the herbage both unpalatable and, in many cases, poisonous to stock (Gladstones, 1969a, 1970d).

Seed shattering and hard seededness were also barriers to general acceptance of the crop (Gladstones, 1967a, 1969a, b, 1970e), although this has not been a problem in either *L. albus* (Gladstones, 1967c, 1975a) or *L. mutabilis*, both of which have had the non-shattering characteristic for some long time (Gladstones, 1967c).

It was realized by plant breeders that if the alkaloid content could be decreased, seed shattering eliminated and hard seededness reduced, the plant, with its high protein content, could have potential as a forage crop (Claridge, 1972).

Modern breeding of lupins as a grain and forage crop began in the early 1920's when von Sengbusch (1938), believing that alkaloid-free forms of the plant could be found, began working on a technique for detection of alkaloid-deficient forms. It was not until the late 1920's that the first low alkaloid, or sweet, plants of *L. angustifolius* and *L. luteus* were isolated, after the study of millions of individual plants (von Sengbush, 1938). At about the same time, von Sengbush succeeded in selecting individuals with soft seed coats in both the above species. Selection for non-shattering was begun in 1929 but it was not until 10 million plants later, in the mid 1930's, that a non-shattering strain was found, having an abnormal structure of the pod suture (von Sengbush, 1938). The combination of these three features

into one cultivar then had to be attempted. Much of this recent breeding work has been completed in Australia (Gladstones, 1967a, b, 1969a, 1970e, 1975a).

1.1.2 *Description of Species and Cultural Requirements*

In general, lupins are cool tolerant legumes which grow well at medium temperatures (15-25°C) under good soil moisture levels, and are noted for their ability to thrive on coarse textured soils of low fertility (Gladstones *et al.*, 1964). Cultivated lupins are all plants of light textured and relatively infertile soils, but consistent differences among species have been shown (Rahman and Gladstones, 1974), *L. angustifolius* and *L. albus* having higher phosphate requirements than many of the other species. Lupins generally require a pH of between 5.4 and 7.5 (Reeves, undated). One of the factors restricting the use of lupins appears to be sensitivity to poor soil aeration and to waterlogged soil (Sim, 1958; van Vuuren, 1964), and Broué *et al.*, (1976) showed that flooding reduced relative growth rate and that susceptibility of lupin plants increased with age. Except at flowering, *L. angustifolius* (more particularly cv. Uniwhite) is probably the most tolerant species to frost conditions (Gladstones, 1974).

Like other leguminous plants, lupins can obtain their nitrogen requirement through symbiotic association with nitrogen-fixing bacteria (Rhodes, 1976). Rhizobia levels in soils that have not grown lupins or a similar legume, seradella, are likely to be low, and inoculation of seeds is recommended (Gladstones, 1969b; Shipton and Parker, 1966, 1967). Rhodes

(1976) obtained good responses to inoculation under New Zealand conditions.

There are very many species of lupin. Edwardson and Corbett (1959) stated that there are 300 or thereabouts and van Vuuren (1962) estimated that there are approximately 550 main species subdivided into 12 000 cultivars or varieties. However, to date, there have been only four annuals used to any great extent that show potential as green fodder crops, *L. angustifolius*, *L. albus*, *L. cosentinii* and *L. luteus*.

An erect plant, with profuse lateral branching, when sown at low populations, *L. angustifolius* has dark green foliage, narrow leaves (Gladstones, 1969a), blue or white flowers and small grey and brown seeds (Gladstones, 1974). The older bitter cultivars, such as New Zealand Bitter Blue, and many of the earlier sweet cultivars, such as Borre, have blue flowers (Gladstones, 1974), but the newer sweet cultivars carry marker genes for white flowers, such as cv. Blanco (Edwardson and Corbett, 1959). The sweet non-shattering cultivars, Uniwhite, Uniharvest and Unicrop, also have white flowers (Gladstones, 1974).

Lupinus luteus, or yellow lupin, is a smaller plant than *L. angustifolius*, but is also erect with vigorous basal branching (Gladstones, 1974). As work with this species has concentrated on seed production, most forage cultivars are still bitter, although its later flowering tendency could make it suitable as a forage crop (Gladstones, 1974).

The main species used in Northern America is *L. albus*, a plant with dark green foliage and white flowers (Gladstones, 1974). Several sweet cultivars of this species

exist (Offutt and Davis, 1973; Davis and Offutt, 1975).

Lupinus cosentinii, also known as the sandplain lupin, is an important fodder species in Western Australia (Gladstones, 1974). Hard seededness is a feature of this species, allowing regeneration of stands year after year. This species requires mild to warm growing conditions and is very sensitive to frost (Gladstones, 1959, 1969b).

1.1.3 *History of Lupins as a Forage*

Europe and Northern Africa

In the late eighteenth century, attempts to expand lupin growing in Europe by King Frederick of Prussia were unsuccessful, due to the late maturity of the plant and general unsuitability of the soils (Gladstones, 1970d). Scattered cultivation persisted in Germany during the next 60 years (Gladstones, 1970d), and Hanelt (1960, cited by Gladstones, 1970d) cited evidence that *L. angustifolius* was used as a cattle fodder around Bordeaux before 1820. By the late 1860's, the cultivation of bitter yellow lupins (*L. luteus*) had spread widely on the acid, sandy soils of the Baltic coastal plain, becoming an important basis for the Merino wool industry of Saxony (Gladstones, 1970d, 1975a). Outbreaks of a disease known as lupinosis during the 1860's and 1870's resulted in a sharp decrease in the growing of lupins for sheep feed. A decline in the Saxony wool industry, together with the increasing availability of nitrogen fertilizer, further reduced the area under lupins in the early part of this century (Gladstones, 1970a), although the plant was still widely used for green manuring on the Baltic coastal plain (Gladstones, 1975a). A resurgence of interest in the

crop occurred following the breeding in Germany of sweet lines (Gladstones, 1975a).

Sweet lupins were first grown in Sweden in 1935 (Winkler, 1943) and the suitability of this crop as a fodder in that country was determined by Winkler (1946). One of the major problems with lupin growing in Sweden was the problem of obtaining reasonable seed yields (Tedin and Josefsson, 1946). An attempt to introduce a variety that began growth earlier in the season, and so matured earlier (Tedin and Josefsson, 1946), did not appear to be successful. Gladstones (1970d) attributes the unreliable ripening of seed in Sweden to the humid climate of the region.

The importance of yellow lupins, *L. luteus*, as a crop in Southern Portugal was emphasized by the fact that at one stage they were being used four times in a nine year rotation, twice as greenfeed and twice as a seed crop (Silva and de Olivera, 1958). The crop was used for fodder, grazed green or as a dry standing crop, cut for silage, or as a stubble after harvest of the seed (Silva and de Olivera, 1958).

Russian work reported (Mironenko and Zaben'kova, 1968; Proskura et al., 1969; Strelkov et al., 1969; Mironenko and Rugul'chenko, 1972; Kolosova, 1974; Mironenko, 1974; Rulinskaya, 1974; Yukhimchuk, 1974; Mironenko et al., 1975) indicates that lupins may be used to some extent as a green fodder in that country. In Hungary, the practice of feeding *L. luteus* to dairy cows, either as a green fodder mixed with a low protein feed, or as silage, has been shown to increase milk yield by as much as eight per cent (Papp, 1968). Experimental and limited commercial cultivation has been reported from the Netherlands, and to some extent on the sandy

and acid soils of Denmark (Hackbarth, 1964, cited by Gladstones, 1970d), and Hudson *et al.* (1976) report that *L. nootkatensis* is grown as a forage crop as far north as the northern coast of Iceland. Reports of experimental work on fodder lupins indicates interest in their potential use in several other European countries: Poland (Jaśkowski, 1970; Kubok and Majewski, 1972; Jasińska and Dmowski, 1973; Nowacka and Nowacki, 1975), Czechoslovakia (Wagner, 1969), Western Spain (Fuentes, 1974) and Bulgaria (Ivanov, 1974, 1975).

Lupins (*L. angustifolius*) were grown in England and used as a sheep feed and for soil improvement as early as the late 1850's (Oldershaw, 1920). After the First World War, attention was drawn to the value of this crop grown on poor light land and used as above, or harvested for seed (Oldershaw, 1920). Stock took some time to adjust to this bitter feed, and sweet lupins, when introduced, were much more successful (Oldershaw, 1944). The crop did not become widely used, however; few farmers outside Suffolk grew lupins, and in more recent years the emphasis has been on seed production (Lees, 1975; Masefield, 1975, 1976), although Lees (1975) reported that some farmers in Surrey were cutting yellow lupins, *L. luteus*, for silage.

Northern America

Although lupins had been grown in Europe for many years, the first successful planting in America of Bitter Blue lupins (*L. angustifolius*) was in 1930 at the Florida Agricultural Experimental Station at Gainesville (Glasscock *et al.*, 1950). During the 1940's, this species was grown for green manure, as a late winter cattle forage, and to some extent as a

sheep feed, in the south eastern coastal region and in the Gulf states (Henson and Stephens, 1960; Gladstones, 1970d). The crop's main use for grazing was in the winter months when there could be an extreme scarcity of feed (Glasscock *et al.*, 1950). Problems were encountered with the bitter cultivars, and Edwardson *et al.* (1963) observed that animals were slow to graze a stand of lupins containing ten per cent or more bitter plants. Frosts, and viral and fungal diseases, have limited the cultivation of *L. angustifolius* in the mild damp conditions of the South Eastern states, but the release of new improved cultivars could see this species again increase in popularity (Gladstones, 1970d).

A little further north, in Arkansas and the more inland states, white lupins, *L. albus*, have been tried with success and much work has been done with both bitter and sweet cultivars (Offutt, 1969, 1971; Davis, 1973; Offutt and Davis, 1973; Davis and Offutt, 1975).

South Africa

Lupins have been cultivated in South Africa since the turn of the century, although this was on a very limited scale at first (van Vuuren, 1962). Bitter *L. angustifolius* was grown mainly as a green manure in orchards and vineyards (Henning, 1949; van Vuuren, 1962) and also became important as a soil fertility builder in crop rotations with wheat (Flight, 1956). In the mid 1930's, some farmers were using the bitter lupins as a sheep feed (van Vuuren, 1962) and by the mid 1940's the crop was used to some extent for this purpose in the Cape Province (Henning, 1949; Swart and Liebenberg, 1954). The value of the crop as a green manure had been recognised and the use of lupins in cropping rotations was

increasing rapidly (van Vuuren, 1962). Flight (1956) noted that sheep thrived and did exceptionally well on the crop, and in the Swartland (within the winter rainfall area), it became the practice to graze sheep on the dry lupin lands from November until late summer rains caused young green lupin forage to be available (Flight, 1956). Sweet lupins replaced bitter cultivars in many vineyards, to be used as sheep fodder (Marais, 1957). In more recent times, *L. luteus*, *L. angustifolius* and *L. albus* have all been grown in the Cape Province for seed production, with some stubble grazing, but also for grazing as a mature standing crop in the late summer (Gladstones, 1970d).

Many workers have shown that good forage yields are obtainable and that the crop is suitable for most regions of South Africa (Marais, 1957; Nel, 1961, 1965; van Zyl, 1967, 1973; Straatman *et al.*, 1972; Lees, 1975). Lupin silage, and to a lesser extent lupin hay, is used by many farmers for sheep, cattle and dairy cows (Henning, 1949; Vosloo *et al.*, 1963; van Zyl, 1967, 1973; Straatman *et al.*, 1972). Lupin seed is a useful supplement when mixed with maize or chaff for sheep (van Niekerk and Louw, 1959; Dippenaar and Cronje, 1961).

Australia

Lupins were probably introduced into Australia in the early or mid nineteenth century for flour milling (Gladstones, 1969a; Anon., 1972). The plant became naturalized along the west coast, being regarded as a weed until it was discovered that sheep would eat it readily (Thomas, 1924; Gardner and Elliot, 1929). Farmers recognized its value for grazing as early as 1894 (Gladstones, 1969a), and since 1910 the plant has

been cultivated on the west coast and adjacent inland areas as a self re-generating crop for both winter greenfeed and soil improvement (Thomas, 1924; Gardner and Elliot, 1929; Quinlivan, 1958; Gladstones, 1967c, 1969b). Paddocks of lupins were a valuable asset to farmers for fattening stock in a dry spell (Gardner and Elliot, 1929). One of the major limitations on animal production in Western Australia is the low quality of dry pasture in the summer months, and the use of lupins as a dry standing feed has grown (Hill and Arnold, 1975).

In general, lupins were well adapted to the medium to light soils of Western Australia (Thomas, 1924; Gladstones, 1970e, 1975b) but *L. cosentinii*, in particular, did well on the poorer soils as a result of its superior ability to take up phosphate (Gladstones, 1970e; Rahman and Gladstones, 1974). A very high level of hard seededness in this species is a protection mechanism against germination of seed in light summer rainfall, allowing survival and regeneration of the stands from year to year (Quinlivan, 1962). Traditionally, bitter lupins have been used in Western Australia for summer grazing, with the stock eating the fallen leaves, pods, smaller twigs, and, to some extent (although apparently very inconsistently), the fallen seed (Gladstones, 1970b). In recent years, sweet lupins have been used with much success (Gladstones, 1970b). *Lupinus angustifolius* cv. Uniwhite was released in the state in 1967, Uniharvest in 1971 and Unicrop in 1973 (Hove, 1974). Not much use has been made of the crop outside Western Australia, although bitter cultivars of *L. angustifolius* have been grown to a small degree, both as a green manure and for grazing, in Tasmania since the early part of the century

(Garside, 1975). In the southern part of Western Australia, there was much interest in the 1940's and 1950's in the planting of lupins on newly cleared land as a grazing crop, but outbreaks of lupinosis led to a rapid decline in this practice (Gladstones, 1969a). One farmer in the 1940's found that growing lupins with oats was an excellent means of bracken control. The paddock was stocked until the lupins came into flower and was then shut up, allowing the lupins to smother the bracken. A good lupin seed yield was obtained and there was summer grazing for sheep available (Snook, 1948).

Today, the more common use for lupin crops is for grain; in 1975 more than 100 000 ha was sown in sweet *L. angustifolius* for grain production in Western Australia (Allen and Wood 1977), but, whether or not they are grown primarily for this purpose, the grazing of standing crops and harvested stubbles will continue to be an important use (Gladstones, 1970b; Allen *et al.*, 1978b). Grazing of the stubble forms a significant part of the economics of grain lupin growing (Gladstones, 1970b, e), and there is little doubt that the stubbles of sweet lupins are greatly superior in grazing value to those of cereal crops (Gladstones, 1970b, e).

New Zealand

Lupins have been grown in New Zealand since the early 1900's (Withers, 1973a, 1975b). The Bitter Blue (*L. angustifolius*) was the most common species grown in the 1920's (Allen, 1949) and its main use was for green manuring, particularly in Canterbury, in an effort to remedy the nitrogen deficiency of the light land used for wheat growing, long before any attempt was made to explore its use as a forage crop

(Claridge, 1972).

Supplementary fodder crops were used extensively in New Zealand, especially in Canterbury, for both fattening store lambs and feeding adult stock (Allison and Thurston, 1952). The value of the lupin as a fodder crop seems to have arisen as a result of the difficulties experienced by mid-Canterbury farmers in the growing and feeding of the more traditional fodder crops, mainly rape and turnips (Adams and Garrett, 1940; Anon., 1942; Inch, 1947; Allen, 1949; Allison and Thurston, 1952; Greenall, 1958; White, 1961; Claridge, 1972).

In spite of its use being limited by its high alkaloid content (Allen, 1949), *L. angustifolius* gained in popularity and by the 1930's had become established as a forage crop for sheep on the Canterbury Plains (Hudson, 1934; McGillivray, 1934; Anon., 1938; Hamblyn, 1940; McPherson, 1940; Anon., 1942; White, 1961; Withers, 1973a, 1975b). The disadvantage of alkaloid poisoning and the fact that sheep did not eat the crop readily until forced to through hunger (Anon., 1938; Anon., 1942; Lancaster and Adams, 1943; White, 1961) was offset by the amount of feed produced, the reliability of the crop, its freedom from disease and insect pests and by its marked capacity to improve the soil (Anon., 1938; Anon., 1942). Although the crop was well adapted to the lighter, drier soils (McGillivray, 1934; Ayson, 1956), it was not restricted to these, doing well on a variety of soil types (Anon., 1938), but did not tolerate the heavier and wetter soils of Southland (Hudson, 1934), and was also tried without success on the pumice lands of the central North Island (Ayson, 1956). Lupins were either sown on their own in a pure stand

at a seeding rate of about 100 kg ha^{-1} for a summer crop (Anon., 1938), or more commonly in a mixture with other crops; rape (Hamblyn, 1940; Anon., 1942), new grass (Anon., 1938), or cereal greenfeeds (Hamblyn, 1940; McPherson, 1940; White, 1961).

Although the initial setback that was experienced when sheep were first introduced to a bitter crop was not serious in mature sheep, younger stock, especially lambs being fattened, were adversely affected. This was overcome to a certain extent by introducing lupins gradually into their diet, but Bitter Blue lupins were definitely not considered satisfactory for lamb fattening (Anon., 1942).

The original German sweet cultivar of *L. angustifolius* was introduced quite early into New Zealand (Anon., 1942; Black and Claridge, 1942; Inch, 1947), but was not acceptable because of its hard seededness (Greenall, 1958; Gladstones, 1970d), slow emergence and early growth, its low seed yield and consequent costliness of seed (Greenall, 1958), and its indistinguishability from bitter types (Gladstones, 1970d). The same situation arose with New Zealand Sweet Blue, which was expected to become a valuable alternative to rape for lamb fattening, but which did not become popular on account of erratic behaviour when grown under adverse conditions (van Stevenick, 1956).

Borre, the soft-seeded sweet blue cultivar of *L. angustifolius* introduced from Sweden in 1948 (van Stevenick, 1956), had few of the above problems, outyielded the other sweet cultivars (van Stevenick, 1956) and rape (Greenall, 1958), and was considered to be ideal as a summer greenfeed for lamb fattening in Canterbury (Allison and Thurston, 1952; Greenall,

1956; van Stevenick, 1956).

The area in lupins was at a peak of 4 000 ha in 1950 (Claridge, 1972; Stoker, 1974). About half of this would have been for greenfeed and half for seed, although many of the seed crops would have been lightly grazed before shutting up (Claridge, 1972; Stoker, 1974). Since the 1950's, interest in the crop has declined markedly (Greenall, 1958; White, 1961; Gladstones, 1970d; Claridge, 1972; Withers, 1973a). This was due to several reasons; as soil fertility was built up, the need for fertility-building crops was less (Claridge, 1972), development of better brassica crops (Withers, 1973a, 1975b), introduction of better varieties of grass and clover (Lees, 1975), more reliance on saved pasture and cereal greenfeeds (Whatman, 1959; White, 1961) for winter feed, and, most importantly, the rapid increase in the use of lucerne for lamb fattening and haymaking (Greenall, 1958; Whatman, 1959; White, 1961; Stoker, 1974; Lees, 1975).

A combination of factors has led to a revival in interest in lupins, but more as a seed crop (providing a protein source for pig and poultry rations) rather than as a forage (Withers, 1973b; Pearson and Carr, 1974). The present interest stems from the development by Gladstones of the three cultivars, Uniwhite, Uniharvest and Unicrop, which are semi or completely non-shattering (Withers, 1975b).

In some North Island areas, lupins have been grown as a winter forage between two maize crops, as they are resistant to the herbicides used in maize and also fix nitrogen (Withers, 1975b; Taylor and Hughes, 1976).

A further use for the Bitter Blue cultivar has been in stabilizing sand dunes prior to pine tree planting (Pearse, 1958; White, 1961).

1.1.4 *Yield, Digestibility and Nutritive Value of Lupins*

Lupinus albus

Offutt (1969) described trials carried out with winter hardy lines of *L. albus* at three different locations in Arkansas. Average yields (herbage cut at flowering) of between 2 893 and 5 125 kg D.M. ha⁻¹ were recorded. The percentage of leaf at flowering was between 50.1 per cent and 54.1 per cent, and nitrogen concentration ranged from 2.77 to 3.65 per cent. One of the cultivars, Hope, was released in 1970 after further trials comparing it with common white lupin (Offutt, 1971). Yields of the cultivar in this trial averaged 4 220 kg D.M. ha⁻¹ as opposed to the 2 910 kg D.M. ha⁻¹ of the common white lupin. However, Hope was a bitter cultivar and its main use was as a green manure rather than as a forage (Offutt, 1971).

In a series of papers, Davis (1973), Offutt and Davis (1973) and Davis and Offutt (1975) studied the nutritive value of a winter hardy sweet white lupin producing an abundance of spring feed, and compared it at three stages of growth with lucerne (*Medicago sativa*). Some of their results are summarised in Table 1.1. The dry matter content of *L. albus* decreased from 20.9 per cent at the pre-flower stage of 15.1 per cent after flowering (Davis, 1973; Offutt and Davis, 1973; Davis and Offutt, 1975). The crude protein varied little

Table 1.1: Nutritive value of sweet white lupin forage (*Lupinus albus*) compared with lucerne.

Species	Stage of growth	Dry Matter per cent	Crude Protein per cent	Crude Fibre per cent	<i>In vitro</i> digestibility
Lucerne	pre-flower	15.3	27.2	15.8	72.3
Lupin		20.9	16.3, 17.9	14.7	70.7, 77.3

Lucerne	early bud	19.7	20.8	25.0	66.0
Lupin	mid flower	15.9	18.0	19.0	74.0

Lucerne	seed formed	25.7	16.4	30.1	59.6
Lupin		15.1	17.5, 17.6	21.5	75.9

From: Davis (1973); Offutt and Davis (1973); Davis and Offutt (1975).

from 17.9 per cent (Davis, 1973) or 16.3 per cent (Offutt and Davis, 1973) before flowering to 18.0 per cent at the mid-flower stage and 17.5 per cent (Davis, 1973) or 17.6 per cent (Offutt and Davis, 1973; Davis and Offutt, 1975) by the seed formation stage. The percentage crude protein in the leaf component increased slightly from pre- to post-flowering and this corresponded to a slight decrease in stem crude protein (Davis and Offutt, 1975) (Table 1.2). On a dry matter basis, the leaf to stem ratio was higher in lupin than in lucerne at each growth stage (Davis, 1973). Crude fibre levels increased with age in both species; from 15.8 per cent (Offutt and Davis, 1973) or 16.2 per cent (Davis, 1973) to 21.5 per cent (Davis, 1973; Offutt and Davis, 1973) in lupins. Lupin leaf fibre fell slightly, whereas stem fibre increased markedly over the period (Davis and Offutt, 1975). *In vitro* digestibility decreased with age in lucerne, but this was not the case in *L. albus* where digestibility increased from 70.7 per cent at the pre-flower stage to 74.0 per cent at medium flower and 75.9 per cent at seed formation (Offutt and Davis, 1973). Davis and Offutt (1975) modified this to some extent by quoting 77.3 per cent at pre-flowering (Table 1.2), and gave the digestibility of the pods to be 90.0 per cent at post flowering, which accounts for the overall increase in digestibility with time. The change in proportion of the plant components was also determined by Davis and Offutt (1975) (Table 1.3). The proportion of leaf was 79.9 per cent at pre-flowering and fell slowly until medium flowering (62.5 per cent) and then dropped rapidly to 31.1 per cent at post-flowering. The proportion of stem increased from 24.1 per cent to 37.5 per cent and then decreased to 29.5 per cent as the pods formed.

Table 1.2: Crude protein, crude fibre and *in vitro* digestibilities of *Lupinus albus* whole plant, and plant components.

	Whole Plant	Plant Components		
		Leaf	Stem	Pods
Crude protein				
pre-flower	17.9 %	20.5 %	9.4 %	-
medium flower	18.0	23.7	8.8	-
post-flower	17.6	26.2	8.2	17.7%

Crude fibre				
pre-flower	16.2%	13.0%	24.3%	-
medium flower	19.0	11.9	32.4	-
post-flower	21.5	10.9	40.5	15.2%

<i>In vitro</i> digestibility				
pre-flower	77.3%	75.7%	72.8%	-
medium flower	74.0	75.3	67.8	-
post-flower	75.9	75.6	51.8	90.0%

From: Davis and Offutt (1975)

Table 1.3: Distribution of total dry matter, crude protein
and crude fibre in *Lupinus albus*.

	Plant Component		
	Leaf	Stem	Pod
Dry matter per cent			
pre-flower	79.9	24.1	-
medium flower	62.5	37.5	-
post-flower	31.1	29.5	39.4

Crude protein per cent			
pre-flower	87.4	12.6	-
medium flower	81.8	18.2	-
post-flower	46.3	13.8	39.9

Crude fibre per cent			
pre-flower	62.8	37.2	-
medium flower	38.0	62.0	-
post-flower	15.8	56.0	28.2

From: Davis and Offutt (1975).

The proportion of total crude protein and crude fibre in the leaves dropped as the proportion of leaf dropped. Total stem crude protein followed the stem dry matter trend and total stem crude fibre increased with the proportion stem crude protein and stem dry matter, but decreased as the pods formed.

A green matter yield from this species of over 45 tonnes ha⁻¹ has been reported in one South African experiment (Lees, 1975).

Lupinus luteus

Lupinus luteus has been the species grown the most successfully in many European countries. Winkler (1946) reported that in Sweden, even in dry localities, green forage yield was rarely less than 28 to 34 tonnes ha⁻¹ and up to 45 to 56 tonnes ha⁻¹ under favourable conditions of soil, fertility and rainfall. In Hungary, green matter yields of up to 15 000 kg ha⁻¹ can be expected in a first crop or 9 000 kg ha⁻¹ in a second crop (Papp, 1968). Lees (1975) reported yields of 21 to 28 tonnes of green matter ha⁻¹ in Surrey, England, and in one early trial a yield of 6.17 tonnes dry matter ha⁻¹ was recorded (Lees, 1976).

In Russian work, fresh fodder yields ranged from 39.7 to 55.2 tonnes ha⁻¹ with increasing plant density from 44 to 250 plants m⁻² (Mordashev and Mordasheva, 1971). Application of a wide range of major and trace elements on the poorer Russian soils have been found to influence the yield of yellow lupins (Tishchenko *et al.*, 1969; Zhurkov and Zhukova, 1969; Komarov, 1970, 1972; Proskura *et al.*, 1971; Klintsare, 1972; Mikhaïlets', 1972; Mironenko and Zabolotnyi, 1974; Mordashev and Bermicheva, 1974; Naïmark and Brantsevich, 1974).

Mironenko and Zaben'kova (1968) observed that total and protein nitrogen in the leaves of the lupin plant decreased during growth, but the amount of essential amino acids in the whole plant was found to be highest at various stages of pod maturity (Strelkov *et al.*, 1969). Mironenko and Rugal'chenko (1972) found that protein levels were highest in leaves at the bud formation stage and in the seeds at maturity.

Edwardson and Corbett (1959) compared *L. luteus* forage yields in the south-eastern United States (information from various research station sources) with those obtained in Germany (Hackbarth and Troll, 1956, cited by Edwardson and Corbett, 1959). Dry matter yields ranged from 4 150 to 5 040 kg ha⁻¹ in Germany and were between 2 350 and 4 710 kg ha⁻¹ in Florida and Georgia. These compared favourably with sweet blue lupins in Germany but there was no great difference between the yields of *L. luteus* and *L. angustifolius* cv. Borre in the United States.

Yellow lupins in New Zealand have been much less successful than *L. angustifolius* cultivars (Gladstones, 1970d). Although wether hoggets fed *ad lib.* on *L. luteus* gained 2.81 kg in 23 days, a much higher growth rate than on other species grown (Anon., 1942), forage yields were so poor that research on this species was discontinued. Poor yields from *L. luteus* were confirmed by Black and Claridge (1942), who suggested that it might be better suited to North Island conditions, and Oldershaw (1944, 1951) who stated that under Canterbury conditions yellow lupins did not do well enough to justify their use.

Stubbles and Dry Standing Crops of

L. cosentinii and *L. angustifolius*

Carbon *et al.* (1972) outlined three ways in which a dry lupin stand could be utilized for grazing:

- . Harvest the seed and graze the stubble.
- . Graze the whole standing crop.
- . Harvest the seed, and graze the stubble, feeding back the seed at the same time.

Residues from lupin crops in Western Australia are normally between 3.75 and 7.5 tonnes ha⁻¹ (Gladstones, 1970b, e) and may be as high as 10 tonnes ha⁻¹ (Gladstones, 1970b). The average grazing value of the material from the higher yielding stubbles is likely to be lower than with lighter crops, as much of the extra weight is in the form of coarse stem (Gladstones, 1970b). Overall, lupin stubbles have greater feeding value than cereal stubbles, and are probably comparable with residues of a good legume based pasture; protein contents in all non-seed components of mature lupins are high compared to cereal stubbles and mature grasses, and are similar to those of mature subterranean clover (Gladstones, 1970d). Mulholland *et al.* (1976) reported a *L. angustifolius* stubble yield of 3 510 kg ha⁻¹; however, this had a digestibility of only 30 per cent.

Lupin stubbles on their own do have some disadvantages. They are known to be low in both Vitamin E (Gardiner, 1967b) and selenium (Masters, unpub., cited by Allen *et al.*, 1977), and there has been an increase in the number of reported cases of ovine weaner white muscle disease (W.M.D.) involving weaners grazing lupin stubbles. In 1975, in Western Australia, almost 75 per cent of all affected weaners were

grazing lupins (Allen *et al.*, 1977).

Early work (Gladstones, 1959) suggested that, although both *L. angustifolius* and *L. luteus* contained 15.0 to 16.0 per cent crude protein in the whole tops between full flowering and the seed formation stage, and that there appeared to be little fall in crude protein concentration with increasing maturity, *L. luteus* would be more suitable for dry grazing than *L. angustifolius* on account of the woodiness of *L. angustifolius* at this stage. However, Gladstones (1970b) reported that although the crude fibre level of the stems was high, that of the pods and leaves (including petioles) was relatively low, with quite high levels of extractable carbohydrates. Sheep appeared to consume all parts of mature *L. angustifolius* (Gladstones, 1970b).

In many cases where lupins are used as a dry standing feed, regeneration of the crop from year to year is desirable and cheaper than annual sowing (Arnold *et al.*, 1975). Gladstones (1969b) outlined the recommended grazing management of *L. cosentinii* with this purpose in mind. Germination of the seed occurs in early winter and stock should not be grazed on the crop at this stage. A light grazing in late winter or early spring could be carried out, as the sheep generally avoid the bitter plants once they have passed the seedling stage, and concentrate on the volunteer grasses in the stand. Much heavier grazing can be started as soon as the lupins are ripe. The crop should be grazed as heavily as possible during the summer, as late summer or early autumn rains may mean that the crop has to be spelled because of the danger of lupinosis (see Section 1.1.7). Stock should be removed in the autumn, and, depending on the seedling density,

should not be replaced until plants are reasonably well grown in mid winter. Controlled grazing may be carried out in the autumn or early winter if seedlings are too dense. Set stocking may become possible in the later years of a stand, except where there is a danger of lupinosis. Stands may have to be mown if they become impenetrable to stock. With proper management, Uniwhite (*L. angustifolius*) gives good regeneration, although the soft seededness of this cultivar may lead to premature germination following summer rains (Gladstones, 1967b). However, Arnold *et al.* (1975) found that the sweet cultivars of *L. angustifolius* could not be maintained as pure stands, as the seed was eaten by stock, regeneration was poor and heavy ingressions of grass occurred.

Because of the danger of lupinosis, together with difficulties in grazing management, it is important that lupins do not occupy too great a proportion of the total farm area (Gladstones, 1969b). Trials on a farmlet scale (Anon., 1972) indicated that the highest wool growth and the best weaner growth rates were obtained on a farm with 20.0 per cent of its area in lupins, grazed for 30.0 per cent of the year.

The use of lupins in a pastoral system for weaner sheep was evaluated by Arnold *et al.* (1975) in three experiments conducted over several years. Yields of up to 9 760 kg D.M. ha⁻¹ were obtained on soils which normally produced pasture yields of 3 000 to 4 000 kg D.M. ha⁻¹. Lupin grain accounted for 20.0 per cent of this yield. The nitrogen concentration of the plant components at the mature dry stage was:

- . Stem 0.7 to 1.4 per cent,
- . Leaf 1.6 to 2.6 per cent,
- . Pod 0.6 to 2.2 per cent,
- . Seed 5.0 to 5.6 per cent.

Liveweight gains in sheep over most years of the trial indicated that lambs could be finished on lupins. A farmlet with 20.0 per cent lupins gave better summer growth rates of sheep and better wool weights than farmlets with vetch or pasture but, over the whole year, wool weights and final liveweights were similar on all farmlets. These workers concluded that, for better wool growth, lupins were better fed in late summer; however, best weight gains were obtained from lupins fed in early summer.

An increase in lambing of 16.0 per cent over ewes on other feeds was obtained by Arnold and Charlick (1976) from ewes grazing mature, unharvested lupins in late summer. This increase was the result of both an increased ovulation rate giving more twin births, and a decrease in the number of barren ewes.

The intake of the seed component of the crop was shown to be significant in liveweight gains in all classes of stock, and in wool growth in sheep (Carbon *et al.*, 1972) but although sheep were able to eat seed from mature, unharvested lupin stands, cattle were able to utilize only 50 per cent of the seed consumed by sheep. Cattle cannot eat the seed off the ground (Henning, 1949; Gladstones, 1970b), but the newer non-shattering cultivars should make the seed more accessible (Gladstones, 1970b). Harvesting the seed, and feeding it back to both sheep and cattle, either grazing the lupin stubble or on non-lupin diets, has been investigated by many workers.

Gladstones (1970a) gives the crude protein concentration of the seeds of *L. angustifolius* as 34.0 per cent with a range over several species of 33.0 to 44.0 per cent, on a dry matter basis. This protein has a digestibility of 88.0 to 89.0 per cent (Hackbarth and Husfeld, 1939, cited by Gladstones, 1970a). Lysine levels are quite adequate (Gladstones, 1970e) but the seeds are very low in methionine (Gladstones, 1970a, e; Hill, 1977). The good digestibility of lupin seed, together with an appreciable and digestible oil content, is reflected in the high energy level of the seeds, which is equal to that of most cereals and higher than for most alternative protein sources (Anon., undated). Excellent results have been obtained by feeding the seed to sheep, cattle and horses. Lupin seed fed to fat lambs results in particularly good carcass formation with a high muscle to fat ratio (Anon., undated).

Carbon *et al.* (1972) showed that cattle fed on a standing unharvested crop did as well as cattle fed on harvested stubble and bin-fed grain for the first month, but after that only maintained weight, while those on stubble and bin-fed grain gained weight at 0.9 kg per head per day throughout the trial.

Lightfoot and Marshall (1974) suggested that low ovulation was one of the major factors limiting flock lambing percentage in Western Australia. Lupin grain supplements of 0.25 to 0.5 kg per head per day increased ovulation rates. Ewes that were grazed on a subterranean clover-based pasture and received supplements of 0.5 kg per head per day starting 14 or 35 days before joining, had an ovulation rate of 1.48, compared to that of sheep on the subterranean clover pasture only, which had a rate of 1.24 (Marshall and Lightfoot, 1974).

Those grazed on a lupin stubble (unharvested) had an ovulation rate of 1.5. Similar results were recorded by Kenney (1975), Knight *et al.* (1975), Brien *et al.* (1976), Lightfoot *et al.* (1976) and Brien *et al.* (1977).

In one trial (Arnold and Charlick, 1976) ewes fed lupin grain in late pregnancy and early lactation had heavier lambs that grew faster initially, but had the same weaning weights as lambs from ewes fed on pasture only. However, in two trials conducted by Arnold *et al.* (1977), birth-weights were unaffected by lupin supplementation of the mothers supplemented for four weeks prior to, and post lambing, but ewe milk production, lamb growth rate, and consequent weaning weight were all increased; at the highest rate of ewe supplementation (600 g day^{-1}) lambs were 3 kg heavier at weaning than lambs of unsupplemented ewes.

Comparison of lupin crops with peas and vetches was undertaken in a field situation by Arnold *et al.* (1976a) and in pen-fed trials by Arnold and Wallace (1977). Wether weaners gained more weight and grew more wool when grazed on lupins under all conditions of feeding (unharvested crop, stubble, stubble and three levels of grain supplementation) than when grazed on peas or vetches. Crossbred lambs gained a similar amount of weight while grazing on unharvested standing lupins and peas, but considerably less on vetches. In the pen-feeding trial, comparing the nutritive value of the three crops without the complication of selective grazing, results were similar to the field trial, but overall differences between the feeds were a lot smaller.

Crocker et al. (1979b) found that at relatively low stocking rates (25 ha^{-1} or less), sheep increased in live-weight for up to 80 days when grazed on lupin stubbles. At higher stocking rates (50 or 75 ha^{-1}), the maximum weights obtained were lower, and reached after a shorter time. In a later trial (Crocker et al., 1979a), sheep grazed at 25 ha^{-1} on stubble alone gained weight over 65 days at 77 g day^{-1} , compared with those at the same stocking rate but with 350 kg ha^{-1} grain added to the stubble, which gained 126 g day^{-1} over the same period. At 50 ha^{-1} , sheep on stubble grew at 82 g day^{-1} for 44 days, and those with grain supplementation grew at only 31 g day^{-1} reaching peak weight at 65 days. A higher degree of lupinosis was evident at the higher stocking rate.

Hawthorne and Fromm (1977) found that there was no difference in liveweight gain, carcass weight or back fat thickness between animals (heifers and weaned lambs) fed whole grain in a mixed hay and lupin ration, and those fed crushed grain in the same feed mixture. However, Axelsen (cited by Hindmarsh, 1980) found that although heifers fed on cracked lupins (in an 80.0 per cent grain, 20.0 per cent hay ration) initially lost weight, a better feed conversion was obtained over a 42 day feeding period, than with whole lupin grain. Problems with bloat and reduced intake meant that overall the results were disappointing and did not reflect the high protein levels available.

Use of *L. angustifolius* as a Greenfeed

Edwardson and Corbett (1959) compared dry matter production of blue lupins (*L. angustifolius*) in the south-eastern United States with those of the species in Germany (data

from Hackbarth and Troll, 1956, cited by Edwardson and Corbett, 1959). The Sweet Blue cultivar in Germany gave a mean yield of 3 700 kg ha⁻¹ compared with a range over three sites of 2 800 to 5 160 kg ha⁻¹ in Florida and Georgia. An experiment in which 22 steers grazing 2.4 ha of blue lupins gained an average per animal of 0.53 kg day⁻¹ was reported by Henson and Stephens (1964).

In South Africa, lupins were used in vineyards as green manure. However, it was found that sweet lupins produced up to 19.0 to 28.6 tonnes ha⁻¹ of green material, which could be grazed or ensiled for livestock instead of being ploughed in (Marais, 1957). After pot trials indicated that high fodder yields could be obtained from lupins or lupin cereal mixtures (Nel, 1961), field trials with *L. angustifolius* and *L. luteus* sown separately and in mixtures with cereals were conducted (Nel, 1965). Dry matter yields of *L. angustifolius* ranged from 3 110 to 8 851 kg ha⁻¹ over three seasons and yield of *L. luteus* ranged from 2 936 to 6 260 kg ha⁻¹. In the cooler area of the Eastern Transvaal, van Zyl (1967) showed that *L. angustifolius* was well adapted to the conditions in early and late summer and yielded well. In a later series of trials over four summer seasons, lupins were sown at intervals from September through until December. Two slow-growing bitter cultivars, Jakkalsfontein and S.E. Blue, yielded an average of 4.87 tonnes ha⁻¹ of air-dried material when planted in early spring, 5.13 tonnes ha⁻¹ from an early summer sowing, and 2.85 tonnes ha⁻¹ when sown in late summer. The sweet cultivars, Borre and Rommel, averaged 4.15, 4.67 and 2.81 tonnes ha⁻¹ at the same sowing times. Where lupins were grown in the Eastern Cape region as a winter legume for silage, yields of

between 20 and 30 tonnes ha⁻¹ of unwilted forage were obtained by Straatman *et al.* (1972). These workers found that, because of initial slow growth, the crop was subject to weed infestation. They further observed that it was undesirable to graze at an early stage of growth, as the growing points of the plants were eaten first and very little regrowth occurred.

The poor regrowth potential of lupins appears to have limited their use as a greenfeed in Australia. Although bitter cultivars could be grazed lightly after the seedling stage (Gladstones, 1969b), it was recommended that sweet cultivars not be grazed at all before the end of flowering, as this would reduce both total dry matter production and seed yield (Gladstones, 1959, 1967b, 1969b, c, 1970b; Garside, 1975). The crude protein concentration of lupins was reported to be 20.0 per cent or greater (on a dry matter basis) until full flowering (Gladstones, 1970b) and fibre content was moderate. However, from late flowering onwards quality fell rapidly. The dry weight of leaves was shown to peak at 19 weeks after sowing, the stem component at 20 weeks, pods at 21 weeks and seed at 24 weeks (Greenwood *et al.*, 1975). Late planting was shown to reduce the length of all growing phases (Perry and Poole, 1975), and Perry (1975) showed that a shortened growing season reduced lateral branch growth, resulting in a reduction of both dry matter and seed yield. Flowering began at 17.0 to 25.0 per cent maximum dry matter accumulation (Perry, 1975). For the same reason, it was recommended by Farrington (1974) that lupins grown as a winter greenfeed should be sown as early as possible.

Much of the early work on lupins in New Zealand was carried out at Lincoln College, Canterbury. Results of

a winter grazing trial with Bitter Blue lupins carried out in 1934 were reported (Anon., 1938). The crop was sown at three dates from December to February, and grazed for six weeks in June to August with some hay supplementation. Ewes grazing the lupins at the pre-flowering stage gained an average of 10.2 kg over the period; those on flowering lupins gained 4.2 kg, while those grazed on ripe lupins lost 1.4 kg.

Lambs born to the ewes grazing green (pre-flowering) lupins were heavier than those born to ewes fed on flowering lupins, but lambs from the ewes fed on ripe lupins were lighter. A study was also made of the plant composition in conjunction with this trial. Protein concentration decreased from 18.0 per cent at pre-flowering to 16.3 per cent at flowering and 15.89 per cent at maturity, although protein in pods and seeds of the ripe plants was 20.48 per cent. As a comparison, good pasture was stated to contain 17.5 per cent protein. Fibre increased from 15.63 per cent at pre-flowering to 24.14 per cent when the plants were ripe. Fat, carbohydrate, total mineral, lime, phosphate and chlorine levels were also recorded.

Summer grazing trials were carried out in the 1940-41 and 1941-42 seasons (Anon., 1942). In the first trial, both bitter and sweet cultivars were sown in September, following a greenfeed oat crop. Grazing commenced in late December, 13 weeks after sowing, at stocking rates that allowed *ad lib.* feeding, with Merino wether hoggets. Those grazed on Bitter Blue at the green pod stage gained 40.8 g day^{-1} over the 23 days, while those on Sweet Blue gained 181.0 g day^{-1} over the same period. In the following year's trial, sweet lupins were sown in early October at 110 kg ha^{-1} and grazed when at the green pod stage, 107 days after sowing, for a 28 day period.

Weight gains averaged $5.38 \text{ kg head}^{-1}$ (192 g day^{-1}). This was compared with a rape crop which was sown 17 days later, but fed at the same time, on which the average weight gain was $4.43 \text{ kg head}^{-1}$ (158 g day^{-1}). The lupins carried 50.0 per cent more stock than the rape, and there was also lupin feed available for a second flock of sheep after the 28 day trial period. It was further suggested (Anon., 1942) that, if care was taken to avoid overgrazing, it would be possible to take a light seed crop after feeding off foliage to lambs.

Lancaster and Adams (1943), comparing blue lupins as a winter feed with several other feeds, showed that the crude protein level of 17.0 per cent, just prior to flowering, was lower than that of pasture and other feeds, including kale and lucerne hay. Because of the high alkaloid content of the cultivar used, the animals found the feed was unpalatable and lost an average of 4.5 kg liveweight during the pre-feeding period before the trial. Lancaster (1943) measured the *in vivo* digestibility of those plants as 77.6 per cent.

Digestibility trials with sweet cultivars of *L. angustifolius*, *L. luteus* and *L. albus* fed at two different stages of plant growth, were subsequently carried out by Allison and Thurston (1952). At the flower bud stage, dry matter yield of *L. angustifolius* was $2\,220 \text{ kg ha}^{-1}$, crude protein 18.1 per cent and *in vitro* digestibility 68.0 per cent. Both the yield and the crude protein concentration of *L. albus*, $2\,950 \text{ kg ha}^{-1}$ and 19.3 per cent respectively, were higher than that of *L. angustifolius*, but the *in vitro* digestibility was slightly lower at 65.3 per cent. *Lupinus luteus* had both a lower yield, $1\,760 \text{ kg ha}^{-1}$, and crude protein concentration, 17.8 per cent, but a higher digestibility than

either of the other two species, at 72.3 per cent. Dry matter yield increased after the pre-flower stage in *L. angustifolius*, and was 2 785 kg ha⁻¹ at green pod formation. Similarly, in *L. luteus*, it was 3 737 kg ha⁻¹ by this stage, but in *L. albus* it had decreased to 2 728 kg ha⁻¹. Crude protein concentration in all three species dropped over this period to 17.9 per cent (*L. angustifolius*), 18.4 per cent (*L. albus*), and 16.8 per cent (*L. luteus*). Digestibility also fell in all species to 55.3 per cent in *L. angustifolius*, 58.5 per cent in *L. albus* and 61.4 per cent in *L. luteus*.

A summary of several Sweet Blue lupin trials, including those of Allison and Thurston (1952), was published by Greenall (1956). The yields recorded by Allison and Thurston (1952) in a normal year were the lowest. Yields of up to 8 036 kg ha⁻¹ were obtained in a wet year, and 6 298 kg ha⁻¹ in a dry year under irrigation, with 3 214 kg ha⁻¹ from an unirrigated soil of low water holding capacity at Ashley Dene (Canterbury) in a very dry season. Digestibility of the foliage, averaged over all the trials, was 70.8 per cent.

Yields of 7 909 kg ha⁻¹ (Borre) and 5 248 (New Zealand Sweet Blue) as compared to 7 207 kg ha⁻¹ of the bitter cultivar New Zealand Bitter Blue, were recorded by van Steveninck (1956) in the first of two spring sown trials. In the second trial, birds and hares severely damaged the two sweet cultivars and yields of only 5 773 and 3 128 kg ha⁻¹ for Borre and New Zealand Sweet Blue respectively were obtained, compared with a yield of 10 616 kg ha⁻¹ from cv. New Zealand Bitter Blue. Borre recovered better from the hare and bird damage than New Zealand Sweet Blue and this was later verified in a pot trial (van Steveninck, 1956). Two recommendations

made by van Steveninck (1956) concerning spring sowing of lupins were:

- . Sowings for both seed and fodder production should be made during September and October and continued until early December for fodder production only.
- . Since highest returns of digestible fodder were obtained when the green pods reached full size and lower leaves began to drop, and rapid deterioration began after this, feeding should begin after the main spikes had finished flowering.

Whatman (1959), however, found that the amount of feed was greatest just prior to flowering and the crop should be grazed at that stage and also that, if the autumn sown crop was not too heavily grazed, it would recover and produce a light seed crop in the following autumn.

Macmillan and Brown (1973) compared Uniwhite (*L. angustifolius*) lupins with five other summer greenfeeds sown in early November on a Eyre stony silt loam at Swannanoa (Canterbury). The lupins yielded 4 120 kg ha⁻¹ at 104 days, which was not promising when compared with the yield of maize, 8 587 kg ha⁻¹; peas, 6 940 kg ha⁻¹; turnips, 6 650 kg ha⁻¹; and kale, 5 820 kg ha⁻¹. The sixth crop, sorghum, grew very poorly and yield was not measured. Observation of the grazing behaviour of ewes fed the crop *in situ* indicated that lupins were least preferred. A poor yield of spring sown *L. angustifolius* was also obtained at Winchmore, in a preliminary trial (Knight, 1980, pers. comm.).

As a winter fodder crop in the North Island, lupins planted in mid-March yielded 3 166 kg D.M. ha⁻¹ by early

August, and outyielded a turnip and Tama ryegrass mixture (Farrell, 1974). Digestibility was 60 per cent, giving 1 900 kg digestible organic matter ha⁻¹, only a little less than from the turnips and Tama mixture. However, two months earlier the lupin crop yielded only 726 kg ha⁻¹ when cut to 8 cm and there was no regrowth.

Winter yields of Uniharvest (*L. angustifolius*) in the South Island were also not very good (Janson and Knight, 1980). Lupins sown in early March at Winchmore yielded only 1 390 kg ha⁻¹ by mid-August, and 3 560 kg ha⁻¹ by mid-October at the secondary flowering stage. In the same trial, subterranean clover yielded 220 and 2 510 kg ha⁻¹ at these two dates, a ryegrass and oats mixture 2 750 and 3 830 kg ha⁻¹, peas 2 830 and 1 890 kg ha⁻¹, while tick beans (*Vicia faba*) outyielded all the other crops with 4 440 and 6 560 kg ha⁻¹ at the two harvest dates. Of the five crops, the most poorly utilized, when grazed by sheep, were the lupins with only a 63 per cent utilization in relation to subterranean clover and the ryegrass and oats mixture. Tick beans and peas were better utilized, at 69 and 75 per cent respectively. Oroua wheat, grown following the forage crops, yielded better after the tick beans and peas, with 3 670 kg ha⁻¹ and 3 890 kg ha⁻¹, compared with only 1 530 kg ha⁻¹ after the lupins, and although nitrogen content of the wheat grain following lupins was as good or better than that of grain following the other crops, the total nitrogen harvested in grain was lower.

Withers (1975a) showed that defoliation of plants at either an early stage of growth (seven to eight leaf stage) or later at the primary bud stage, reduced seed yield, indicating that grazing at either of these stages would not be feasible in a

crop intended for seed, in spite of stimulated lateral branch growth increasing the number of lateral inflorescences.

Herbert (1977b), however, found that there was no reduction of yield in either *L. angustifolius* cv. Unicrop or *L. albus* cv. Ultra, with removal of the main stem inflorescence, as the absence of apical dominance allowed greater production from lateral inflorescences. Total above ground dry matter accumulation for *L. angustifolius* cv. Unicrop was shown not to differ significantly from that of *L. albus* cv. Ultra in a spring sown trial (Herbert, 1977a). At maturity the yield of Unicrop was 731 g m^{-2} at a density of 10 plants m^{-2} , $1\ 049 \text{ g m}^{-2}$ at 53 plants m^{-2} and $1\ 052 \text{ g m}^{-2}$ at 83 plants m^{-2} . There was no significant difference between the yields at the two higher densities.

In a study of growth of *L. angustifolius* cv. WAU 11B, Herbert and Hill (1978) recorded a maximum total above ground herbage of about $1\ 200 \text{ g m}^{-2}$ in an unirrigated crop at 116 days after sowing at a density of 92 plants m^{-2} . A peak dry matter accumulation of just under $2\ 000 \text{ g m}^{-2}$ in 130 days was recorded for irrigated lupins at 92 and $156 \text{ plants m}^{-2}$. As with *L. albus* cv. Ultra and *L. angustifolius* cv. Unicrop (Herbert, 1977a), initial growth over the first six weeks in WAU 11B was very slow. Plants at a high density ($156 \text{ plants m}^{-2}$) were found to have maximum leaf weight about two weeks earlier than those at 92 plants m^{-2} and four weeks earlier than the lowest density plants at 27 plants m^{-2} . At the high density, leaf weight was at a maximum when total biomass was only 48 to 54 per cent of final peak accumulation.

Yields and Nutritive Value of Some Other Greenfeeds

Janson and Knight (1980) showed both tick beans (*Vicia faba*) and peas (*Pisum sativum*) to yield well under New Zealand conditions. Tick bean yields of up to $1\,150\text{ g m}^{-2}$ were obtained from autumn-sown Daffa, and up to 581 g m^{-2} from spring-sown Maris Bead in Canterbury (Newton, 1980). In England, forage yields of winter beans ranged from $9\,100$ to $12\,200\text{ kg ha}^{-1}$ in a trial which compared eight cultivars (Toynbee-Clarke, 1970). August yields from March (spring) sown Herz Freya and Maris Bead were up to $3\,080$ and $2\,510\text{ g m}^{-2}$ respectively (Sprent *et al.*, 1977). *In vitro* digestibility ranged from 55 to 67 per cent and crude protein varied between 13 and 18 per cent in the eight cultivars investigated by Toynbee-Clarke (1970). Dehydrated whole plant pellets, fed as a supplement to maize silage to increase protein intake levels, were found to have an *in vitro* digestibility of 59 per cent and a crude protein content of 16 per cent (Lonsdale and Tayler, 1969).

Pea yields of $4\,250\text{ kg ha}^{-1}$ (Whero at 89 plants m^{-2}) and $5\,750\text{ kg ha}^{-1}$ (Huka at 103 plants m^{-2}) have been measured (Falloon, 1978), and Askin (1980, pers. comm.) obtained a yield in irrigated Puke peas of $6\,100\text{ kg ha}^{-1}$.

Vetches and tares (*Vicia* spp.) as used in some situations in Australia (Arnold *et al.*, 1976a), have not been used to any great extent in New Zealand (Claridge, 1972). The same applies to serradella (*Ornithopus* spp.), which, although it has an extremely high feed value and contains no oestrogens (Francis, unpublished, cited by Gladstones and McKeown, 1977), is of minor importance in Australia (Cariss and

Quinlivan, 1967; Gladstones and McKeown, 1977). Another legume which has potential as a forage is sainfoin (*Onobrychis sativa*). Feeding trials at Palmerston North have proved this crop to be an excellent greenfeed for both cattle and sheep, being more palatable and nutritious than many of the conventional pasture species (Anon., 1974). Little is known of its agronomic characteristics or yield under New Zealand conditions, but it is non-bloating and can outyield lucerne in some situations (Anon., 1974).

Lucerne yields have been found to be very variable. Annual yields of 3 180 to 8 360 kg ha⁻¹ on unirrigated light land have been recorded (Iverson, unpub.; Vartha, unpub., both cited by Vartha, 1971). Wier et al. (1960) found that the yield of lucerne over a period of 24 weeks (spring-summer) varied between 11 784 kg ha⁻¹ under frequent cutting (three weekly intervals) and 21 054 kg ha⁻¹ if cut less frequently (six weekly intervals). Protein concentration, however, was higher in the frequently cut treatment at 25.3 per cent compared with 16.3 per cent. The average digestibility of the organic matter varied between 61 and 71 per cent. Spring-summer (September to April) yields of 19 900 kg ha⁻¹ under grazing were recorded by Vartha and Allison (1973), and total nitrogen yield was 678 kg ha⁻¹. With application of nitrogen, Hoglund et al. (1974) obtained a yield of 28 200 kg ha⁻¹ over the November-March period. The yield from the plots without nitrogen was 24 000 kg ha⁻¹ over the same period. The highest mean growth rate in this trial was 150 kg ha⁻¹ day⁻¹, recorded in mid-summer.

Annual production, in Canterbury, of both lucerne and clover based pastures was measured by O'Connor *et al.* (1968). Over eight years, lucerne averaged an annual yield of 14 108 kg ha⁻¹, of which over 11 200 kg ha⁻¹ was produced during the spring-summer period. In comparison, mean annual yields of a Ruanui ryegrass and Huia white clover pastures averaged 10 165 kg ha⁻¹, of which just under 4 500 kg was spring production and just over 2 800 kg was produced in the summer. Pasture species vary greatly in production, depending on both district and season (O'Connor *et al.*, 1968).

The brassicas, in particular rape and kale, have been used for late summer/early winter forage and yield well in Canterbury. Yields of as high as 10 275 kg ha⁻¹ in early April from giant kale planted in late October were obtained by Mortlock (1975). February yields of the crop planted at the same date averaged just over 6 000 kg ha⁻¹. Later harvesting of October sown marrow-stemmed kale (July) produced yields of up to 21 000 kg ha⁻¹ (Stephen *et al.*, 1978). Rangi rape, also sown in late October, yielded 5 940 kg ha⁻¹ and one fodder raddish cultivar planted in mid-December reached a yield of 5 363 kg ha⁻¹ by mid-February (Mortlock, 1975). Winter yields of kale in the North Island of up to 10 000 kg ha⁻¹ were reported by Jagusch *et al.* (1977). The digestibility of this crop was 71 per cent (*in vivo*) (Jagusch *et al.*, 1977), but Barry (1979) reports the digestibility of kale to be over 80 per cent and that of rape to be 85 per cent. In the North Island, Jagusch *et al.* (1977) obtained an autumn yield of turnips of 10 300 kg ha⁻¹. Although the digestibility of this crop (74 per cent) was lower than that of rape, it appeared to be better

utilized by lambs.

Other fodder crops, grown mostly in the North Island, are maize and sorghum. Sorghum yields of about 9 500 kg ha⁻¹ in 77 days, in mid- to late summer, were obtained by Gerlach and Cottier (1974). In Nelson and Marlborough, very good forage yields (17 000 to 18 000 kg ha⁻¹) were obtained from November sowings of Sudax sorghum and PX610 maize in the late summer and early autumn.

1.1.5 *Use of Lupins for Hay and Silage*

In Europe, lupin silage has been commonly used for sheep, beef and dairy cattle and pig feed (Herbst, 1938a, b; Winkler et al., 1956, cited by Gladstones, 1959; Silva and de Olivera, 1958; Papp, 1968; Rykshina et al., 1974; Lees, 1975, 1976). Winkler et al. (1956, cited by Gladstones, 1959) found that *L. luteus* made good silage, but *L. angustifolius* did not because of its greater woodiness and lower palatability and feed value. The best results with *L. luteus* silage in terms of digestible nutrients per hectare were obtained by delaying ensiling until seed formation had occurred (Winkler et al., 1956, cited by Gladstones, 1959).

Sweet lupins have been successfully used to make both hay and silage in Australia (Gladstones, 1970b), the best results being obtained by cutting towards the end of flowering. The thick fleshy stems of *L. luteus* made it less suitable than other species for hay making, as it was difficult to dry. The *in vitro* digestibility of lupin hay (57.3 per cent) measured by Hill and Arnold (1975) was lower than that of an oat and lucerne hay mixture (64.2 per cent). The *in vivo* digestibilit-

ies of the two hays were 55.2 per cent and 61.9 per cent respectively. Hill and Arnold (1975) concluded that hay from lupins cut at the late flowering stage had a similar nutritive value to hays made from temperate pasture species of the same digestibility, even when the lupin hay was infected, to a low degree, with *Phomopsis leptostromiformis* causing mild lupinosis (see Section 1.1.7).

Lupins are used fairly extensively for silage production in South Africa but less commonly for hay. Blue lupins (*L. angustifolius*) are not considered suitable for hay making because, where rains occur during drying (Henning, 1949), there is severe leaf loss when they are raked and baled (Straatman *et al.*, 1972). An analysis of lupin hay cut at full maturity was given by Marais (1957). A yield of just over 4 tonnes ha⁻¹ (11.97 per cent crude protein and 36.41 per cent crude fibre) was obtained.

Marais (1957) showed that, although lupin silage had a high nutritive value and was especially rich in protein, it was low in sugars, and he suggested that the crop should be cut at the young succulent stage and left for 4 days, and that sugar should be added in the form of molasses (three to four per cent by weight). Vosloo *et al.* (1963), on the other hand, stated that lupin silage was limited in some amino acids and should be supplemented with grain or fish meal. *Lupinus angustifolius* was shown to be promising as a silage crop on its own, or in a mixture with maize or sorghum to increase the protein concentration of the ration (van Zyl, 1967, 1973). The crop is used for silage in the Eastern Cape region (Straatman *et al.*, 1972), where it is cut when pods in the main clusters are well formed and the leaves are beginning to drop.

1.1.6 Pests and Diseases of Lupins

Lupins are subject to a number of fungal diseases and at least one important virus (Gladstones, 1969c, 1970d) which may affect their reliability as a forage. Grey leaf spot, caused by *Stemphylium solani* (Weber) and *S. botryosum* (Wallr) (Forbes et al., 1975), may result in severe leaf drop and has been a major problem in *L. angustifolius* grown in the North Island of New Zealand (Tate, 1968, cited by Withers, 1975a). However, there is little evidence of this disease occurring in crops before flowering and if the crop is utilized at the pre-flower stage for livestock forage, no crop losses from this disease occur (Tate, 1970). Brown leaf spot (*Pleiochaeta setosa*), Anthracnose (*Glomerella cingulata*), Fusarium wilt (*Fusarium erysorum*), mildew (*Erysiphe* spp.) and Lupin wilt (*Botrytis cinerea*) can also be problems (Gladstones, 1969c, 1970d). *L. angustifolius* cultivars, Unicrop, Uniwhite and Uniharvest, are more susceptible to brown leaf spot than *L. luteus* cultivar Weiko III (Palmer, 1976), but the Marri cultivar of *L. angustifolius* is resistant to grey leaf spot and anthracnose (Department of Agriculture of Western Australia, 1976). The Ultra cultivar of *L. albus*, although having a higher degree of resistance to *Phomopsis leptostromiformis*, the fungus responsible for lupinosis in stock (see Section 1.1.7), which is also known as stem blight (Ostazeski and Wells, 1960), is less resistant to brown leaf spot (Department of Agriculture of Western Australia, 1976). Pea mosaic virus has been a problem in the past in New Zealand, causing a condition known as sore shin in the plants (Whatman, 1959; White, 1961). Bean yellow mosaic virus affects a wide range of legumes (Gladstones, 1969c) and is transmitted by aphids. The

risk of this virus is lessened by early sowing to ensure that plants are well advanced before aphid flights, or, particularly in narrow leaved lupins, by the use of relatively high seeding rates (Gladstones, 1969c).

Budworms (*Heliothis* spp.) are a problem in Northern America (Silva and de Olivera, 1959), and in both South Africa and Australia (Gladstones, 1969c, 1970d). Other destructive insect pests in Western Australian lupin crops are climbing cutworms (*Heliothis punctigera*), red legged earth mites (*Halotydeus destructor*) the lucerne flea (*Smynturus viridus*) (Gladstones, 1969c, 1970d) and aphids (Ferguson, 1979). Harris (1980, pers. comm.), studying insect pests in lupin crops in the 1978/79 season at Lincoln College, found that no obvious insect damage of any significance occurred. A survey of Canterbury growers in that season revealed that no insecticide treatment was required in lupin crops (Harris, 1980 pers. comm.). The more likely insect pests to attack summer grown lupins in the Canterbury environment were outlined by Harris (1980, pers. comm.) as follows:

- . Agromizydae (Leaf miners)
- . Anthomyiidae
- . *Calocoris norvegicus* (potato mirid)
- . *Acyrtosiphon kondoi* (blue green lucerne aphid)
- . *A. pisum* (pea aphid)
- . *Myzus persicae* (green peach aphid)
- . *Macrosiphum euphorbiae* (potato aphid)
- . *Sidnia kinburg*.

Birds (Allen, 1949; Greenall, 1956), rabbits (Inch, 1947; Claridge, 1972) and hares (Black and Claridge, 1942; Allen, 1949; White, 1961; Claridge, 1972; Hill, 1980, pers. comm.) are reported to have been a problem in some sweet lupin crops.

1.1.7 *Lupinosis*

In spite of good yields and high digestibility, the use of lupins as a forage has been seriously limited by a disease known as lupinosis, which may develop in animals grazing the crop. Lupinosis is a mycotoxosis caused by the ingestion of a fungus *Phomopsis leptostromiformis* syn. *P. rossiana* growing on lupin plants (van Warmelo et al., 1970). It should be clearly distinguished from lupin poisoning (also known as alkaloid poisoning, lupine madness and American lupinosis) (Gardiner, 1967b) which is a nervous disorder caused by the presence of alkaloids in bitter lupins (Bennetts, 1960; Gardiner, 1967b). Tests have revealed the poisons to be similar, but lupin alkaloids do not cause the liver damage that is characteristic of lupinosis (Petterson and Parr, 1970).

Outbreaks of lupinosis were first recorded in Germany in the 1860's (Gardiner, 1967b; Gladstones, 1970b; Petterson and Parr, 1970) but have been virtually unknown there since the introduction of sweet lupins. However, the disease has been one of the major problems associated with the feeding of lupins to livestock in both South Africa (Flight, 1956; Straatman et al., 1972; van Warmelo et al., 1970; Marasas, 1974) and Australia, particularly in Western

Australia, where it has become an increasingly serious problem since 1950 (Bennetts, 1959; Gardiner and Williams, 1960; Neil et al., 1960; Gardiner, 1964, 1967b; Gladstones, 1970b; Marasas, 1974; Culvenor et al., 1978). It is one of the major factors limiting expansion of the lupin industry in that state (Allen et al., 1978b).

It is now well established that both sweet (low alkaloid content) and bitter lupins are capable of causing lupinosis (Gardiner, 1967b; van Warmelo et al., 1970; Healy, 1972) and that lupin alkaloids are in no way involved in the aetiology of the disease (van Warmelo et al., 1970; Gardiner and Petterson, 1972).

It is only comparatively recently that the cause of the disease has been known. Choline and methionine deficiencies were considered as possible causes of the liver damage (Groenewald et al., 1954; Bennetts, 1957) and the possibility of other nutrient deficiencies being involved, particularly vitamin E, was also investigated (Gardiner, 1967b). Gardiner and Neil (unpub.) found that the severity of lupinosis was definitely correlated with copper and cobalt levels in lupin leaves, and Gardiner (1964, 1966, 1967a) showed that liver copper concentration had a definite role in the pathogenesis of the disease. Liver iron content in affected animals was shown to be higher than that of non-affected animals, as total iron binding capacity increased with severity of the disease (Gardiner, 1965).

In the late nineteenth century it was suggested (Kuhn, 1880, cited by Marasas, 1974) that lupinosis might be caused by a hypothetical toxin, "ictrogen", from a fungal organism *Cryptosporium leptostromiformae*, but it was not until

the early 1960's that this theory was investigated, first in Western Australia (Gardiner and Nottle, 1960; Gardiner, 1964, 1966) and, following an outbreak of the disease in 1969, in South Africa (van Warmelo *et al.*, 1970). These investigations led to the independent discovery in both countries that the fungus *P. leptostromiformis* syn. *P. rossiana* was the organism responsible for the disease (Gardiner, 1964, 1966, 1967b, 1975; van Warmelo *et al.*, 1970; Wood and Brown, 1975).

Phomopsis infection of plants by spores can take place at any time from the seedling stage onwards and in most cases plants are infected several times (Wood and Brown, 1975). Two types of spores have been identified; pycnidiospores for short range (less than 100 metres) infection, and wind-blown ascospores which are a very effective means of long range infection (Wood and Brown, 1975). The optimal temperature for vegetative growth of the fungus ranges from 24 to 28°C (van Warmelo and Marasas, 1972), and a temperature of at least 20°C (Marasas, 1974) is necessary for reasonable growth.

Studies of the *P. leptostromiformis* life cycle have revealed that the reproductive stage of the fungus is restricted to the dead material (Healy, 1972) or the coarser central and lateral stems of the lupin plant (Wood, unpub., cited by Allen and Wood, 1977), and in only one instance have *Phomopsis* pycnidia been observed on the green leaves of a dense self-sown stand of lupins, apparently acting as a source of secondary infection and spreading the disease to other plants (Wood and Brown, 1975). This situation is rare as the fungus normally survives in infected lupin stubble and debris for re-infection of new crops (Marasas, 1974; Wood and Brown, 1975). Infected

seed can also serve as a source of infection (Ostazeski and Wells, 1960; Wood and Brown, 1975). Although the fungus is usually present on green lupin stems, it does not normally produce sufficient toxin to cause symptoms of lupinosis in stock grazing the green material (Gardiner, 1967b; Gladstones, 1970d; Wood and Brown, 1975).

The chemical nature of the toxin has remained uncertain for some time. The early German workers demonstrated that it remained stable in stored dry lupins for at least 18 months and that it was not destroyed by dry heat, but could be broken down under high pressure steam (Marasas, 1974). Roloff (1883, cited by Marasas, 1974) suggested that it might contain phosphorus, whereas Petterson and Parr (1970) concluded that on the basis of its solubility it must be phenolic and/or acidic in nature. Gardiner (1975) classified it with the mitotic inhibitors, and Culvenor *et al.* (1978) described the disease as being the result of ingestion of toxic metabolites, the main one of which is Phomopsin A.

Generally, dry stubble can be safely consumed by stock and there appears to be a complex relationship between the amount of summer dew or rainfall, humidity, temperature, and density of the lupin stubble, all of which affect the toxin production of the fungus (Gardiner, 1964). Dry lupins often become unsafe a few days after summer rainfall, especially if it is followed by humid weather (Gardiner, 1964, 1975) and it has been recommended as a control measure that stock should be removed from lupin paddocks, only being returned after two or three weeks of hot dry weather (Gladstones, 1967b; Healy, 1972).

The toxin is cumulative in its effect (Bennetts,

1975). Symptoms may be acute, occurring within a few days of the animals eating the toxic plant, or chronic, where loss of appetite is the most noticeable feature and death may result partly from malnutrition (Herbert, unpub.). The signs of acute lupinosis are complete inappetance, followed by icterus (skin lesions) and death two days to two weeks after toxic lupins are ingested (Brash, 1943; Bennetts, 1957, 1960; Gardiner, 1965, 1967b; van Warmelo *et al.*, 1970). The liver of an acutely affected animal is greatly swollen, very yellow in colour, and shows signs of a massive infiltration of fat into the cells (Gardiner, 1967b, 1975).

In less acute cases, the anorexia is only partial and is associated with dullness, depression, loss of weight and icterus, followed by death up to two months after removal from lupins (Gardiner, 1965, 1967b; Gardiner and Parr, 1967; Bennetts, 1975). Lesions of the ears and muzzle due to photosensitization have also been reported (Bennetts, 1957, 1960), but this is somewhat unusual (Gardiner, 1965, 1967b). Seven types of liver abnormality associated with the acute form were outlined by Croker *et al.* (1975); severity of damage is not as great in chronic cases (Gardiner, 1975). Other organs, kidneys and spleen (van Warmelo *et al.*, 1970; Petterson and Lanigan, 1976), gall bladder (Gardiner, 1975), duodenum (Petterson and Lanigan, 1976), lymph nodes (van Warmelo *et al.*, 1970), lungs (van Warmelo *et al.*, 1970) and subcutaneous fat (van Warmelo *et al.*, 1970; Gardiner, 1975) may also be affected in varying degrees.

Chronically affected animals may look "dejected and depressed" (Gardiner, 1975), but if not too badly affected recovery is possible if they are taken off the infected stand

and given access to good quality alternative fodder (Gardiner, 1975).

Lupinosis is normally assumed to be primarily a disease of sheep, probably not because they are any more susceptible, but because lupins have been used more extensively as a feed for sheep than for other animals (Marasas, 1974). Other animals are also affected; cattle (Bennetts, 1960; Gardiner and Williams, 1960; Gardiner, 1967a, b, c; Allen *et al.*, 1979), horses (Bennetts, 1960; Gardiner, 1967c; Allen *et al.*, 1979), donkeys (Allen *et al.*, 1979), pigs (Marasas, 1974) and experimentally in goats, dogs, rabbits, mice (Marasas, 1974) and rats (Papadimitriou and Petterson, 1976).

The nutritional aspects of the disease have been studied by many workers including Gardiner (1964, 1967a, b, 1975) and Hill and Arnold (1975). There is clearly an association between this disease and cobalt deficiency, parasitism (Gardiner, 1964) and poor unpalatable feed, involving both a reduction in total intake, and in the consumption of feed of lower quality (Gardiner, 1967b). Although palatability may be decreased by the fungal growth, digestibility does not appear to be adversely affected (Hill and Arnold, 1975).

As yet, no satisfactory control of the fungus has been found. Wood *et al.* (1975), working with a wide range of products, concluded that fungicide treatment could not be considered as a practical means of controlling the disease. These workers suggested that biological control using micro-organisms that break down the toxin might be effective, after experimental evidence showed that dry lupin material under laboratory conditions retained its toxicity for much longer, in the absence of the micro-organisms, than the one to two weeks

under field conditions.

Fungal build-up is most likely where successive lupin crops have been grown and under conditions of inadequate fertility (Healy, 1972). As the fungus is capable of surviving in infected debris for several years (Kockman, 1957; van Jaarsveld, 1973, cited by Marasas, 1974), a cropping rotation as suggested by the early German workers (Marasas, 1974) and Healy (1972) may not be effective. Destroying crop residues before the spores are released (Bennetts, 1975; Wood and Brown, 1975) wastes much nutritious feed, and, as previously mentioned, the fungus can survive in the infected stalk and other material remaining after burning or grazing (Neil et al., 1960). Roadside stands of lupins can also carry the fungus (Wood and Brown, 1975).

Resistance of species to attack by *P. leptostromiformis* has also been investigated. *Lupinus albus* is generally more susceptible (Ostazeski and Wells, 1960; van Jaarsveld, 1973, cited by Marasas, 1974; van Jaarsveld and Knox Davies, 1974), together with *L. luteus* (Ostazeski and Wells, 1960; Arnold et al., 1976b), than is *L. angustifolius*, although Gladstones (1976) suggested that *L. albus* was less susceptible than the narrow leaved species, and Arnold et al. (1978) showed that the cultivars Weiko III (*L. luteus*) and Ultra (*L. albus*) were partially resistant under Western Australian conditions. Any resistance shown by *L. angustifolius* (Ostazeski and Wells, 1960; van Jaarsveld, 1973, cited by Marasas, 1974; Arnold et al., 1976b) and *L. luteus* (van Jaarsveld, 1973, cited by Marasas, 1974) in the young growing plant breaks down when the fungus develops as a sporophyte on the dead plant (Marasas, 1974). *Lupinus mutabilis* has been shown to have a degree of resistance (van Jaarsveld and Knox

Davies, 1974) but this species is bitter and unsuitable for grazing.

Although controlling the fungus does not appear to be an encouraging prospect (Wood and Brown, 1975), grazing management to ensure that the toxin is not ingested, or is consumed only at low levels so that it does not cause serious damage, can be practised. Removal of stock from lupin crops over danger periods has been discussed earlier. Neil *et al.* (1961) showed that the incidence of lupinosis could be reduced by means of supplementary feeding due to either less toxin being ingested, or the animals being in better condition and hence less affected. Gardiner (1975) confirmed the former by concluding that liver damage was likely to be greater in sheep grazing at high stocking rates, as increasing grazing pressure allows less selective grazing and forces consumption of more toxic and possibly less palatable material, earlier and in greater quantities.

Baling of lupin stubble failed to reduce liver damage incidence in at least one case (Allen *et al.*, 1978a), but reduced incidence of *Phomopsis* infection resulting in a decrease in toxin to a negligible level. They were cut after pod formation, but prior to leaf drop, and were left in an open swath until they were raked into windrows just prior to rolling and baling. Conventional baling of green lupins treated with formalin was unsuccessful (Department of Agriculture of Western Australia, 1972). Premature baling increases the risk of lupinosis due to conditions within the bale being favourable for fungal growth (Gladstones, 1970d). Bennetts (1959), although citing no evidence, also suggested that lupin silage should be treated with caution. In view of the fact

that high copper levels increase the severity of liver damage in infected sheep, Gardiner (1964) stated that it was definitely dangerous to provide sheep grazing lupins with any form of copper supplementation, either as licks or drench.

In New Zealand, the situation regarding lupinosis is unclear. Two outbreaks of a disease in sheep grazing *L. angustifolius* were reported by Brash (1943). In both cases, the symptoms appeared to be synonymous with those of lupinosis and Brash himself concluded: "It is evident that in both these mortalities, the symptoms and post mortem findings correspond closely with the condition described as acute lupinosis, in the cause of which the ictrogenic factor predominates. In no case did the findings suggest that alkaloids alone were responsible for the deaths as has been observed in America." However, Marasas (1974) stated that *P. leptostromiformis* was not known to occur in New Zealand. This was confirmed by Harvey (1978, pers. comm.) and Close (1980, pers. comm.). Harvey (1978, pers. comm.) further stated that any cases of lupinosis that had been reported until that date had been due to alkaloid poisoning rather than *Phomopsis* toxin. This is almost certainly the case in the deaths mentioned by Claridge (1972) and Stoker (1974).

1.1.8 Potential of Lupins as a Greenfeed Crop

The increase in the use of lucerne for both spring and summer feed, and as hay for winter feed, was one of the main reasons for the decline in popularity of lupins. In more recent times, problems such as root and stem nematodes (Grandison, 1976; Burnett et al., 1978; Dunbier, 1979; Dun-

bier *et al.*, 1979a), various leaf spot diseases (Sanderson, 1976; Harvey, 1979a), crown rot (Sanderson, 1976; Dunbier, 1979; Harvey, 1979b), bacterial wilt (Sanderson, 1976; Dunbier, 1979), and attack by various insect pests such as the sitona and white fringed weevils (Todd, 1964; Somerfield and Burnett, 1976; Henzell *et al.*, 1979), lucerne fleas (Somerfield and Burnett, 1976) and both lucerne and pea aphids (Somerfield and Burnett, 1976; McSweeney and Dunbier, 1978; Dunbier, 1979; Dunbier *et al.*, 1979b; Kain *et al.*, 1979a, b) have decreased lucerne yields, and the crop has not proved to be ideal. Cultivars resistant to these disease and insect pests (Dunbier *et al.*, 1976; Burnett *et al.*, 1979; Dunbier, 1979) and in some cases stricter grazing management (Penman *et al.*, 1979) may overcome these problems to some extent, but there is also an added complication, that of the plant's high oestrogen content, making it an unsuitable feed for pre-tup flushing of ewes (Coop and Clarke, 1960; Coop, 1977; Smith *et al.*, 1979).

One of the principal factors limiting farm production in Canterbury is the likelihood of drought conditions in mid to late summer. If this situation occurs, feed supplies from unirrigated lucerne and pasture fall grossly short of demand and there is a need to grow high yielding crops that are easy to feed off and are not too expensive to produce (Macmillan and Brown, 1973). With rising energy costs, and the consequent increasing costs of nitrogen fertilizers, leguminous crops which fix nitrogen are increasing in importance (Gladstones, 1975b). Lupins fit logically into a pasture crop rotation, following a cereal or other non-leguminous crop, and are very flexible in their use (Gladstones, 1970c). Herbert (1977a) has shown

dry matter yields to be promising, and Clarke (unpub.) has suggested that digestibility of this greenfeed is very high. The crop, therefore, has a high potential for use in ruminant feeding on Canterbury farms.

1.2 EVALUATION OF THE NUTRITIVE VALUE OF A FODDER

1.2.1 Introduction

Although a forage such as lupins may yield well, the nutritive value of the feed is a far more important consideration. The digestibility of a feed is the most important factor which determines its feeding value (Thurston, 1949; Tilley *et al.*, 1960; Joshi, 1972; Manidool, 1974). Digestibility has been defined by Manidool (1974) as:

$$\frac{\text{Amount of foliage consumed} - \text{amount of faeces}}{\text{Amount of forage consumed}} \times \frac{100}{1}$$

This value can be obtained directly through feeding the animal and measuring faeces output (Manidool, 1974). However, these *in vivo* techniques are costly, time consuming and require large amounts of the forage. Because of these difficulties, various *in vitro* methods, in which fermentation of a substrate is conducted under conditions simulating those of the rumen, have been developed (Shelton and Reid, 1960; Joshi, 1972). It has been shown that the *in vivo* digestibility of a forage can be predicted with a high degree of accuracy by the use of *in vitro* techniques (Shelton and Reid, 1960; Raymond, 1969; Joshi, 1972). *In vitro* methods are still slow and still involve the animal to a certain extent, in that rumen liquor must be available. Many methods of chemical analysis have also been in-

investigated to find a simple one that will relate a component or components of the feed to its digestibility, with a reasonable degree of accuracy.

1.2.2 *In vivo Methods*

The extent of digestion in any section of the gastro-intestinal tract is a function of both the rate of digestion and the time available for digestion (Pearce, 1955). Marker techniques, involving both internal (naturally occurring within the feed) and external (materials added to the feed) markers, can provide estimates of both the extent and time of retention in individual sections of the gut, and are an indirect method of estimating intake and digestibility (Faichney, 1975). Microscopic examination of faeces for undigested components was shown by Regal (1960) to be a rapid method for evaluating herbage but is probably only of value where very small amounts of material are available, such as from plant breeding and evaluation trials.

The uses of marker techniques were grouped by Faichney (1975) as follows:

- . Continuous ingestion and total sampling.
- . Continuous ingestion and time sequence sampling.
- . Single ingestion and time sequence sampling.

The first of these requires killing the animal and examination of the whole gastro-intestinal tract (Faichney, 1975), but the other two, although they require the use of cannulae, allow experiments to go beyond the limitations of slaughter (Macrae, 1975).

Conventional T-shaped cannulae can be used with little or no disruption to the normal life of the animal, but sampling from these interrupts digesta flow through the rest of the tract, and if observations at further points are required, the use of re-entrant cannulae is recommended (Macrae, 1975). However, life expectancy of the animal decreases when these are fitted (Macrae, 1975).

As collection procedure appears to decrease digesta flow and cause the problems associated with both types of cannulae (Bruce *et al.*, 1966; Macrae and Armstrong, 1969, cited by Macrae, 1975; Topps *et al.*, 1968), automatic collection is suggested in order to give greater accuracy (Macrae, 1975).

The nylon bag technique described by Chenost *et al.* (1970) allows the study and estimation of the digestibility of small samples of forage. The sample is placed in a silk or nylon bag and inserted in the rumen. The time that the bag was left in the rumen was found to be critical to the values obtained (Chenost *et al.*, 1970) and Harris (1970) outlined an *in vitro* method that was equally reliable.

1.2.3 *In vitro* Methods

Since the 1940's, increasing interest in the evaluation of forage quality, without involving animals, or the large amounts of forage which are necessary with *in vivo* methods, has led to the development of *in vitro* techniques of evaluation (Baumgardt *et al.*, 1962a, b). Many of the older artificial rumen methods were reviewed by Baumgardt *et al.* (1962a, b), but the simple two-stage technique for estimating

digestibility from small samples of dried forage which was developed by Tilley and Terry (1963) is probably the best known. Modifications of this method, including that of using artificial saliva in the first stage and also simulating animal movement by swirling the test tubes at intervals, have been reported (Harris, 1970).

The first stage of the procedure involves anaerobic digestion in rumen liquor. It is important that an active sample of this liquor is obtained, good control of pH and temperature is maintained, oxygen is completely excluded, and that a good sample of forage is used. Problems occurring with this method are most likely to be due to the failure to observe one or more of these conditions (Harris, 1970). The second stage, digestion with acid pepsin, was introduced to remove bacterial protein and undigested feed protein. Tilley and Terry (1963) obtained a correlation of .97 between *in vitro* and *in vivo* values, over a wide range of forages from both grasses and legumes. The equation for finding *in vivo* digestibility was given by Tilley and Terry (1963) as:

$$\text{Digestibility } in \text{ vivo} = .99 \text{ digestibility } in \text{ vitro} - 1.01 \\ SE = \pm 2.31.$$

High correlations from the method were also obtained by O'Shea and Wilson (1965), .94, Wedin *et al.* (1966), .996 and Ademosum *et al.* (1968), .96. Full details of the technique were given by Tilley and Terry (1968).

1.2.4 Chemical Analysis

The digestibility of a plant is related to its chemical composition, and chemical analysis to find the amounts and proportions of plant constituents has been shown to give useful information on digestibility, provided other factors such as age and plant species are taken into account (Sullivan, 1974). Sullivan (1974) divided the chemical analysis methods used into five main groups:

- . Nitrogen and protein concentrations.
- . Fibre levels.
- . Lignin concentration.
- . Cellulose content.
- . Alcohol soluble and insoluble portions.

The crude protein concentration is used widely as a criterion in determining the quality of forages and has been shown to be highly and positively correlated with both the digestibility of dry matter and its own digestibility (Stallcup and Davis, 1965; Manidool, 1974; Sullivan, 1974). The Kjeldahl method for determining the per cent nitrogen concentration is usually used (Harris, 1970), and per cent nitrogen multiplied by 6.25 gives the traditional value for crude protein. Several other methods for determining nitrogen concentration are outlined by Harris (1970).

It was found by Sullivan (1974) that regression equations for predicting the digestion coefficient of dry matter from protein concentration in grasses differs from those for legumes. Correlations were much lower for legumes, and no single prediction equation could be derived for mixed herbage. For practical purposes, the crude protein technique is

good, as only one analysis, that of per cent nitrogen, which is relatively easily performed, is required and only a small forage sample is needed (Manidool, 1974; Sullivan, 1974).

Perhaps the most widely used chemical measure of quality in forage is crude fibre concentration. Fibre is the least digestible portion of the feed, and a high fibre level is an indication of low digestibility in both grasses and legumes (Sullivan, 1974). Determination is again relatively simple and requires only a small sample (Harris, 1970), but a major criticism is that crude fibre is not a single uniform substance, and its composition varies. As fibre levels increase, the digestibility of the fibre decreases, so that in high fibre forages the fibre has a lower digestibility than fibre from a lower fibre forage (Kivimäe, 1960; Sullivan, 1974). The inadequacy of crude fibre as a determinant of nutritive value of a forage was clearly established some time ago (Norman, 1935, cited by Raymond, 1969), and van Soest (1976) was particularly critical of this method. However, it is the easiest of the fibre determination methods (Kivimäe, 1960) and so is still used in many instances.

Several other fibre determination methods, including normal acid fibre, acetic acid fibre and ammonium oxalate fibre, have been considered more precise than crude fibre (Raymond, 1969), although other workers (Kivimäe, 1960; Harris, 1970; Sullivan, 1974) found them to be no more accurate. Detergent fibre analysis methods, in which the weight of fibre is related to digestibility of the forage, are rapid, but again are claimed to be no more accurate than crude fibre (Sullivan, 1974).

The two fibre methods developed by van Soest

(1963a, b), neutral detergent fibre and acid detergent fibre, are probably the best for predictive purposes. Neutral detergent fibre is considered to determine cell wall and cell content, and cannot be used with feeds that have high protein and low fibre concentrations (Harris, 1970). Acid detergent fibre provides a rapid method for the determination of lignocellulose, and this method is often used as a preparatory step for lignin determination (Harris, 1970). Van Soest (1963b) obtained a correlation between acid detergent fibre and digestible dry matter of $-.79$ compared with $-.73$ for crude fibre and digestible lignin.

McLeod and Minson (1974) criticised the method used by van Soest (1963b), in that no allowance was made in the acid detergent fibre method for variable levels of ash. These workers found that pre-treatment of the sample with a neutral detergent reduced the level of ash significantly. However, they were working with forages from tropical pasture species that might well have had much higher ash levels than the temperate forages used by van Soest (1963b) in the development of this method. Joshi (1972) found the acid detergent fibre method of van Soest (1963b) to be more closely related to digestible dry matter and digestible organic matter within forage classes than the neutral detergent method, but where a comparison of different forages was being made he found no difference (except in the case of silage, where the acid detergent fibre method had a definite advantage).

Like other workers (Kivimäe, 1960; Sullivan, 1974), Joshi (1972) found that lignin gave the best estimation of digestibility. Correlations given by total lignin with digestible dry matter of $-.95$ in grasses and $-.83$ in lucerne

were higher than those obtained with any other constituent, and errors of prediction were lower (Sullivan, 1974). Acid insoluble lignin (also known as acid detergent lignin), utilizing the acid detergent fibre method of van Soest (1963b) as a preparatory step, is, however, the more usual method of lignin determination (Harris, 1970). Correlations of between $-.66$ and $-.95$ with *in vivo* digestibility of dry matter within individual species have been reported by Oh et al. (1966).

Methoxyl determination was proposed as an alternative to the complex and expensive lignin method (Kivimäe, 1960) as being easier and less expensive, but its accuracy was much more variable. Kivimäe (1960) found that the lignin method enabled a more accurate estimation of the digestibility of different plant species and mixed herbage, at different stages of both growth and regrowth, than did measurement of other components (with the exception of methoxyl in some circumstances). However, there were still the problems of varying composition of the lignin and the degree of contamination with other substances (Kivimäe, 1960).

Two cellulose determination methods were recognised by Sullivan (1974), one for natural, and the other for true cellulose. True cellulose determination was described by Harris (1970) as an indirect method of determining lignin. The natural cellulose method can be used for grasses but not for legumes (because natural cellulose is greater than true cellulose in grasses but equal in legumes), and the method involves further breakdown of true cellulose. Errors are smaller, but the method is tedious (Sullivan, 1974).

Alcohol soluble and insoluble matter determinations overlap with other determinations. Alcohol insoluble matter

includes all cell wall materials, together with much of the protein and other substances insoluble in 80 per cent alcohol. It is a larger proportion of the plant than crude fibre, and is negatively correlated with digestibility. A further breakdown of this to non-protein alcohol insoluble material gives a closer correlation with digestibility (Sullivan, 1974). Alcohol soluble matter is positively correlated with digestibility, but this fraction is very easily changed during harvest or preservation, and estimations based on this are therefore likely to be much more variable than with measurements of other constituents (Sullivan, 1974).

1.2.5 *Choice of Method*

The method used to evaluate a forage depends very largely on the accuracy required, together with availability of both equipment and time. The type of plant material and the type of comparisons being made should also be taken into account. Kivimäe (1960), working with red clover and timothy, found that crude fibre and lignin determinations were equally reliable for the prediction of digestibility of dry matter of the legume, but for the grass the lignin or methoxyl methods were more suitable than crude fibre. Oh *et al.* (1966) and van Soest (1976) were both critical of chemical analyses and recommended that none of them should be used where it was at all possible to use *in vitro* methods.

The Tilley and Terry method probably gives the best estimate of *in vivo* digestibility and can be used in most circumstances for accurate prediction of forage nutritive value (Raymond, 1969). If *in vitro* analysis is not practical, then the acid detergent fibre method of van Soest (1963b) is probably

the best of the chemical methods, although neither the lignin nor the crude protein determination should be overlooked (Raymond, 1969). Although a full *in vivo* determination of digestibility must be regarded as the best and most accurate method of determining the nutritive value of a forage, for the plant breeder or the agronomist, the large quantity of forage and the number of animals that this requires allows only a limited range of lines to be evaluated at one time. The use of the *in vivo* method, therefore, is usually only possible at the final stages in the evaluation of a new forage species or genotype.

CHAPTER TWO

DRY MATTER YIELD AND NUTRITIVE VALUE

OF SPRING-SOWN SWEET LUPINS

(Lupinus angustifolius CV. UNIHARVEST)

2.1 INTRODUCTION

In the period 1930 to 1950, lupins were grown in New Zealand, mainly in Canterbury, both as a green manure and as a summer greenfeed, principally for lamb fattening (Hudson, 1934; Anon., 1938; Hamblyn, 1940; McPherson, 1940; Anon., 1942; White, 1961; Withers, 1973a). This practice declined, probably due to the high alkaloid content of the bitter cultivars (Anon., 1938; Anon., 1942; Lancaster and Adams, 1943; Allen, 1949), pod shattering, and the consequent difficulties in obtaining seed (Greenall, 1958). The increasing popularity of other summer greenfeeds, particularly lucerne (Greenall, 1958; Whatman, 1959; White, 1961; Stoker, 1974; Lees, 1975; Withers, 1975b), also hastened the decline in the use of the crop.

With the more recent introduction of improved, sweet cultivars (Withers, 1975b) and increasing problems with lucerne (Coop, 1977; Burnett *et al.*, 1978; Harvey, 1979a, b), the possibility of lupins being used more extensively as a summer greenfeed for fattening lambs, or in the autumn for flushing ewes, can be considered. Western Australian work on nutritive value (Gladstones, 1959, 1970a, b, d; Carbon *et al.*, 1972; Arnold *et al.*, 1975, 1976a, 1978; Arnold and Charlick, 1976; Mulholland *et al.*, 1976; Arnold and Wallace, 1977) was mainly

concerned with evaluation of the crop as a dry standing feed, and there is little published information on the digestibility of the green fodder apart from that of Allison and Thurston (1952).

Some preliminary results under Canterbury conditions, obtained by Clarke (unpub.) from unreplicated trials, showed lypin plants (*L. angustifolius* cv. Unicrop) to have *in vitro* digestibilities of up to 93.7 per cent at 42 days after sowing. Dry matter production in relation to other summer greenfeeds has, however, not been found to be promising (Macmillan and Brown, 1973; Knight, 1980 pers. comm.), although a yield of just under 2 000 g m⁻² from irrigated *L. angustifolius* was obtained by Herbert (1977a).

The purpose of the experiment reported here was to measure the dry matter accumulation of *L. angustifolius* cv. Uniharvest over time, and to measure variation in some of the components of nutritive value of the crop in order to determine a possible optimum time for grazing the crop to maximise both yield and nutrient quality.

2.2 MATERIALS AND METHODS

2.2.1 The Trial Site

This investigation was carried out during the 1978-79 summer season, by sampling within the extensive border rows from an existing agronomic trial. This was situated on the Lincoln College Henley Block on a Templeton silt loam soil type (Soil Bureau, 1954). The trial was unirrigated. Previous crops grown on the trial site were:

- . 1975-76 - Wheat, sown after a one year white clover and perennial ryegrass pasture, which responded well to nitrogen addition (Dougherty, Love and Mountier, 1978, 1979).
- . 1976-77 - Lupins at 50 cm row spacings (a seed multiplication crop).
- . 1977-78 - Wheat, from which an unpublished nitrogen response was obtained.
- . Winter 1978 - A very poor greenfeed oat crop which was ungrazed and ploughed in.

Four different areas of the border (sown on 26 September 1978) were used as replicates.

2.2.2 *Treatments*

Sampling was carried out at approximately 21 day intervals from 9 November 1978 (45 days after sowing) until 6 March 1979, just prior to seed harvest, giving seven sample dates.

2.2.3 *Sampling*

At each harvest, for each replicate, four 0.25 m² quadrats were cut, and the material bulked. A sub-sample for the determination of *in vitro* digestibility and nitrogen concentration was taken, frozen immediately and freeze dried at a later date.

2.2.4 Measurements

(i) Dry Matter

All green material collected was weighed and one tenth was oven dried to obtain the dry matter concentration. Both total dry matter and the proportion by dry weight of the various plant components were measured.

(ii) Nitrogen Concentration

The nitrogen concentration of the bulked whole plant, and of the plant components, was determined using the micro-Kjeldahl digestion and auto-analyser measurement of ammonia. For ease of comparison with other published material, nitrogen concentration was converted to crude protein by multiplying by 6.25.

(iii) Digestibility

The *in vitro* digestibility of the whole plant and separate plant components was assessed using the two stage *in vitro* analysis outlined by Tilley and Terry (1968) on 0.5 g samples of the forage, freeze dried and ground to pass through a 0.5 mm screen. Three blanks (no sample) and three samples of a known standard were run with each batch. Digestibility was then calculated as follows:

$$\frac{\text{Initial} - \text{residue} - \text{blank}}{\text{Initial}} \times \frac{100}{1} = \% \text{ digestibility}$$

(Tilley and Terry, 1968)

(iv) Metabolizable Energy

Metabolizable energy was calculated using the following formula:

$$\text{ME(MJ)} = \text{DDM (kg)} \times \text{GE(MJ)} \times .81$$

where: DDM is the digestible dry matter as calculated from measurements obtained using the *in vitro* method outlined.

GE is gross energy. This is normally determined in a bomb calorimeter, but an average value of 18.2 MJ kg DM⁻¹ was calculated using the GE figures for all green legumes given by M.A.F.F. (1975). This value should be valid for all stages of growth measured, with the possible exception of the final mature dry stage. A value of 20.6 for sweet blue lupin seeds was given by M.A.F.F. (1975) but the value for pods was only 17.7 and it was therefore decided to use the 18.2 average for all stages.

The sum of methane and urine energy loss is considered to be reasonably constant as a proportion of digestible energy (DE) averaging 19% (M.A.F.F., 1975).

Thus ME = .81 DE.

2.2.5 *Statistical Analysis of Results*

Results were analysed using the standard statistical programme, TEDDYBEAR, developed by Wilson (1979).

2.3 RESULTS

2.3.1 *Dry Matter Accumulation*

Plant emergence was very slow, possibly due to a spell of very dry weather which was experienced in the two weeks following sowing (Figure 2.1). Not all the plants in the final population had emerged by the first sampling date (45 days after sowing), and for this reason a plant count to establish plant population was delayed until the second sampling date (66 days). Mean plant population at this stage was 80 plants m^{-2} . No attempt was made to control weeds and these were a problem in two of the plots.

At 45 days after sowing, the plants were between 30 and 90 mm high and were at the four to eight leaf stage. Total dry matter accumulation was very low, at only 16.4 g m^{-2} (Figure 2.2). This had increased by just over four times to 66.7 g m^{-2} by 66 days after sowing, as rapid growth had taken place. The plants were up to 400 mm high and secondary branching had commenced. Primary (main axis) flowering (see Herbert, 1977a) began at about 84 days after sowing and most plants were flowering by 87 days. Dry matter was still increasing rapidly with the growth of secondary branches and had reached 250.4 g m^{-2} at 87 days. By 109 days after sowing, green pods were beginning to form on the main stem, and flowering on the secondary branches had just finished. Although leaf drop had just begun, dry matter was 645.5 g m^{-2} at this stage and was still increasing (as the pods filled) to reach 844.8 g m^{-2} at day 129. A peak of 987.4 g m^{-2} was recorded at day 150. Leaf drop had nearly finished at this stage, and the plants were drying off. Growth rate from day 66 to day 150 was just under 11.0 g m^{-2}

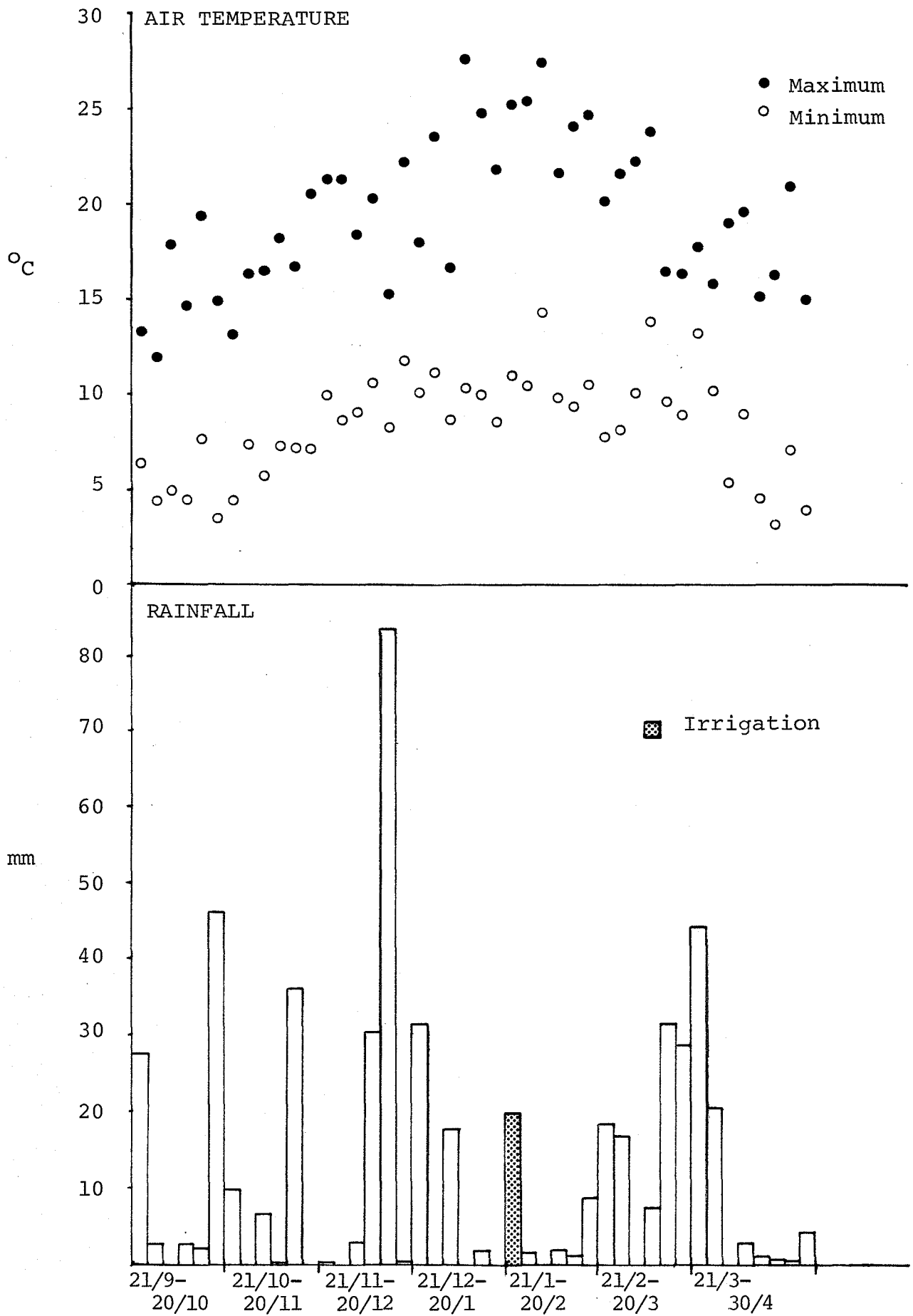


Figure 2.1: Temperature and rainfall records for the 1978-79 growing season (five day averages).

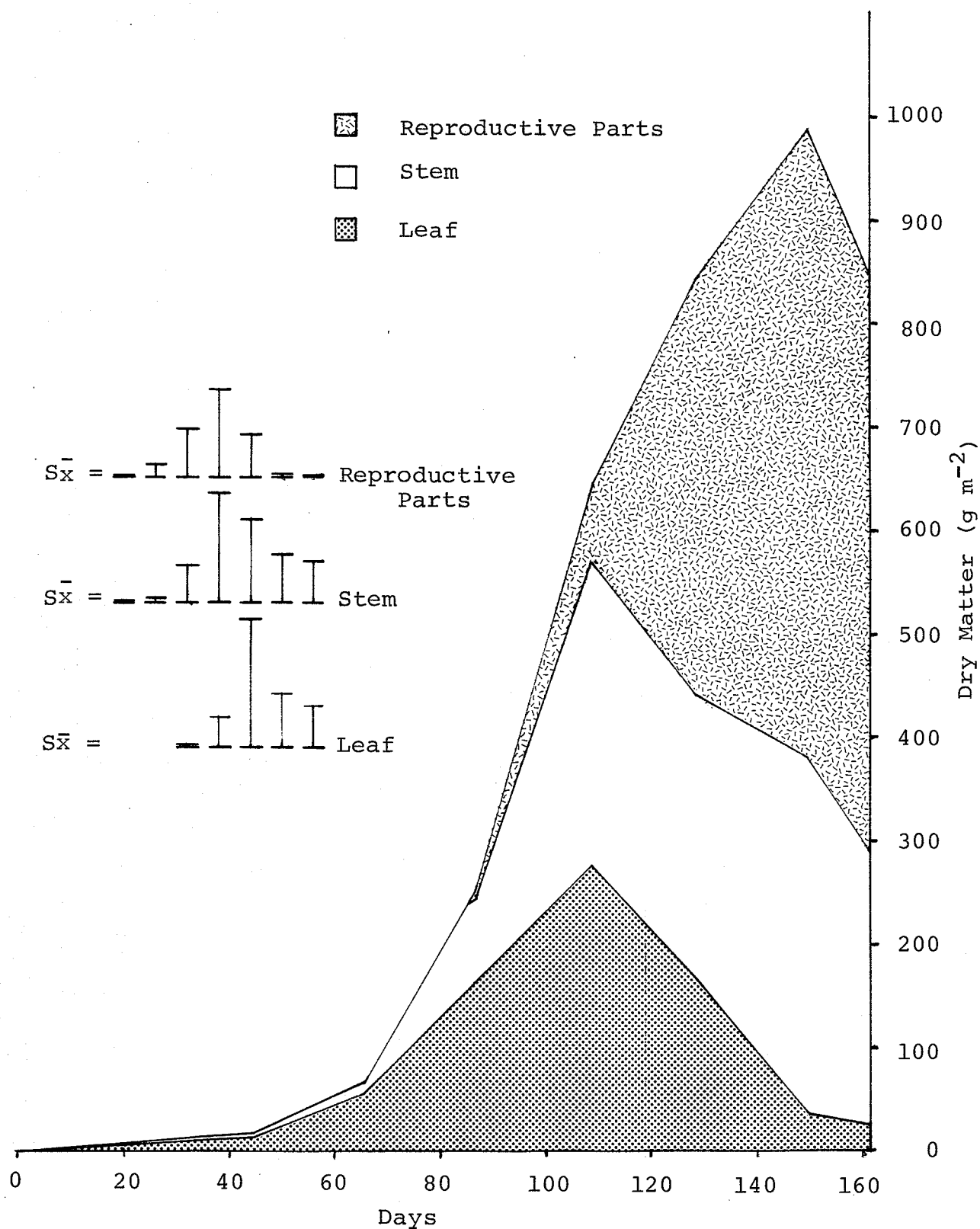


Figure 2.2: Dry matter accumulation of *L. angustifolius* cv. Uniharvest, with time.

day⁻¹.

Little or no leaf was left at the final harvest (162 days after sowing), when the pods were ripe and the plants almost completely dry. Dry matter totalled 841.3 g m⁻² at this stage.

2.3.2 *Change in the Proportion of Plant Components Over the Growing Period*

At 45 days after sowing, the proportion of leaf, including petiole, was just under 88 per cent (Figure 2.3). As the plant aged, this proportion decreased rapidly as the proportions of stem, and later of pod, increased and leaf drop commenced. The proportion of pod increased with age until day 124 when (from the fitted regression curve) it was 38 per cent of the total plant. As the seeds filled, the proportion of reproductive parts increased rapidly from just over five per cent at 87 days to over 70 per cent at 162 days, which accounted for the decrease in stem proportion.

Regression analysis of total dry matter and plant component proportions (Figure 2.4) showed that the proportion of leaf was the best indicator of total dry matter present.

$$DM = 1008.25 - 11.21 \text{ LEAF} \quad ***$$

$r = -.85$. The proportion of reproductive parts could also be used from day 87 onwards.

$$DM = 104.51 + 31.17 \text{ REPR.} - .36 \text{ REPR}^2 \quad ***$$

$r = .83$. Although the regression was highly significant ($P \leq 0.001$) for the proportion of stem and dry matter ($r = .64$), the equation

$$DM = -217.43 + 25.1 \text{ STEM} \quad ***$$

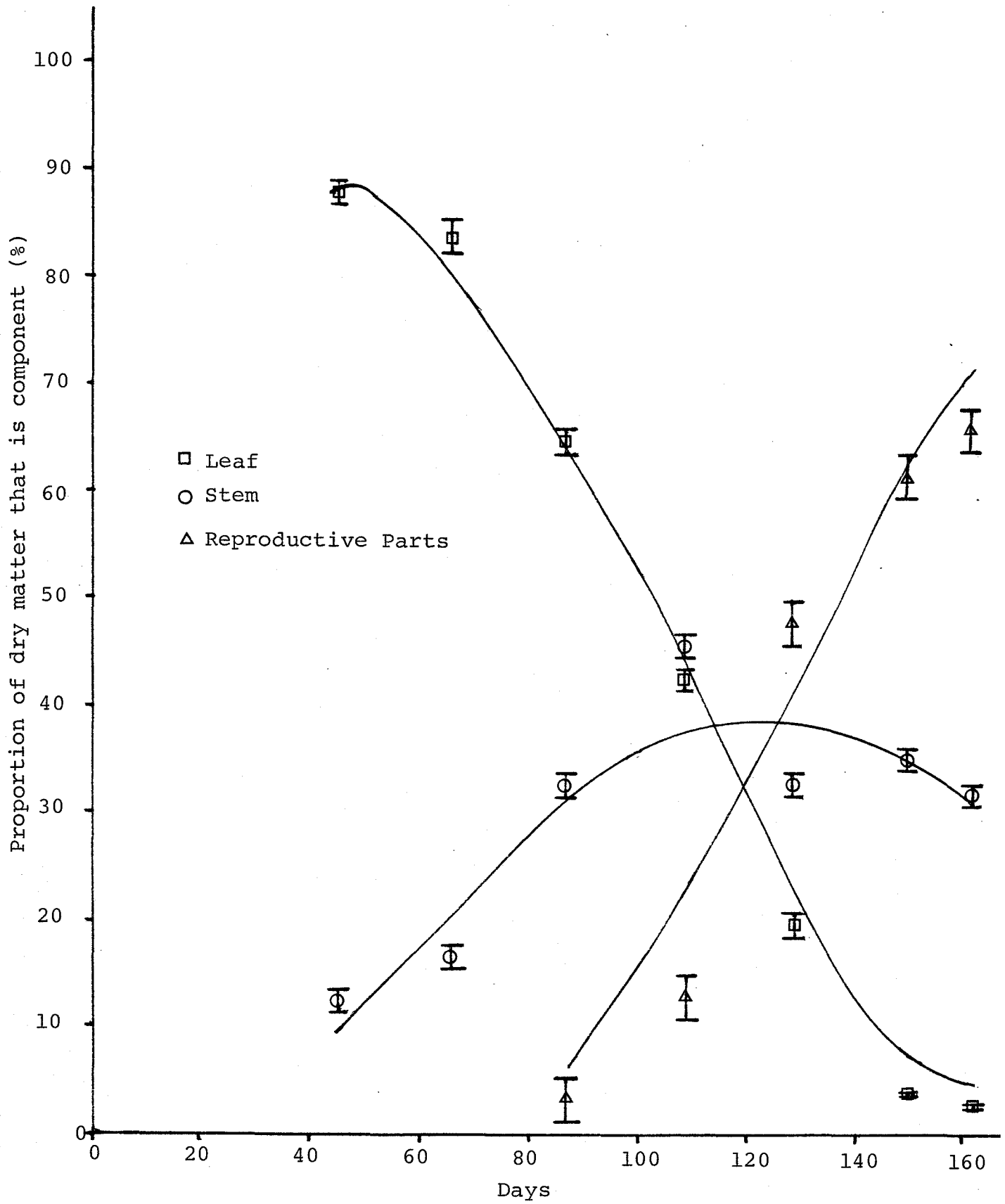


Figure 2.3: Changes in proportion of plant components of *L. angustifolius* cv. Uniharvest, with time.

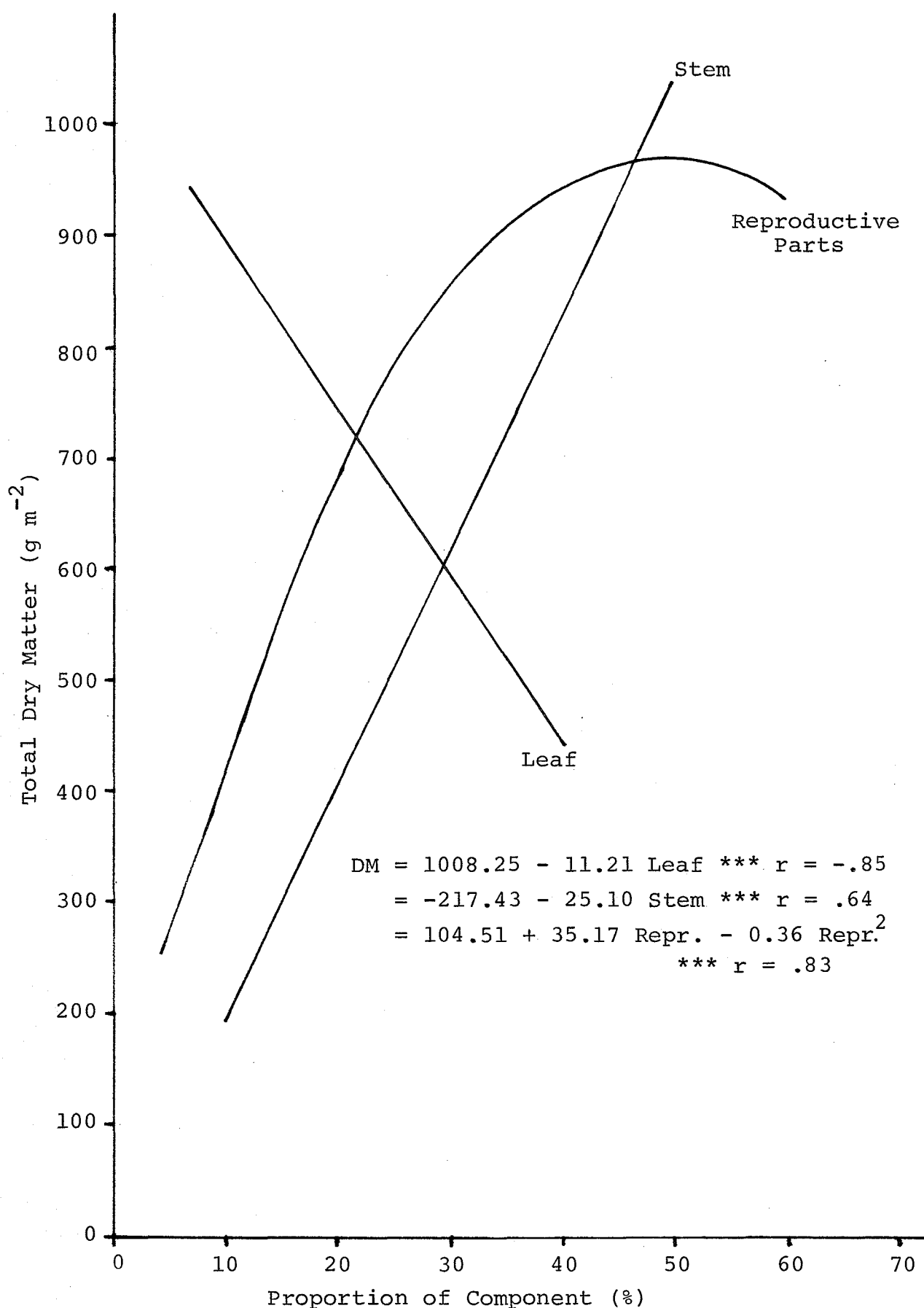


Figure 2.4: Correlation of total dry matter of *L. angustifolius* cv. Uniharvest with component proportions.

only accounted for 41 per cent of the variance. This is explained by the fact that the proportion of stem at first increased, with increasing total dry matter, but then decreased in relation to the proportion of reproductive parts, even though total dry matter was still rising (Figure 2.2).

2.3.3 *Plant Nitrogen*

Total nitrogen followed very much the same trend as dry matter accumulation (Figure 2.5). Nitrogen concentration in the whole plant decreased from 4.6 per cent at 45 days after sowing to just over 2.0 per cent at 162 days (Figure 2.6), but with increasing dry matter the total amount per plant rose from just under 1.00 g m^{-2} at day 45 to 2.33 g m^{-2} at day 66 and 7.17 g m^{-2} at day 87. The sharp increase after this to 20.75 g m^{-2} at day 109 is due both to the rapid increase in total dry matter accumulation, particularly of pods (including seed), and the fact that the nitrogen concentration of the pod increased from 3.2 per cent at 87 days to just over 40 per cent at day 135. Total nitrogen content of the forage at day 129 was 25.2 g m^{-2} , and a peak of 31.63 g m^{-2} was recorded at day 150. This then began to drop, and had fallen to 26.70 g m^{-2} by day 162 as both the total dry matter and the nitrogen concentration of each of the components had decreased. Total plant nitrogen increased at a rate of $0.29 \text{ g m}^{-2} \text{ day}^{-1}$ over the 45 to 150 day period. Due to a shortage of plant material from the first sample, the nitrogen in the leaves and stem was not measured at this harvest. Nitrogen concentration was just under 3.65 per cent in leaves at day 66 and dropped slowly to 3.35 per cent by day 150. Leaf nitrogen was not measured for day 162 due, again, to a shortage of plant material following

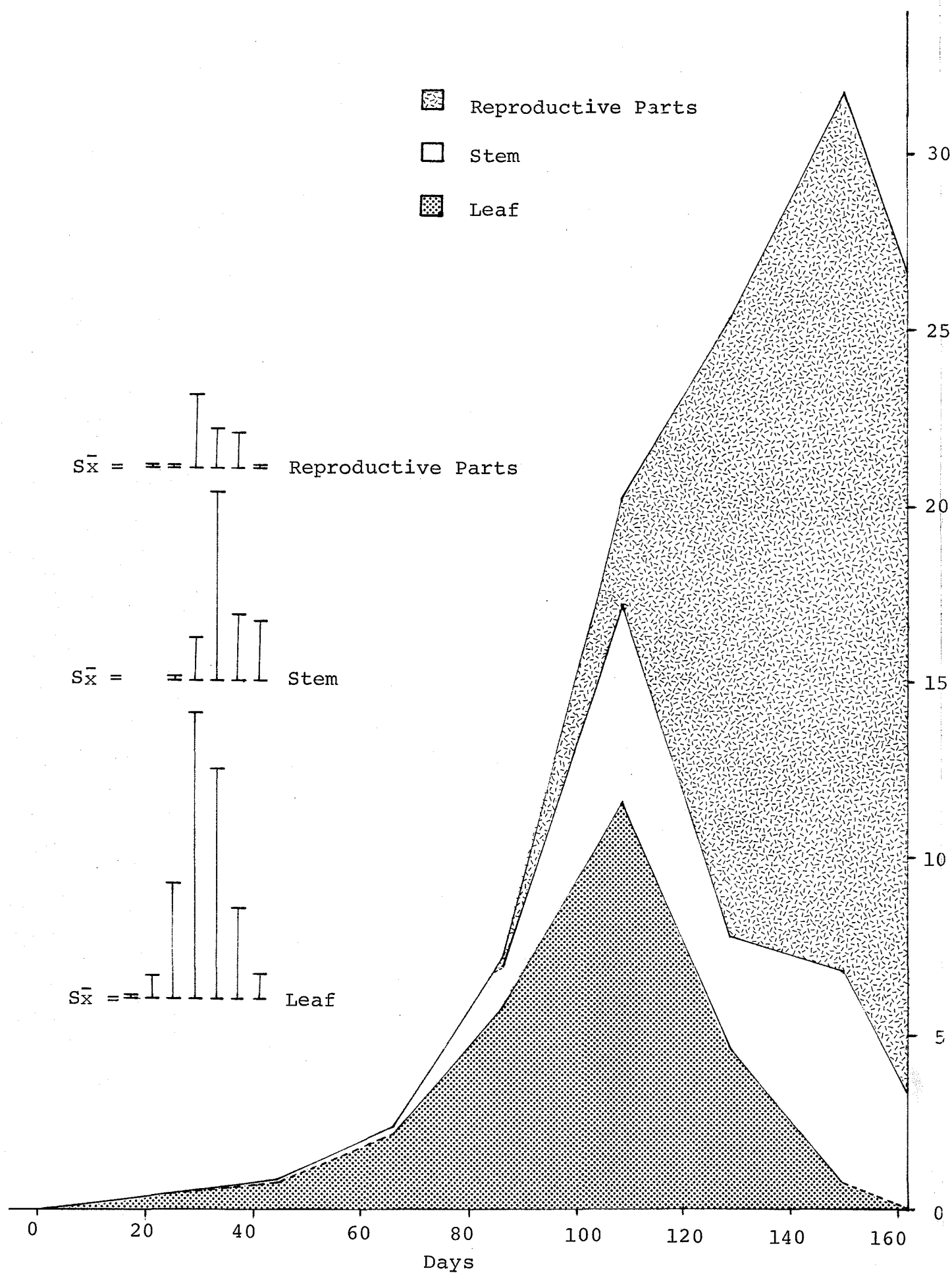


Figure 2.5: Total nitrogen accumulation in *L. angustifolius* cv. Uniharvest, with time.

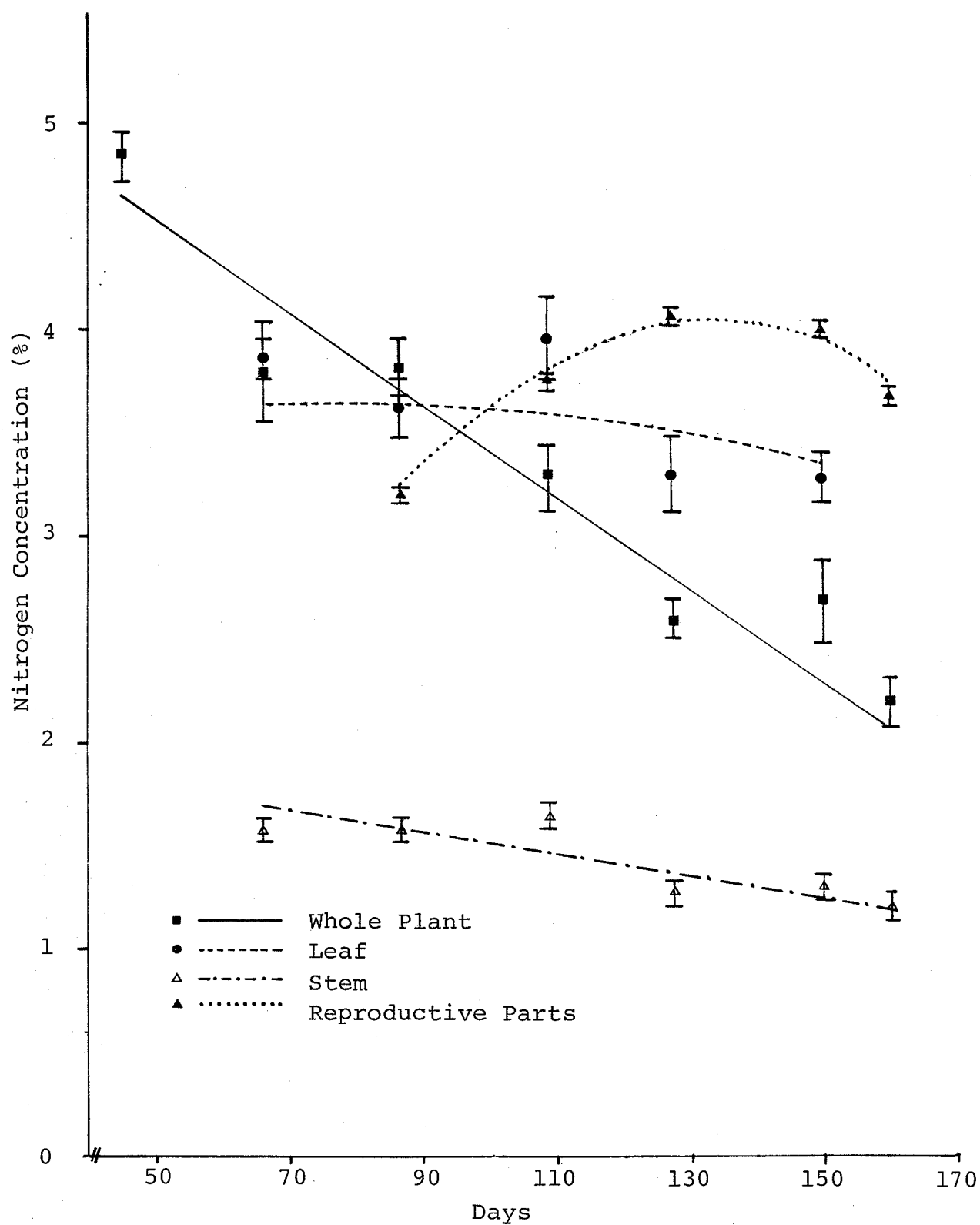


Figure 2.6: Nitrogen concentration of *L. angustifolius* cv. Uniharvest components, with time.

leaf drop. Stem nitrogen decreased from 1.65 per cent to 1.20 per cent over the same period.

2.3.4 *Correlation of Nitrogen Concentration with Total Dry Matter and Plant Components*

The correlation of per cent nitrogen to total dry matter was very highly significant ($P \leq 0.001$), $r = -.84$ (Figure 2.7).

$$N = 4.48 - 0.0045 DM + 0.0000025 DM^2 \quad ***.$$

Initially, per cent nitrogen was high, but as dry matter increased, nitrogen level decreased. However, at higher total dry matter accumulation, nitrogen concentration again began to increase. This is explained by the high proportion of the plant which was pod by this stage.

Of the plant components, per cent leaf was the best indicator of quality in terms of nitrogen concentration of the whole plant (Figure 2.8). The regression equation

$$N = 2.17 + 0.026 LEAF \quad *** , r = .93$$

had a very high level of significance.

As the per cent leaf declined, whole plant nitrogen level decreased. The stem component was not such a good indicator, although the equation

$$N = 7.33 + 0.27 STEM + 0.0039 STEM^2 \quad *** , r = .75$$

was still very highly significant. At low total proportion of stem, whole plant nitrogen concentration was high, but as the amount of stem increased, nitrogen concentration fell. At the stage where the proportion of stem was highest, however, proportion of pod was also high, so that overall nitrogen con-

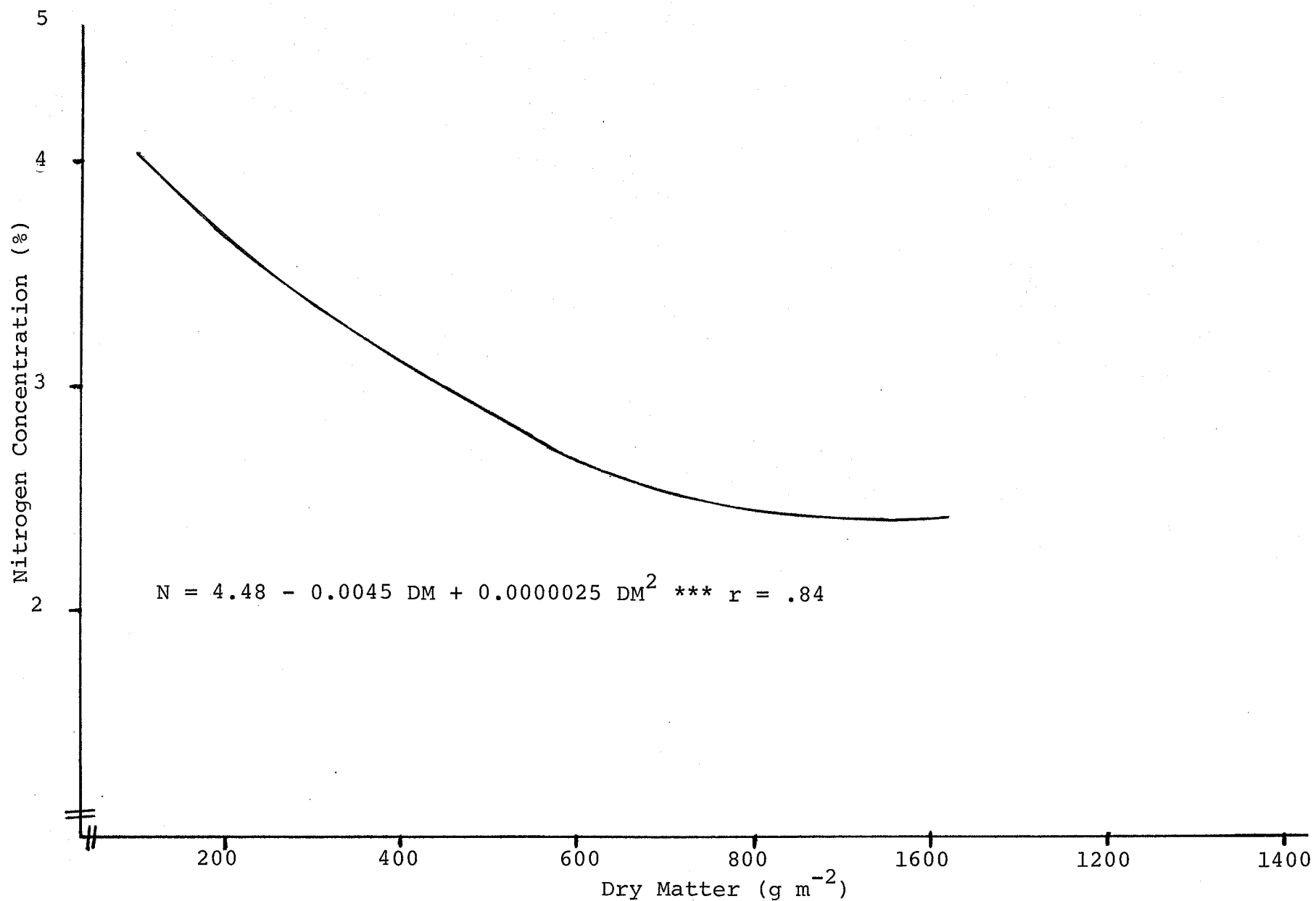


Figure 2.7: Correlation of nitrogen concentration of *L. angustifolius* cv. Uniharvest, with dry matter accumulation.

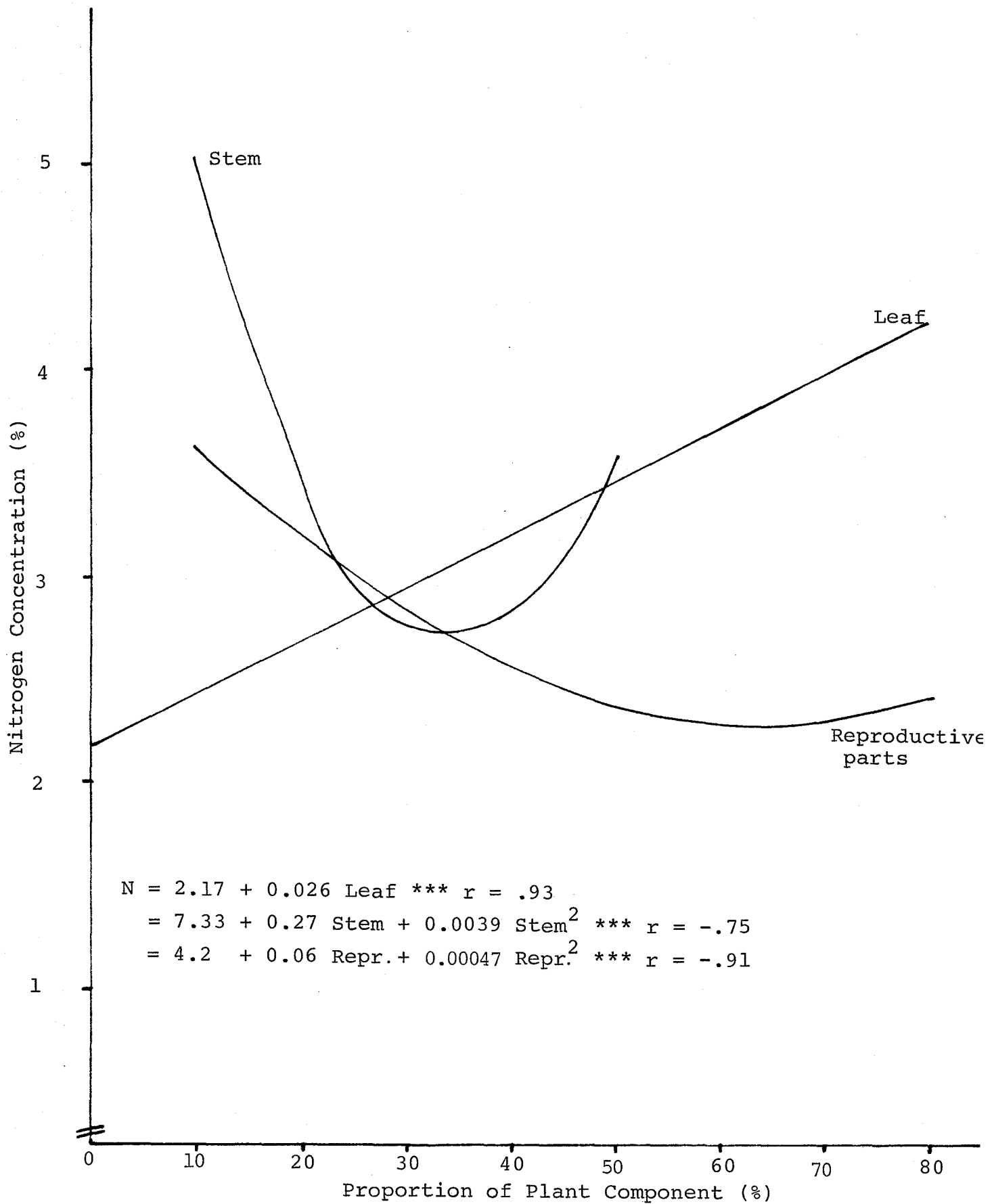


Figure 2.8: Correlation of nitrogen concentration of *L. angustifolius* cv. Uniharvest with proportion of plant component.

centration was again high. Initially, as the proportion of reproductive parts increased, whole plant nitrogen concentration fell due to the presence of the other low nitrogen-containing components. When the highest proportion of reproductive parts had been reached, however, overall nitrogen concentration was slightly increased. The equation is

$$N = 4.2 + 0.06 \text{ REPR.} + 0.0047 \text{ REPR.}^2 \quad *** , r = .91.$$

2.3.5 *Protein Concentration*

A peak protein level of 28.75 per cent in the whole plant was observed in the early stages of the plant's development (45 days) and this decreased as the plant matured to 12.8 per cent at maturity (162 days). The protein in the leaf component varied from 22.8 to 20.9 per cent over the period, and stem protein averaged 8.9 per cent. Peak protein concentration of the reproductive parts (pod valve and seed) was just over 25.0 per cent at 135 days when seeds were fully formed and just beginning to dry off.

2.3.6 *Digestibility*

Whole plant digestibility was highest (just under 65 per cent) at about day 125 (Figure 2.9A), at which point the digestibility of the young pods was rising rapidly. Leaf digestibility, although declining, was still reasonably high at just over 65 per cent (Figure 2.9B), and the stem was also still over 51 per cent digestible (Figure 2.9C). Previous to this, whole plant digestibility had fallen from just under 65 per cent at 45 days to just under 59 per cent at about 98 days (Figure 2.9A). After the peak at 124 days, digestibility

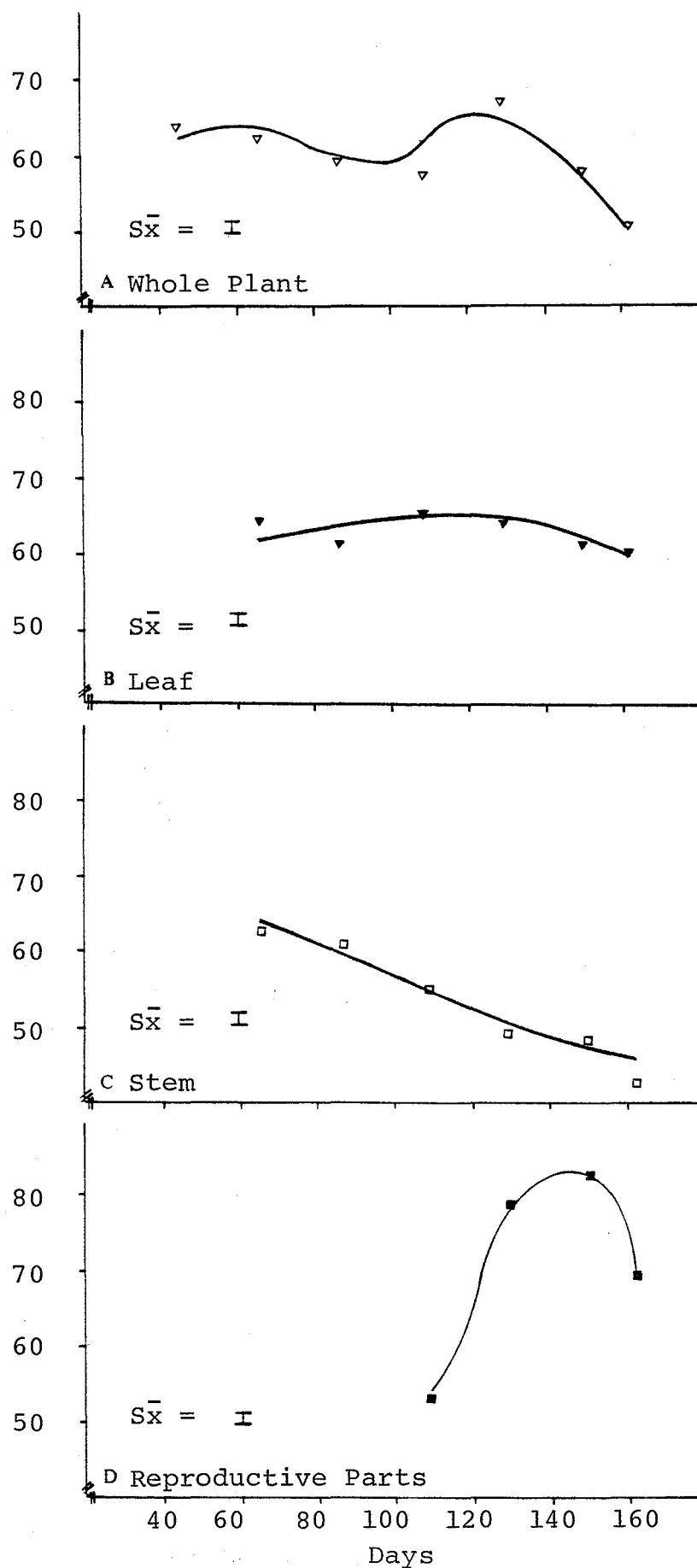


Figure 2.9: Digestibility of *L. angustifolius* cv. Uniharvest, whole plant and plant components, with time.

dropped rapidly to just under 50 per cent at day 162. As might be expected from the small change in protein concentration, leaf digestibility remained fairly constant at between 64 and 65 per cent, and only declined to just over 59 per cent at day 162, when most of the leaf component which remained on the plant was petiole (Figure 2.9B). The digestibility of the stem decreased slowly as the plant aged, from 67 per cent at day 45 to just over 45 per cent at day 162 (Figure 2.9C). Peak pod digestibility was 83 per cent at 148 days (Figure 2.9D). The relatively low digestibility of the flowers at just over 50 per cent at day 98 increased rapidly as pods began to form. Pod digestibility decreased after the peak to just over 70 per cent by day 162.

2.3.7 *Correlation of Whole Plant Digestibility with Proportion of Plant Components and Nitrogen Concentration*

The digestibility of the whole plant was best correlated with the proportion of leaf, rather than with the proportions of stem and reproductive parts (Figure 2.10).

The regression equations were as follows:

$$\text{Digestibility} = 52.1 + 0.071 \text{ LEAF} - 0.018 \text{ LEAF}^2 + 0.00014 \text{ LEAF}^3$$

**, $r = .74$

$$\text{Digestibility} = 65.0 - 0.021 \text{ STEM} \quad *, \quad r = -.48$$

$$\text{Digestibility} = 62.48 - 0.6 \text{ REPR.} + 0.02 \text{ REPR.}^2 - 0.00019 \text{ RPRP.}^3$$

**, $r = -.67$

Only the proportion of stem was linearly related (negative to digestibility). Whole plant digestibility was high with high leaf proportion, coinciding with the early growth stages.

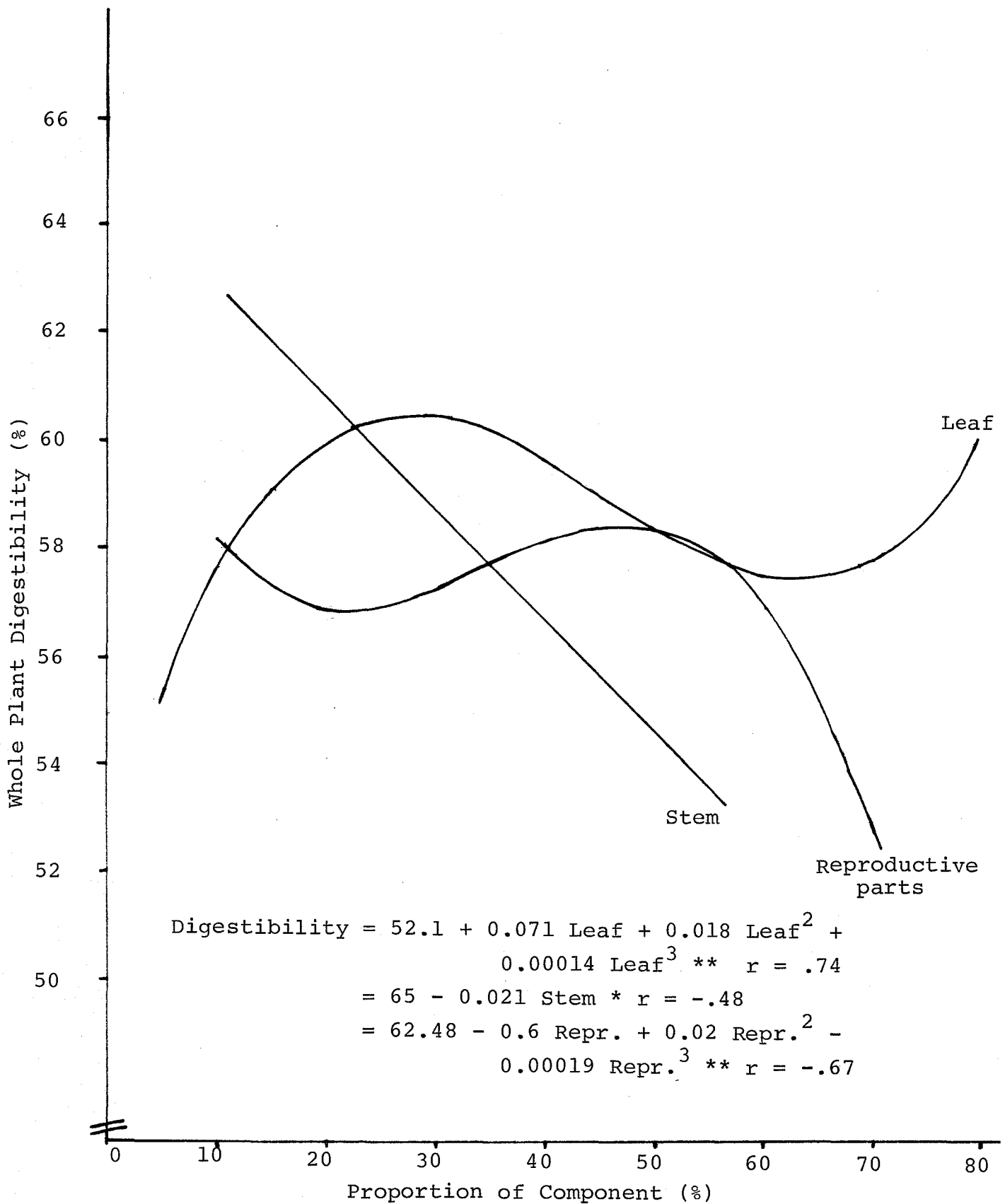


Figure 2.10: Correlation of whole plant digestibility of *L. angustifolius* cv. Uniharvest with component proportions.

It was lower between 55 and 75 per cent leaf, but peak whole plant digestibility was at about 30 per cent leaf (peak pod maturity). With lower leaf proportion, following leaf drop, whole plant digestibility declined. With an increasing proportion of reproductive parts, whole plant digestibility initially decreased (following formation of unfilled pod valves) and then increased to a peak when about 50 per cent of the plant's dry matter was pod. The decline in whole plant digestibility after this was probably a result of the poor digestibility of the other plant components at high levels of pod. There was a very highly significant relationship ($P \leq 0.001$) between digestibility and nitrogen concentration. The relationship was linear and positive (Figure 2.11):

$$\text{Digestibility} = 48.122 + 3.28 N \quad ***, r = .63.$$

2.3.8 Metabolizable Energy Content

The metabolizable energy (ME) of the plant ranged from 8.5 MJ kg^{-1} to 9.4 MJ kg^{-1} , but only at 45 days was the value of 9.4 MJ kg^{-1} significantly higher ($P \leq 0.05$) than over the rest of the period (Table 2.1). Total ME accumulation (Figure 2.12) increased at a rate of $0.079 \text{ MJ m}^{-2} \text{ day}^{-1}$ after day 50 and reached a peak of 8.05 MJ m^{-2} at day 152, corresponding closely to peak dry matter accumulation. As the digestibility of the plant changed very little over the period, dry matter and total ME available (MJ m^{-2}) were very closely related:

$$\text{ME} = -0.024 + 0.0088 \text{ DM} \quad ***, r = .97.$$

ME (MJ m^{-2}) could also be predicted from the nitrogen concen-

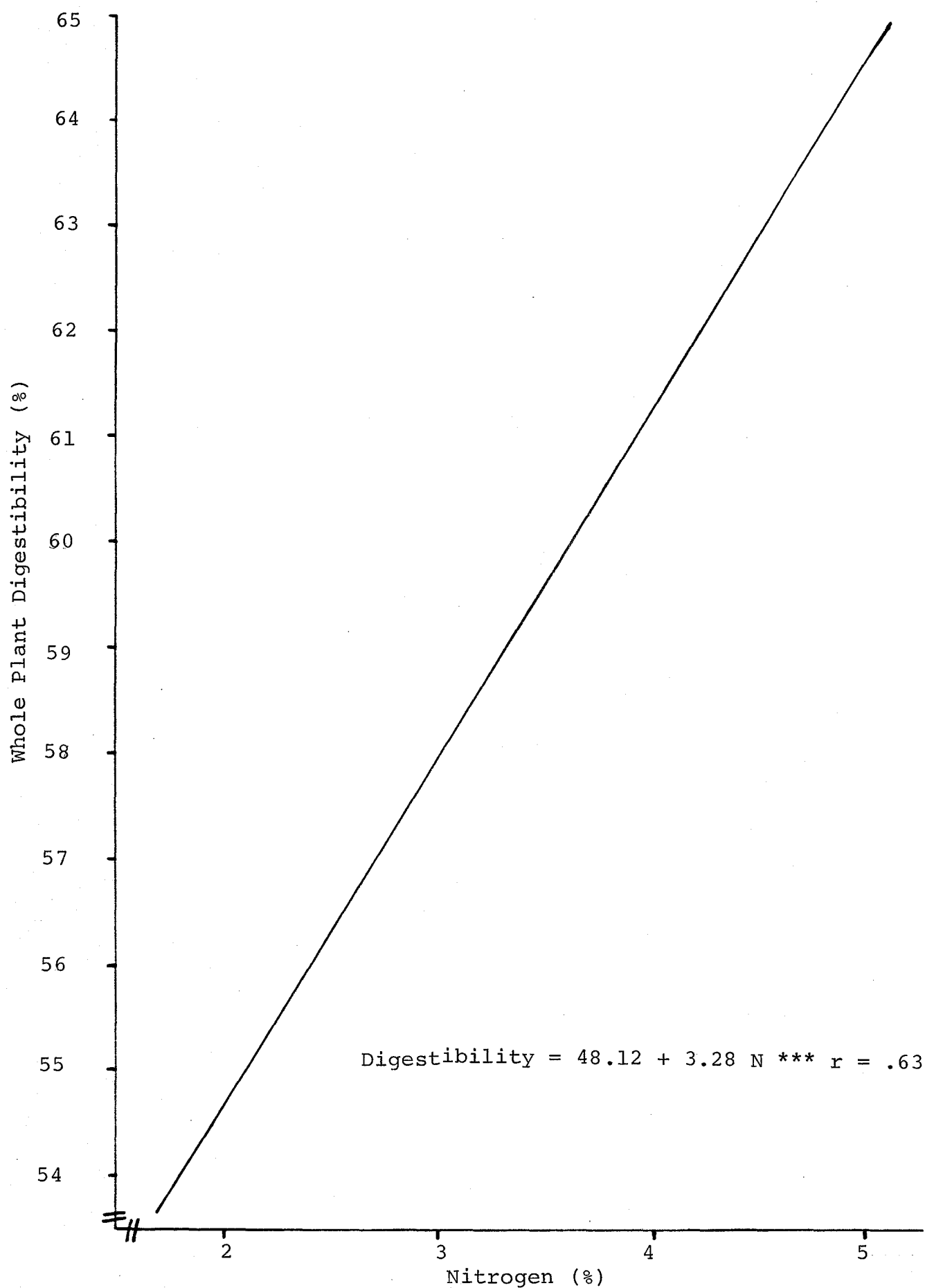


Figure 2.11: Correlation of the whole plant digestibility of *L. angustifolius* cv. Uniharvest with nitrogen concentration.

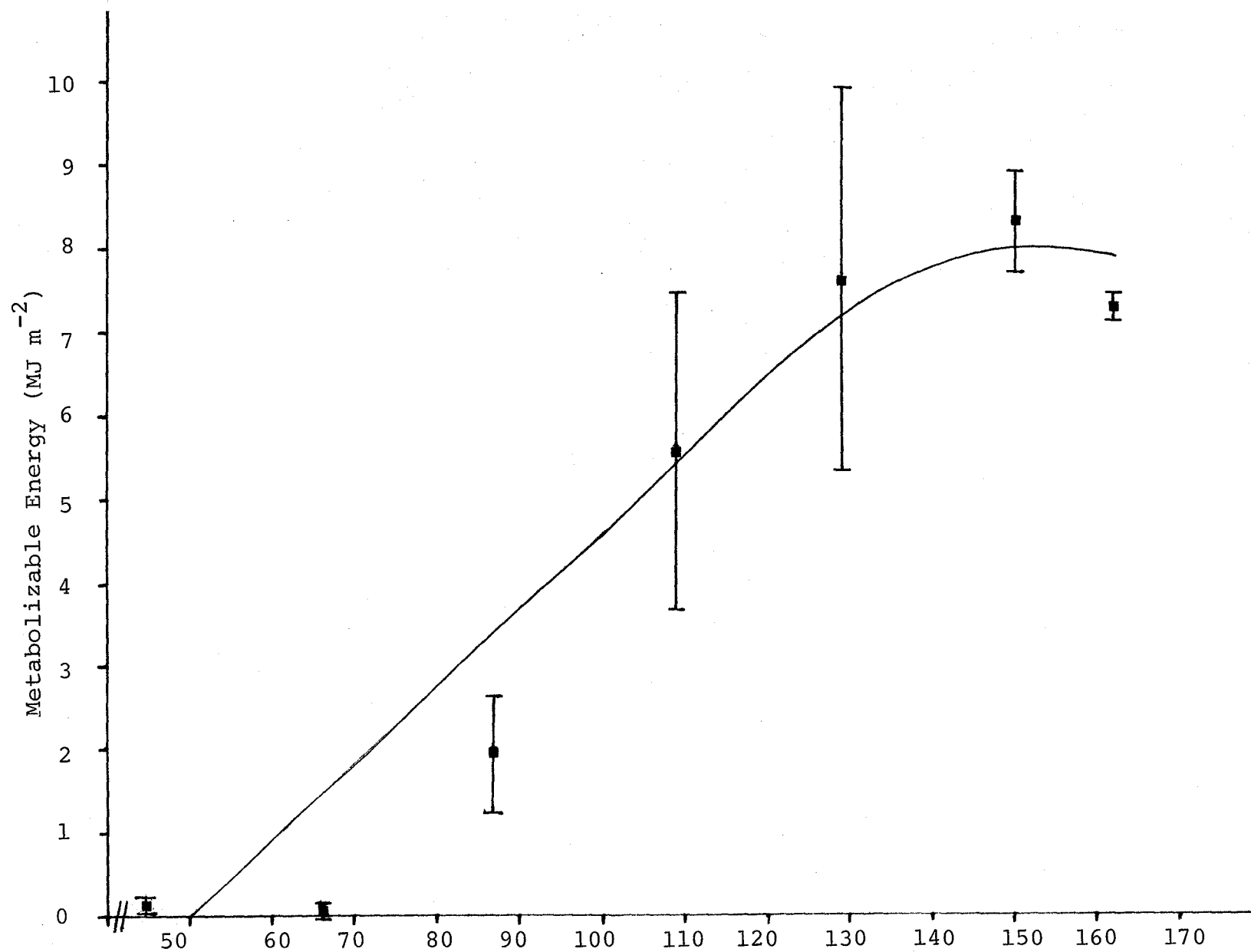


Figure 2.12: Metabolizable energy accumulation (MJ m⁻²) of *L. angustifolius* cv. Uniharvest, with time.

tration of the whole plant, but was not so highly correlated:

$$ME = 14.83 - 3.13 N \quad ***, r = .75.$$

The proportion of the various plant components could also be used as an indicator of total ME available:

$$ME = 8.78 - 0.097 \text{ LEAF} \quad ***, r = .84$$

$$= -1.76 + 0.215 \text{ STEM} \quad ***, r = .62$$

$$= 0.921 + 0.305 \text{ REPR.} - 0.0031 \text{ REPR.}^2 \quad ***, r = .82.$$

Table 2.1: Metabolizable energy concentration of lupins
(*Lupinus angustifolius* cv. Uniharvest).

Days After Sowing	ME MJ kg ⁻¹
45	9.36
66	9.18
87	8.74
109	8.50
129	9.00
150	8.52
162	8.73

$$S\bar{x} = 0.23$$

2.4 DISCUSSION

Dry matter accumulation followed very much the same trend as that found by Herbert (1977a). However, the peak yield of 987 g m⁻² after 150 days, at a plant density of 80 plants m⁻², was less than the 1 200 g m⁻² in 116 days reported by him under unirrigated conditions, and considerably less than the 2 000 g m⁻² in 130 days obtained under irrigation for *L. angustifolius* at a density of 92 plants m⁻² (Herbert, 1977a). The very slow emergence and poor initial growth in this trial probably de-

creased the potential total yield. On the other hand, the yield of this trial compared very favourably with the 4 120 kg ha⁻¹ in 104 days obtained by Macmillan and Brown (1973) under summer conditions in Canterbury, and also with yields of sweet blue lupins obtained by other workers in both New Zealand (Allison and Thurston, 1952; Greenall, 1956; van Stevenick, 1956; Knight, pers. comm.) and overseas (Edwardson and Corbett, 1959; Nel, 1965). This yield was, however, lower than that of a crop of New Zealand Bitter Blue lupins (van Stevenick, 1956).

Primary flowering began at 84 days, at just under 24 per cent dry matter accumulation. Flowering was later than that observed by Porter *et al.* (1976) (77 days) and Herbert (1977a) (62 days), but was within the range of dry matter accumulation (17-25 per cent) at commencement of flowering, reported by Perry (1975). The later flowering was probably due again to the slow early growth of the crop, and the high dry matter accumulation may well be related to density, as secondary branching was not inhibited at this density and was well started by the 84th day.

The yield of both leaf and stem components peaked at about 109 days, and pod at approximately 150 days, which coincided with peak total dry matter. This was a much greater time span than that observed by Greenwood *et al.* (1975) who found maximum dry matter of leaf, stem and pod to occur at 133, 140 and 147 days respectively under Western Australian spring conditions. At a medium density (92 plants m⁻²), Herbert (1977a) found leaf and stem peaked at the same time (102 days) but this was much later and at different times, at both lower (27 plants m⁻²) and higher (156 plants m⁻²) densities.

From the regressions of total dry matter accumulated with per cent plant component (Figure 2.4), the proportion of leaf present was the best indicator of total dry matter present. As total dry matter increased, the proportion of leaf fell rapidly.

Nitrogen and protein concentrations were high, and were higher than expected at the pre-flower stage; 24 per cent protein in the whole plant as compared with both bitter and sweet *L. angustifolius* (17-18.1 per cent) (Anon., 1938; Lancaster and Adams, 1943; Allison and Thurston, 1952). There was little drop in protein level at flowering, and it was again higher than that recorded by Anon. (1938) for bitter *L. angustifolius*. At maturity, however, the whole plant protein level had dropped to just over 13 per cent, which was lower than the 15.9 per cent of Anon. (1938). Although nitrogen and protein levels fell steadily as the plant aged, increasing dry matter compensated for this, and peak total nitrogen coincided with peak dry matter accumulation at 150 days.

The prediction of digestibility from nitrogen or protein concentration was not shown to be very accurate. Several workers (Stallcup and Davis, 1965; Manidool, 1974; Sullivan, 1974) have shown protein concentration to be positively and highly correlated with dry matter digestibility. However, Sullivan (1974) found that this correlation was much lower for legumes.

Fibre or lignin determinations could well have given better correlation. Both the crude fibre and neutral detergent fibre methods would have been unsuitable, the first because of the decreasing digestibility of fibre as fibre levels increase (Kivimäe, 1960; Sullivan, 1974). Clearly this is not

a method to be used when comparing a forage over a period of time. The second is not recommended where feeds have high protein and low fibre concentration (Harris, 1970), both of which, especially at the earlier stages of growth, would have been likely with the lupin material. Both acid detergent fibre determination (van Soest, 1963b) and total lignin concentration would probably have been suitable, each being fairly reliable for legumes, although correlations are lower with lignin determination (Sullivan, 1974). However, both methods are reasonably complex, and as *in vitro* digestibility determinations were carried out, chemical analysis other than nitrogen (crude protein) concentration was not considered necessary.

The *in vitro* digestibility of the forage was highest, 26 days before peak dry matter and nitrogen accumulation, at day 124. The value of just under 65 per cent was very much lower than that expected from the preliminary work of Clarke (unpub.), who obtained a peak digestibility of 93 per cent at 42 days after sowing, and the material was still 87 per cent digestible at 126 days. Plant component digestibilities in the present trial were all lower, and followed different trends from those obtained by Clarke.

Although digestibility was highest at 124 days, total metabolizable energy coincided with peak dry matter and protein at 150 days, and it was therefore at this stage, when the plants were drying off, that the maximum total energy and protein would have been available for grazing. This was a little later than the stage recommended by van Stevenick (1956), who found the highest amount of digestible fodder to be present when the green pods were full sized and the lower leaves of the

plant were just beginning to drop.

This is in contrast with lucerne, in which the highest dry matter yields were obtained at the green bud or 10 per cent flower stage, and whole plant digestibility declined rapidly as the proportion of leaf fall with increased maturity of the plant (Thom, 1978).

The yield of lupins obtained in this trial compared favourably with that of other fodder crops. Although it was less than the summer production of good lucerne stands (Wier *et al.*, 1960; O'Connor *et al.*, 1968; Vartha and Allison, 1973; Hogland *et al.*, 1974), it was better than many others, especially those on unirrigated land reported by Iverson (unpub.) and Vartha (unpub.) (both cited by Vartha, 1971), and those where disease and insect damage had occurred (Burnett *et al.*, 1978; Dunbier *et al.*, 1979b; Harvey, 1979a, b; Kain *et al.*, 1979a).

Production from this trial was higher than that obtained from summer crops of kale and rape in the South Island (Macmillan and Brown, 1973; Mortlock, 1975), and was considerably higher than the average summer pasture production recorded by O'Connor *et al.*, (1968).

A lupin crop sown in September and grazed at about 150 days after sowing would fit well into the cropping rotations practised on many Canterbury farms. Grazed *in situ*, the crop contributes to the nitrogen level of the soil indirectly, through dung and urine return, and could well play an important role as a fertility restoring crop used between cereals.

Lupins could also have a role in a pasture renewal situation in which old pasture could be ploughed in the spring, put into lupins to be grazed in mid-to late summer and sown with

new grass in the autumn. In view of the increased cultivation and sowing costs involved, however, this practice may not be considered economic by many farmers.

2.5 CONCLUSION

The maximum amount of dry matter obtained from this crop was available at 150 days after sowing. In spite of both declining digestibility and protein concentration, the maximum amounts of metabolizable energy and total protein were also available at this stage.

With a potential such as this, together with their fertility-restoring ability, lupins could well play a role on many Canterbury mixed farms in cereal crop rotations.

CHAPTER THREE

THE YIELD AND NUTRITIVE VALUE
OF SPRING-SOWN SWEET LUPINS
(*Lupinus angustifolius* CV. UNIHARVEST)
GRAZED AT FOUR DIFFERENT STAGES OF GROWTH

3.1 INTRODUCTION

Both bitter and sweet lupins have been grown in the past in Canterbury as a summer greenfeed for fattening lambs (Hudson, 1934; Anon., 1938; Hamblyn, 1940; McPherson, 1940; Anon., 1942; White, 1961; Withers, 1973a). This practice began to decline in the 1950's due both to problems with the crop (Anon., 1938, 1942; Lancaster and Adams, 1943; Allen, 1949; Greenall, 1958), and the increasing popularity of other summer greenfeeds, particularly lucerne (Greenall, 1958; Whatman, 1959; White, 1961; Stoker, 1974; Lees, 1975; Withers, 1975b).

The recent resurgence of interest in the crop has been mainly concerned with seed production (Withers, 1975b). However, increasing problems with lucerne (Coop, 1977; Burnett et al., 1978, 1979; Harvey, 1979a, b), together with the good potential yield of lupins shown by Herbert (1977a), and the high digestibility obtained in a preliminary trial by Clarke (unpub.), indicated that lupins as a greenfeed could well have a potential use in Canterbury.

Western Australian work on the nutritive value and optimum stage of growth for grazing lupin stands (Gladstones, 1959,

1970a, b, d; Carbon *et al.*, 1972; Arnold *et al.*, 1975, 1976a, 1978; Arnold and Charlick, 1976; Mulholland *et al.*, 1976; Arnold and Wallace, 1977) has been mainly concerned with the evaluation of both *L. angustifolius* and *L. cosentinii* as dry standing fodder crops, and there is little published information on the digestibility of green *L. angustifolius* crops apart from some early New Zealand trials (Anon., 1938; Allison and Thurston, 1952).

Work with *L. albus* (Davis, 1973; Offutt and Davis, 1973; Davis and Offutt, 1975) has indicated that digestibility and chemical composition (particularly nitrogen and fibre concentrations) vary markedly with the age and stage of growth of the plant.

In the experiment reported here, the available dry matter and the nutritive value, in terms of digestibility and nitrogen concentration, at four different stages of growth, were measured both before grazing and over a five day grazing period to determine a possible optimum time for grazing the crop while green, and also the optimum level of utilization of the crop when grazed by weaned lambs.

3.2 MATERIALS AND METHODS

3.2.1 *Setting up the Trial*

Lupins (*Lupinus angustifolius* cv. Uniharvest) for this trial were sown on 8 December 1978. The trial was situated on the Lincoln College Research Farm on a Wakanui silt loam soil type (Soil Bureau, 1954). The crop followed potatoes, grown in the 1977-78 season. Previous to this, the block had been in old dairy pasture, topworked in February 1976,

fallowed, ploughed and sown in barley in the summer of 1976-77. As the soil was high in phosphate (Meijer, pers. comm.), no fertilizer was used.

Due to a shortage of seed, three plots had to be sown in a mixture of the seed of several sweet *L. angustifolius* cultivars. However, a very high proportion of this mixture was Uniharvest seed, but a few plants flowered early, and were therefore probably Unicrop. These were rogued when they became obvious.

3.2.2 Irrigation

The whole trial area was irrigated on 25 January 1979 (48 days after sowing) with the equivalent of 22 mm precipitation.

3.2.3 Treatments

Separate plots were grazed by weaned lambs at each of the four following stages of growth:

- . Pre-flowering (67 days after sowing).
- . Primary flowering (73 days after sowing).
- . Secondary flowering (87 days after sowing).
- . Post-flowering (green pod formation) (104 days after sowing).

There were two sowing rates, 140 and 280 kg seed ha⁻¹; this gave plant densities of 60 and 100 plants m⁻². There were four replicates of each treatment giving a total of 32 plots. The trial was laid out as a randomized block design, and each plot was 9 m by 11 m (99 m²). A general view of the trial

area is shown in Plate 1.

3.2.4 *Animals*

A line of 40, mixed sex, weaned Dorset Down cross lambs, aged between 15 and 19 weeks and averaging just over 26 kg in weight, was obtained from "Ashley Dene", the commercial light land farm operated by Lincoln College. These lambs were weighed prior to the first grazing period, and again at the end of the fourth. Lambs were pre-fed with lupin material for five days before the start of the trial, to familiarize them with the feed. Plots were stocked with five animals (equivalent to 2 000 ha⁻¹) for five days (Plate 2).

At each grazing, lambs were allocated randomly to plots, and between grazings were returned to an old ryegrass and white clover paddock, where they were fed lupin material daily.

3.2.5 *Fencing*

Plots were individually fenced using "Flexinet" (electrified netting that is portable, and is used in many situations for temporary and small plot fencing).

3.2.6 *Sampling*

Four 0.25 m² quadrats were cut and bulked from each plot, just prior to the animals being put in, and daily for five days. Material for *in vitro* digestibility and nitrogen analysis was frozen immediately and freeze dried at a later date.



Plate I
General view of the trial area.



Plate 2
Weaned lambs, on the third day of grazing, in a high density plot ($100 \text{ plants m}^{-2}$) of lupins (*Lupinus angustifolius* cv. Uniharvest) grazed at the primary flower stage.

3.2.7 Measurements

(i) Dry Matter

All green material collected was weighed, and one tenth of this was oven dried to obtain the dry matter concentration. Both the total dry matter and the proportion of plant components were measured on every day of each grazing period, in order to determine the total dry matter consumed each day and also the preference of the animals for the various plant components.

(ii) Nitrogen and Protein Concentration

The nitrogen concentration of the daily whole plant material was measured using the Kjeldahl method. For details, see Chapter Two. Protein concentration of the forage was obtained by multiplying the nitrogen value by 6.25.

(iii) In vitro Digestibility

The *in vitro* digestibility of the whole plant material was assessed using the two stage *in vitro* analysis of Tilley and Terry (1968). For further details of this method, see Chapter Two.

(iv) Metabolizable Energy

The metabolizable energy of the plant material present was calculated using the formula outlined in Chapter Two.

3.2.8 *In Vivo Digestibility*

In an attempt to calibrate the *in vitro* values obtained and actual *in vivo* digestibility of the forage, a small separate trial was carried out.

Two sheep (identified by the numbers 104 and 140) fitted with faeces collection bags, were

fed measured quantities of oven dried lupin material, cut at the green pod stage from regrowth that occurred in the grazing trial (referred to in Chapter Four). After five days of pre-feeding to accustom the animals to the feed, *in vivo* digestibility was recorded over two consecutive ten day periods. Faeces were collected, dried and weighed twice daily.

The *in vivo* digestibility was calculated daily as follows:

$$\frac{(\text{Total feed} - \text{residue}) - \text{faeces}}{(\text{Total feed} - \text{residue})} \times \frac{100}{1}$$

In vitro analysis, as previously described, was carried out on samples of this feed.

3.2.9 Statistical Analysis of Results

Results were analysed using the standard statistical programme, TEDDYBEAR, developed by Wilson (1979).

3.3 RESULTS

3.3.1 Plant Density

It was intended that the two densities should have been 70 and 140 plants m⁻². However, in spite of good rainfall in the period immediately after sowing (Figure 2.1), emergence was poor and the two final densities obtained were close to 60 and 100 plants m⁻² respectively.

3.3.2 *Description of Plants at Each Growth Stage
Before and During Grazing*

(i) Pre-flower

The majority of the plants were at the green bud stage, although a few were showing colour (Plate 3). After one day's grazing, flower buds, young leaves and growing points in the upper positions had been eaten. Many plants had been trampled, and grazing had been patchy. By the third day, much of the leaf material had been eaten, together with the softer portions of the stem. After four days' grazing, there was very little feed left in the low density plots. Because of this, and also problems with retaining the lambs with the electric fence, they were taken out of these plots a day earlier than originally intended.

In the high density plots, when the sheep were removed after five days, very little dry matter was left except for stems 150 to 200 cm tall.

(ii) Primary Flower

Most plants had begun flowering on the main stem, and some of the more advanced had small green pods forming (Plate 4). Leaf fall was beginning with the loss of a few lower leaves. The grazing pattern was the same as for the pre-flower treatment, although grazing was less patchy, the lambs preferring to move around the crop rather than staying in one place. Leaf material was pulled off during the early stages and was left on the ground. However, much of this was eaten on the fifth day when there was very little standing feed left.

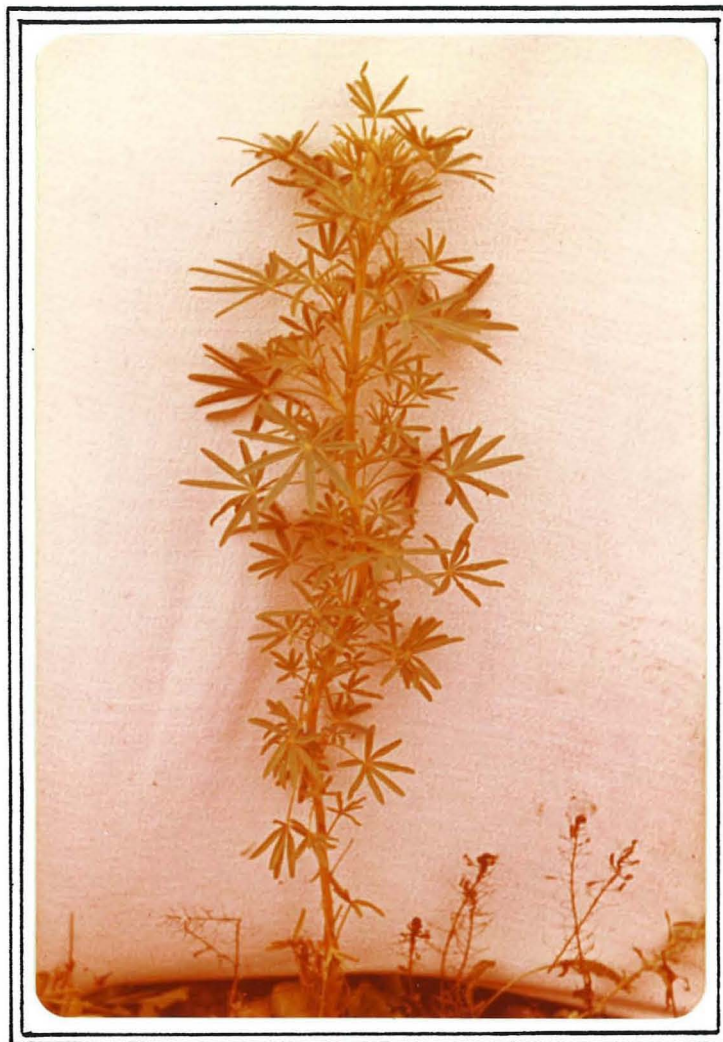


Plate 3

Typical *Lupinus angustifolius* cv. Uniharvest plant at the first grazing stage (pre-flower). Plant is approximately 0.6 m tall.

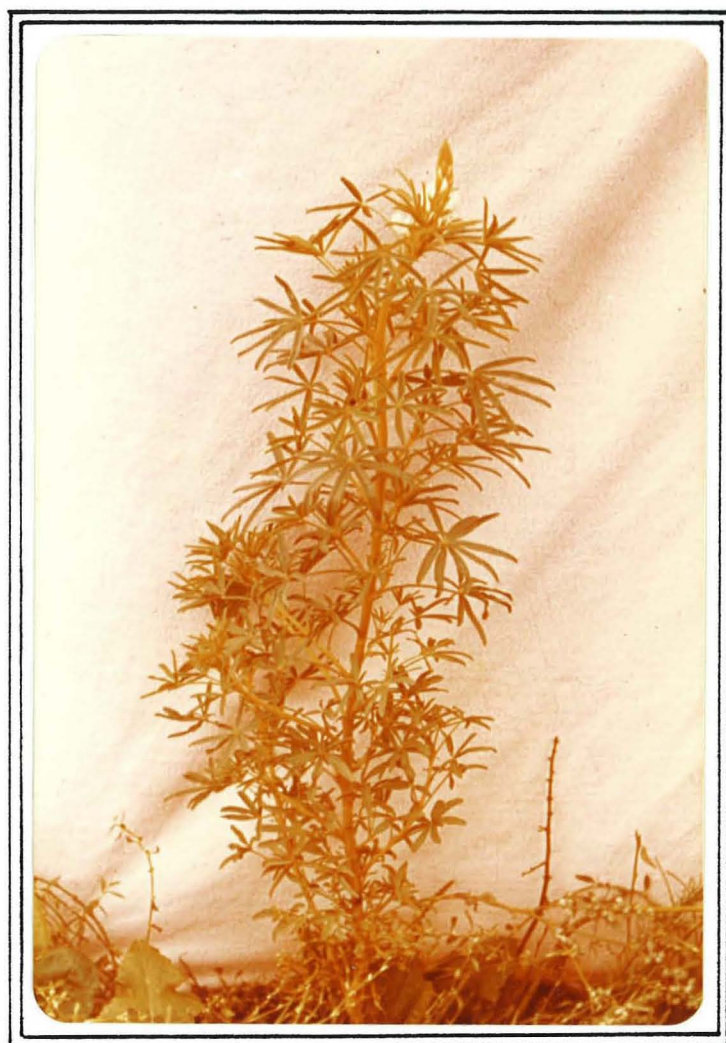


Plate 4

Typical *Lupinus angustifolius* cv. Uniharvest plant at the second grazing stage (primary flower). Plant is approximately 0.7 m tall.

(iii) Secondary Flower

At this stage, most of the secondary branches were flowering and green pods were forming on the primary stem (Plate 5). The difference in amount of feed present between the two densities was less obvious at this stage and for both densities there was some low quality feed remaining after the five day grazing period.

(iv) Post Flower

Flowering had finished on most secondary stems and pods were beginning to form on these (Plate 6). Green pods on the primary stem were well formed. The pods were very quickly eaten by the animals, being preferred to the leaf component, and had virtually disappeared after one day's grazing. By the end of three days most of the leaf component had also been eaten and the lambs seemed to find the stem component unpalatable, as not much of it appeared to be grazed in the next two days, and there was a considerable amount of stem left when the animals were removed.

3.3.3 *Animal Data*

The average weight of the 40 lambs prior to the start of the trial was 26.13 kg, and this increased at a rate of 97 g day⁻¹ to 30.21 kg over the trial period. (The weights of two lambs that had been fly-struck during the trial were excluded when this average was calculated.) Apart from the two cases of fly-strike, there was no animal health problem and the lambs grazed the feed readily. Weight was gained over the whole trial period, in spite of the fact that during the last two or three days of each grazing period, little palatable feed appeared to be available.



Plate 5

Typical *Lupinus angustifolius* cv. Uni-harvest plant at the third grazing stage (secondary flower). Plant is approximately 0.8 m tall.



Plate 6

Typical *Lupinus angustifolius* cv. Uni-harvest plant at the fourth grazing stage (green pod). Plant is approximately 0.8 m tall.

3.3.4 *Dry Matter and Proportion of Plant Components*

At the pre-flower stage (67 days after sowing), the dry matter available in the higher density plots (100 plants m^{-2}) was just over 510 g m^{-2} , and this decreased at a rate of approximately 60 g day^{-1} to just under 200 g m^{-2} after five days of grazing (Figure 3.1A). At the lower density (60 plants m^{-2}) there was about 100 g m^{-2} less at all stages of the grazing period, and by the end of the fourth day the animals were removed as there was not enough feed left for another day.

The difference in dry matter available between the two densities was less at the primary flower grazing stage. In the higher density plots, just over 600 g m^{-2} dry matter was available before grazing, compared with 575 g m^{-2} at the lower density. At both densities, this was grazed at a similar rate to that of the pre-flower grazed plots overall, although for the lower density the rate at which the material was eaten was faster at first and slackened off over the last two days (Figure 3.1B). This was partly because of the unpalatability of the feed at that stage of the grazing period, and also because, due to problems with the fencing, lambs in three of the low density plots were out for several hours on the last day.

At the secondary flower stage, dry matter had increased to 700 g m^{-2} in the higher density plots and decreased to 250 g m^{-2} over the five day period. The dry matter available in the lower density plots was still less than that of the higher density at the beginning of the period (560 g m^{-2}), but after five days an amount similar to that of the higher density plots remained (Figure 3.1C). One lamb in a lower density plot was troubled by fly-strike during this grazing

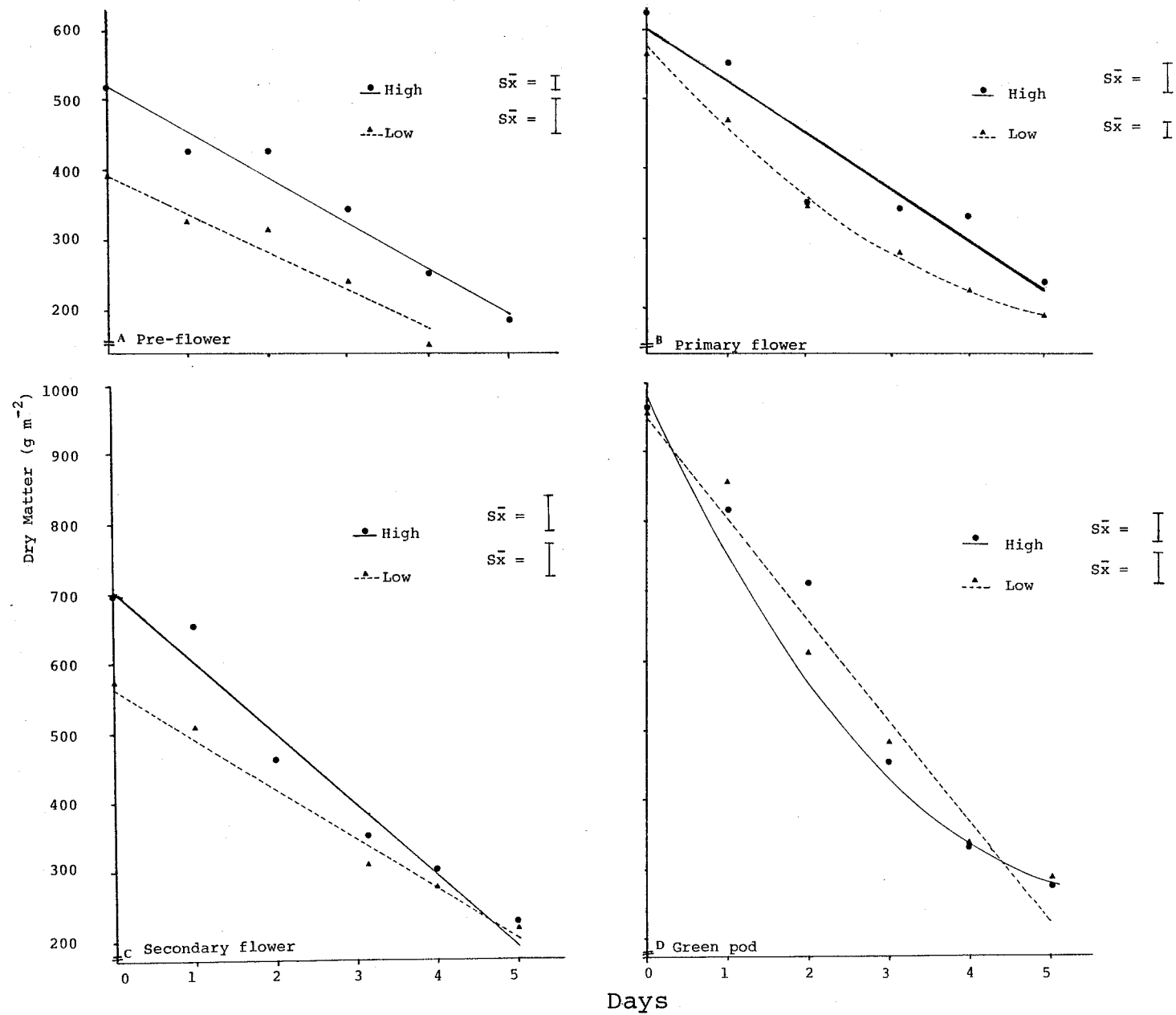


Figure 3.1: Dry matter available in a lupin crop (*Lupinus angustifolius* cv. Uniharvest) over five days of grazing, at four stages of growth, at plant densities of 60 plants m⁻² (Low) and 100 plants m⁻² (High).

period but this is not thought to have seriously affected the results. During grazing at the green pod stage there was no significant difference (except on day two) between the amount of dry matter present at the two densities. Between 950 and 1 000 g m⁻² was available at the beginning of the period and this declined to just under 300 g m⁻² in the higher density and just over 250 g m⁻² at the lower density (Figure 3.1D).

At each grazing stage, the leaf proportion declined rapidly over the grazing period as this was the component preferred by the animals (Figure 3.2), although this decline was less rapid, initially, at the later stages of growth of the crop as the flowers and pods were also eaten quickly. Only 1.0 to 2.0 per cent of the plant was reproductive material at the pre-flower grazing stage at both densities. This largely disappeared on the first day of grazing. At the primary flower stage, between 2.0 and 4.0 per cent of the plant was flowers. The higher density plants at the secondary flower stage were more advanced, having 8.0 per cent flowers and pods, compared with only 3.6 per cent at the lower density. There was less difference, 12.0 per cent and 10.0 per cent respectively, at the green pod stage. At both stages, this component had been eaten by day three.

The proportion of leaf at the pre-flower stage was just under 60 per cent at the higher density and about 64 per cent at the lower density before grazing (Figure 3.2A). This declined to just under 15 per cent and 23 per cent respectively after five days of grazing. Most of the leaf material left at this stage was petiole. The stem proportion increased corresponding with the decline of the leaf component. There was very little difference in the proportion of plant components between

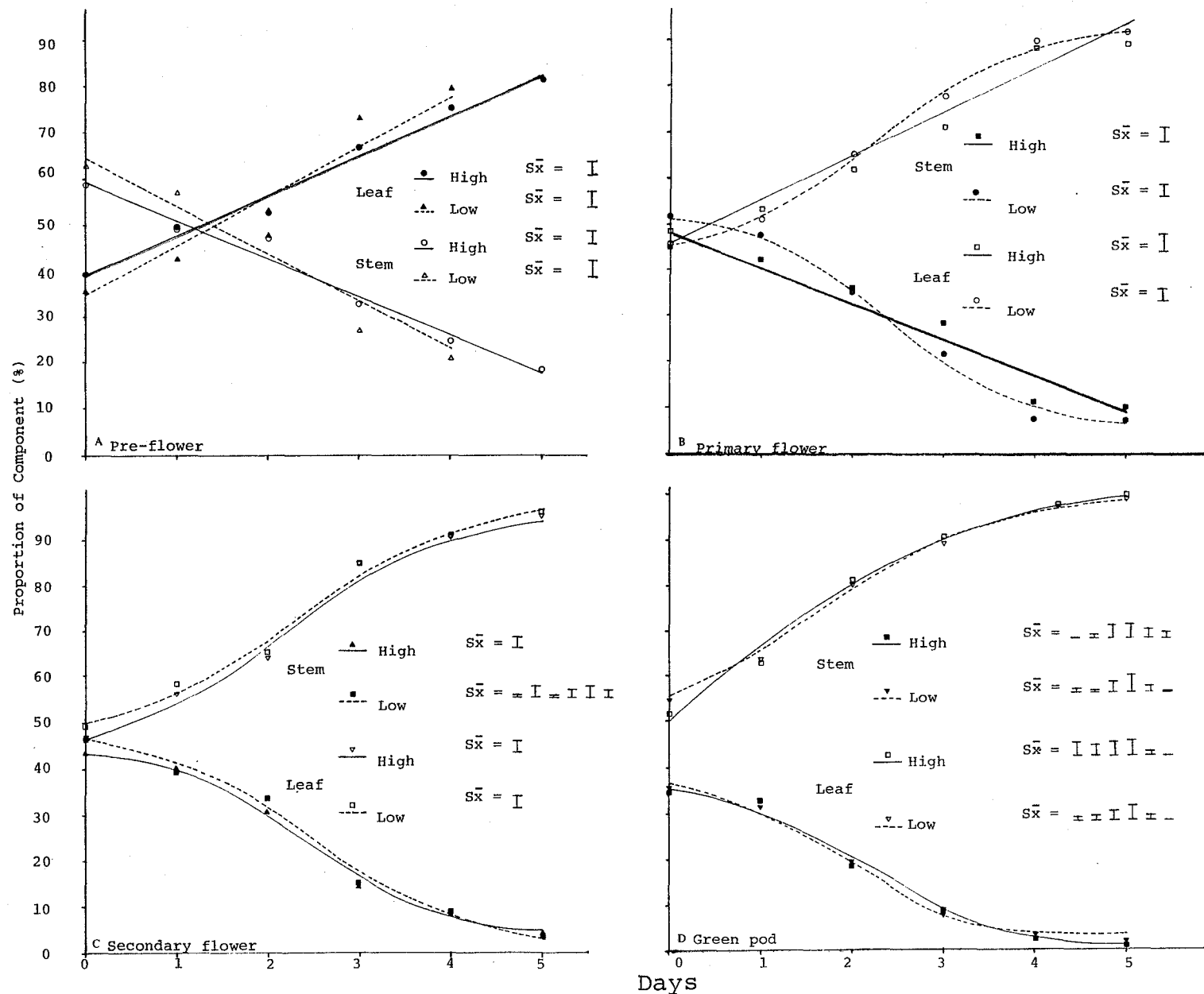


Figure 3.2: Proportion of plant components in a lupin crop (*Lupinus angustifolius* cv. Uniharvest) over five days of grazing, at four stages of growth, at plant densities of 60 plants m^{-2} (Low) and 100 plants m^{-2} (High).

densities at the three later stages of grazing (Figure 3.2B, C, D).

3.3.5 *Nitrogen and Protein Concentration*

The nitrogen concentration in the forage decreased over each grazing period (Figure 3.3). The highest concentration (3.85 per cent) was found at the lower density in the pre-flower grazed plants. This decreased to 2.9 per cent in the material left after five days (Figure 3.3A). At the higher density, nitrogen concentration was less, 3.15 per cent before grazing, and decreased to 2.75 per cent. A similar trend occurred in the primary flower grazed plants (Figure 3.3B), with the lower density plants having a higher initial concentration, 3.75 per cent, compared with 2.75 per cent at the higher density, and both decreased to just under two per cent at the end of the period. The lower density plants of the treatment grazed at secondary flower again had a higher nitrogen concentration (3.4 per cent) compared with the higher density (3.1 per cent), but although the concentration decreased steadily at the lower density by 0.43 per cent per day to be 1.25 per cent at day five, it appeared to increase slightly at the higher density and then dropped more slowly to reach 1.7 per cent after five days (Figure 3.3C).

At the green pod stage there was a lower concentration of nitrogen (2.7 per cent) at the lower density than at the higher density (3.1 per cent). This had decreased to 1.4 per cent (lower density) and 1.15 per cent (higher density) by day five (Figure 3.3D).

The protein concentrations of the plants at each stage, and over each grazing period, are shown in Table 3.1.

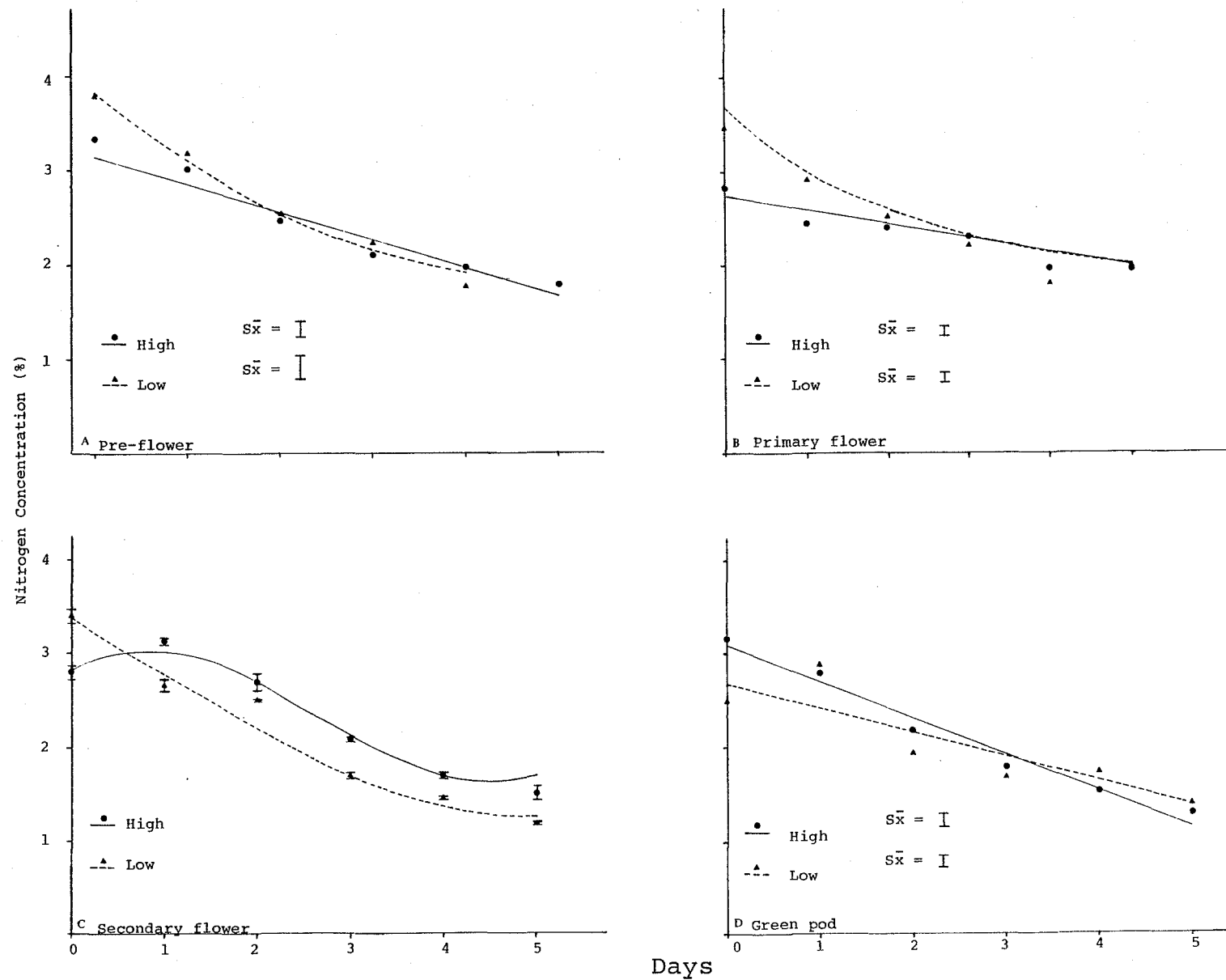


Figure 3.3: Nitrogen concentration in a lupin crop (*Lupinus angustifolius* cv. Uni harvest) over five days of grazing, at four stages of growth, at plant densities of 60 plants m⁻² (Low) and 100 plants m⁻² (High).

Table 3.1: Protein concentration of lupins (*Lupinus angustifolius* cv. Uniharvest) at four stages of growth, measured at 24-hour intervals over five days of grazing.

Density (plants m ⁻²)	Days after grazing	Stage of Growth at Which Grazed			
		Pre- flower	Primary flower	Secondary flower	Green pod
100	0	21.0%	17.7%	17.5%	19.7%
	1	19.0	15.3	19.4	17.5
	2	15.5	15.0	16.1	13.9
	3	13.3	14.4	13.1	11.2
	4	12.5	12.4	10.7	9.8
	5	11.5	12.2	9.8	8.0
60	0	23.7%	23.1%	21.3%	15.6%
	1	19.9	18.0	16.7	18.1
	2	15.9	15.4	15.6	12.2
	3	14.0	13.9	10.8	10.6
	4	11.1	11.6	9.2	10.9
	5	11.8	12.2	7.5	8.8

The highest concentrations of over 23 per cent were found in the plants at the lower density before grazing. Protein concentrations at the later stages of grazing were very much lower, and were under 11 per cent on the last two days of the secondary flower and green pod grazed plants at the higher density, and on the last three days of these two grazing periods at the lower density.

The nitrogen concentration was positively correlated to the dry matter available at all stages of growth. At the pre-flower grazing the nitrogen concentration dropped by about 0.44 per cent per 100 g m⁻² dry matter decrease at both densities (Figure 3.4A). At the primary flower stage, the nitrogen concentration in the lower density plants fell more rapidly (0.40 per cent per 100 g m⁻²) than at the higher density (0.17 per cent per 100 g m⁻²) (Figure 3.4B). Trends similar to the pre-flower grazed lupins were shown for the plants grazed at the two later stages of growth, although the correlation at the lower density of the secondary flower grazing appeared to be negative at the higher amounts of dry matter (Figure 3.4C, D).

3.3.6 *In Vitro* Digestibility

At the higher density the dry matter available at the pre-flower stage had a digestibility of about 80 per cent. This declined over the first three days of grazing at a rate of 9.2 per cent per day, and then remained fairly constant at just above 50 per cent. The decline at the lower density was less pronounced, from 74 per cent before grazing to just over 53 per cent after four days (Figure 3.5A). At the primary flower stage, the digestibility of both densities was similar, just

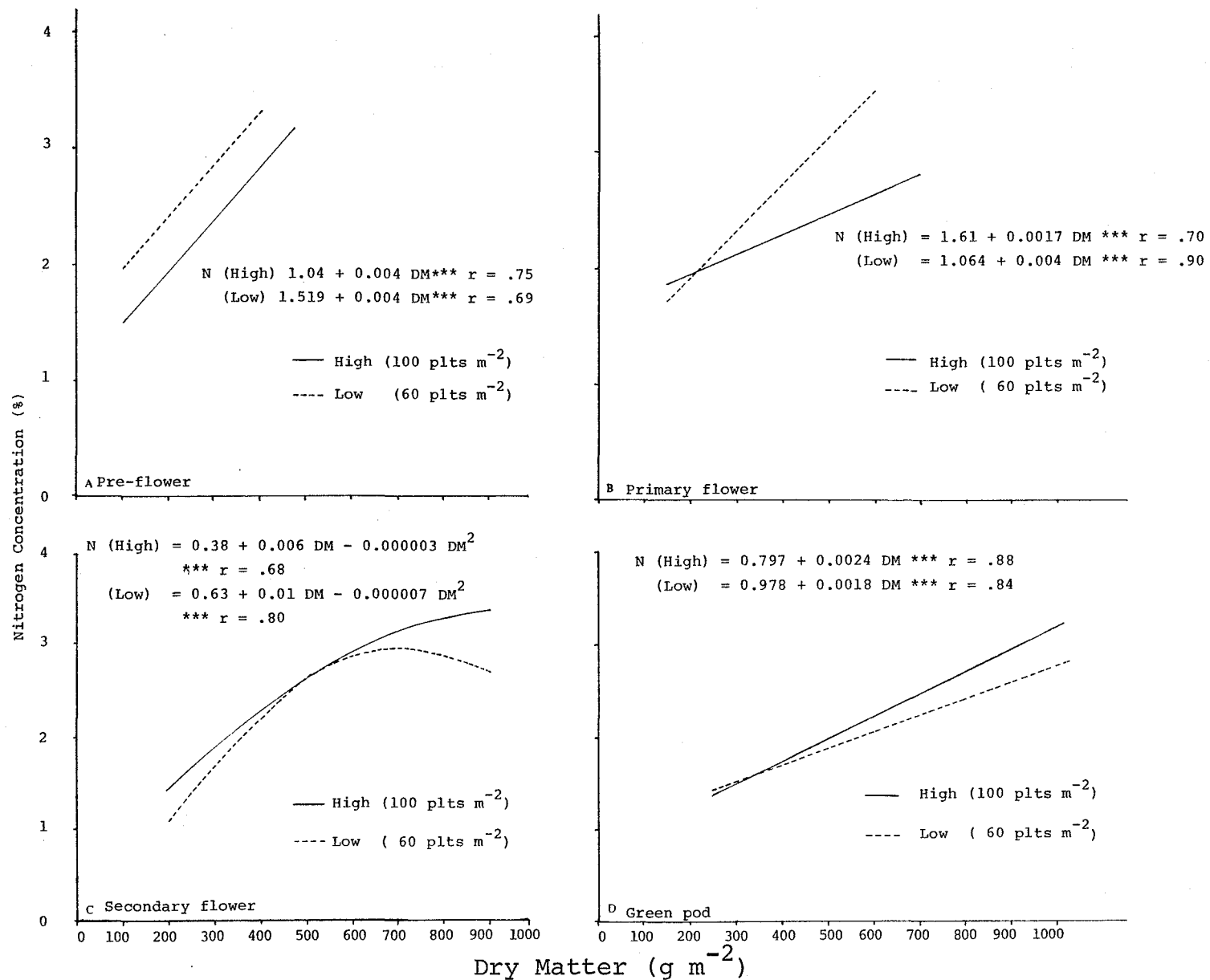


Figure 3.4: Correlation of nitrogen concentration with dry matter, in a lupin crop (*Lupinus angustifolius* cv. Uniharvest) over five days of grazing, at four stages of growth, at two plant densities.

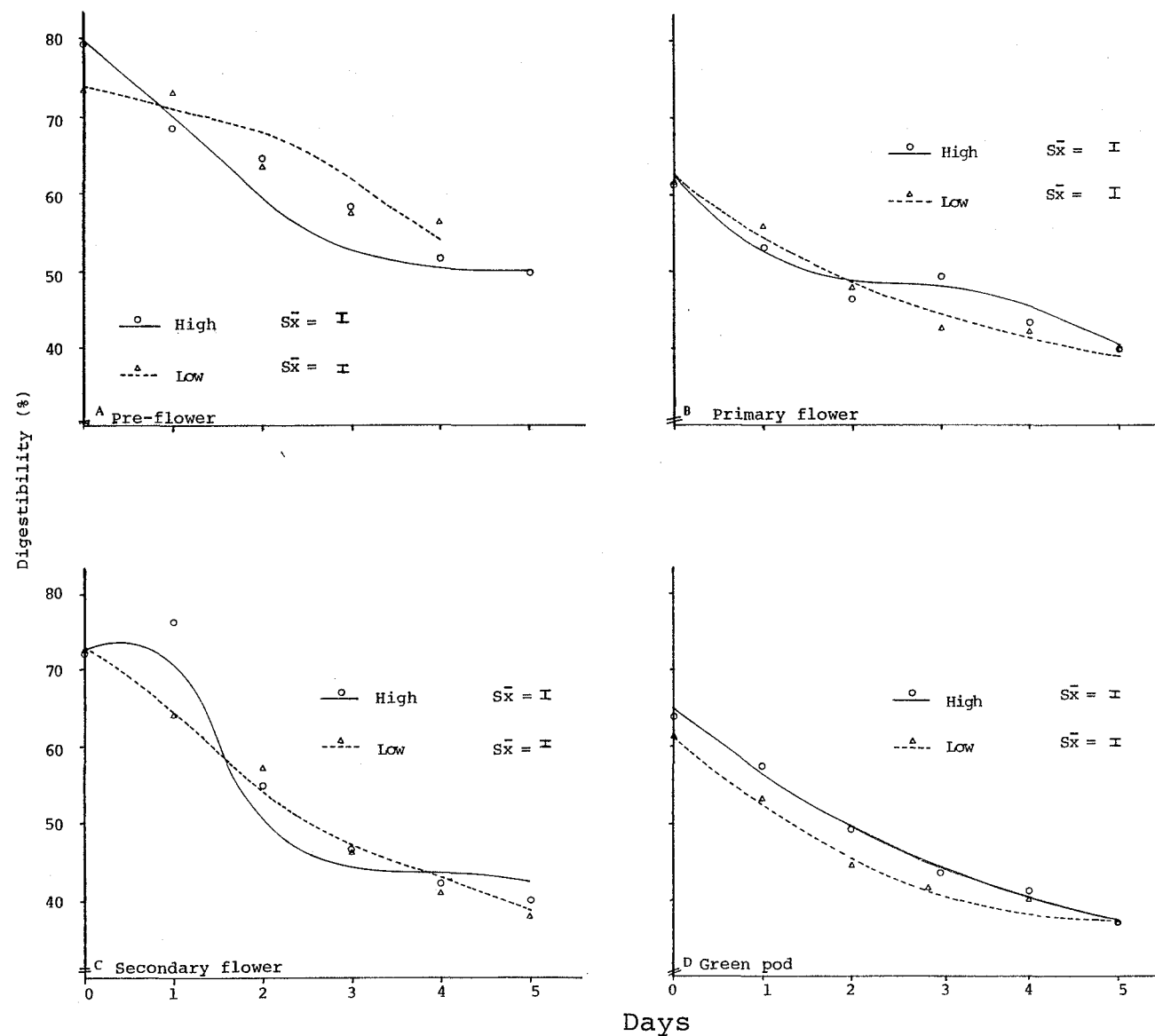


Figure 3.5: Digestibility of lupins (*Lupinus angustifolius* cv. Uniharvest) over five days of grazing, at four stages of growth, at plant densities of 60 plants m⁻² (Low) and 100 plants m⁻² (High).

under 67 per cent before grazing. At the lower density it fell fairly steadily at a rate of 3.6 per cent per day to 49.0 per cent after five days, but at the higher density it fell over the first two days, levelled off, and then fell over the last two days to just over 50 per cent (Figure 3.5B). Digestibility was lower at the last two stages of growth, but the trends were similar. At both the secondary flower and the green pod stages, the digestibility at the lower density declined fairly steadily over the grazing period, from 73.0 per cent to just under 40 per cent for the former (Figure 3.5C), and from just over 60 per cent to 37.0 per cent for the latter (Figure 3.5D). At the secondary flower stage the digestibility of the higher density plants remained fairly stable to the end of day one (about 73 per cent), decreased rapidly over the next two days and then levelled off at about 43 per cent over the last two days. The digestibility of the higher density plants at the green pod stage followed a trend similar to the lower density, starting a little higher (65.0 per cent) and dropping to just over 37 per cent.

Digestibility decreased with decreasing dry matter available, the trends being similar at all four stages of growth (Figure 3.6). The rate of decrease was faster (especially for the higher density) at the pre-flower stage than at subsequent stages.

3.3.7 *Metabolizable Energy*

The metabolizable energy concentration of the plants was similar for the two densities, with the possible exception of the higher density pre-flower grazed treatment which was slightly higher overall. Levels of metabolizable energy in the available feed decreased over the grazing period

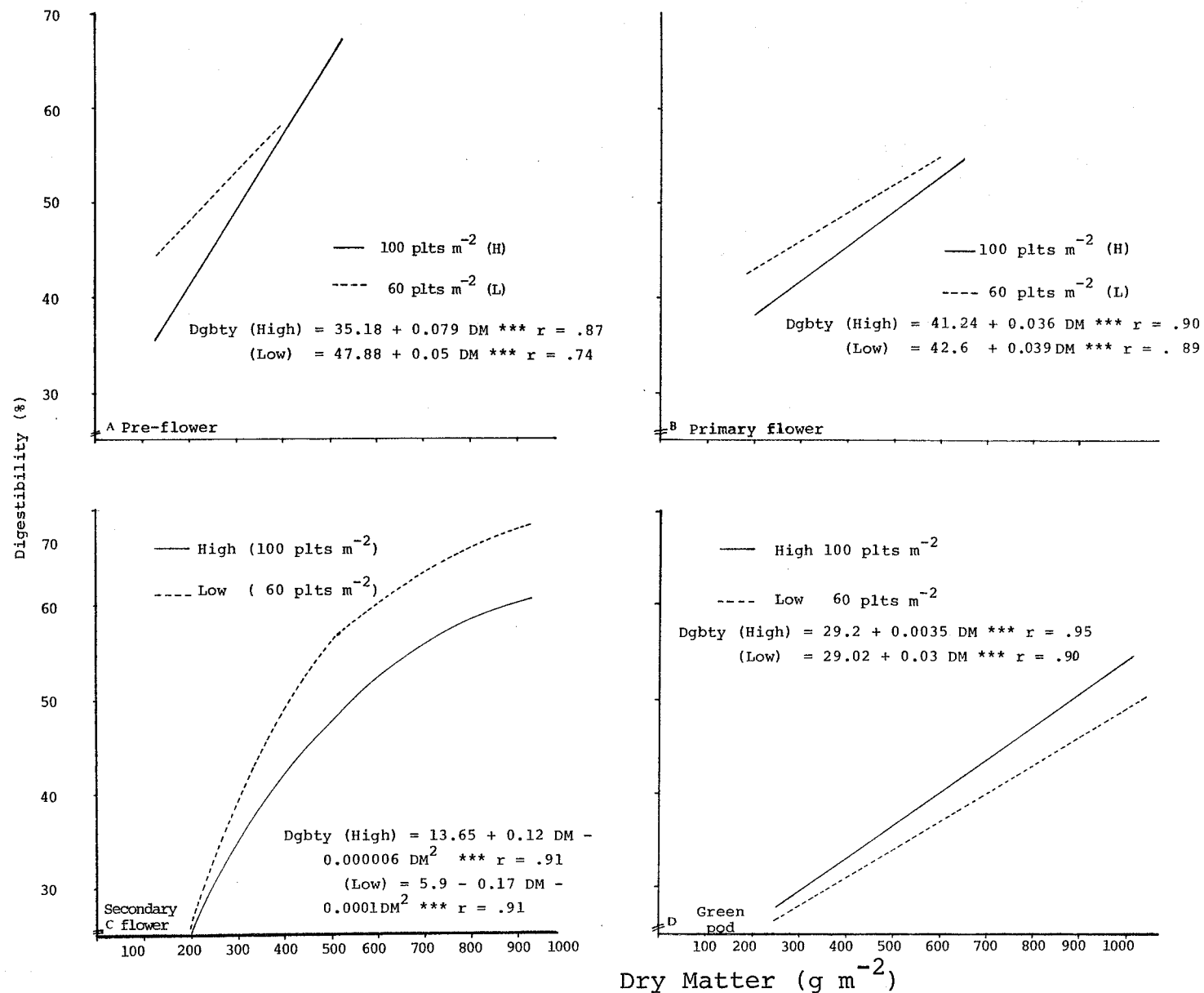


Figure 3.6: Correlation of digestibility with dry matter in a lupin crop (*Lupinus angustifolius* cv. Uniharvest) over five days of grazing, at four stages of growth, at two plant densities.

in all treatments from between 8.97 and 11.74 to between 5.44 and 7.47 MJ kg⁻¹ (Table 3.2), but this was more marked at the two later stages of growth.

Total ME available ranged from 4.08 MJ m⁻² in the lower density, pre-flower grazed plots to 9.40 MJ m⁻² in the higher density lupins grazed at the green pod stage (Table 3.3). In these two treatments, 16.2 MJ and 37.2 MJ was available per lamb per day, respectively (Table 3.3).

3.3.8 *In Vivo Digestibility*

During the first ten day feeding period, *in vivo* digestibility was recorded as 77.3 per cent from animal 104 and 75.1 per cent from animal 140. This was compared with an average *in vitro* digestibility of the feed over the period of 74.6 per cent (Table 3.4). The average *in vitro* digestibility over the second period was 73.3 per cent, and *in vivo* values of 74.3 and 75.5 per cent from animals 104 and 140 respectively were obtained.

The regression equation

in vivo digestibility = 15.37 + 0.81 *in vitro* digestibility **
was calculated, $r = .991$, $S\bar{x} = 1.61$.

3.4 DISCUSSION

The dry matter yields obtained at the four stages of growth in this trial were higher than at similar times after sowing in the trial described previously (Chapter Two). Commencement of flowering in the present trial was earlier, about day 71 compared with about day 85 in the previous trial,

Table 3.2: Metabolizable energy (MJ kg^{-1}) concentration of lupins (*Lupinus angustifolius* cv. Uniharvest) at four stages of growth measured at 24 hour intervals over five days of grazing.

Plant Density (plants m^{-2})	Days after grazing	Stage of Growth at Which Grazed			
		Pre- flower	Primary flower	Secondary flower	Green pod
100	0	11.74	9.78	10.66	9.54 (0.06)
	1	11.00	8.81	10.40	8.50 (0.16)
	2	9.54	8.07	8.08	7.23 (0.20)
	3	8.55	7.86	6.83	6.44 (0.16)
	4	7.93	7.70	6.29	6.09 (0.10)
	5	7.47	7.37	5.86	5.88 (0.52)
\bar{Sx}^*		.14	.13	.15	
60	0	10.60 (0.21)	9.80	10.73	8.97 (0.11)
	1	10.07 (0.06)	9.12	9.46	7.82 (0.11)
	2	9.40 (0.05)	8.23	8.43	6.34 (0.10)
	3	8.48 (0.13)	7.66	6.73	7.19 (0.13)
	4	8.48 (0.77)	7.61	6.03	5.89 (0.08)
	5	7.35 (0.01)	7.31	5.53	5.44 (0.72)
\bar{Sx}^*			.14	.13	

* \bar{Sx} - where the difference in error variance is not significant (Bartlett's test). Where this is significant, individual standard errors are shown.

Table 3.3: Metabolizable energy (MJ) of lupins (*Lupinus angustifolius* cv. Uniharvest) available at each of four stages of growth.

Plant Density (plants m ⁻²)	Stage of Growth at which grazed	ME Available at Day 0	
		MJ m ⁻²	MJ per animal per day *
100	Pre-flower	6.05	24.0
	Primary flower	5.87	23.2
	Secondary flower	7.51	25.6
	Green pod	9.40	37.2
60	Pre-flower	4.08	16.2
	Primary flower	5.64	22.3
	Secondary flower	6.01	23.8
	Green pod	8.52	33.7

* Five animals per plot (plot size = 99.0 m²).

Table 3.4: *In vivo* and *in vitro* digestibility of lupins
(*Lupinus angustifolius* cv. Uniharvest).

Feeding period	Animal no.	<i>In vivo</i> digestibility	<i>In vitro</i> digestibility
one (10 days)	104	77.3%	74.6%
	140	75.1%	
two (10 days)	104	74.3%*	73.3%
	140	75.5%	

* Taken over eight days only as this animal became ill.

Regression equation is

In vivo digestibility = $15.37 + 0.81$ *in vitro* digestibility **

$r = .991$ $S_{\bar{x}} = 1.61$

and also took place at a higher dry matter accumulation, 550 to 600 g m⁻² compared with 250 g m⁻². This earlier flowering agrees more closely with the time of flowering observed by Porter *et al.*, (1976) (77 days) and Herbert (1977a) (62 days). The shorter time to flowering was probably because of the later (mid-December) sowing of the crop, and the better growth rate due to favourable climatic conditions immediately after sowing.

The difference in dry matter accumulation between densities decreased as the plants aged, and is therefore only of importance where the crop is grazed at either of the two earlier stages of growth. The fact that there was greater secondary branch development in the lower density plants would account for these plants "catching up" by the secondary flowering stage.

If increased dry matter production is required, increasing the seeding rate to achieve this is only likely to be effective if the material is to be utilized at the earlier stages of growth and also, the extra cost of seed could well make this uneconomic.

The feed available was eaten fairly evenly over each grazing period, except perhaps at the lower density of the primary flower grazed treatment and at the higher density of the green pod stage. In both cases this may have been due to the unpalatability of the feed at these stages. In the first instance this was because the lower total dry matter available meant that only coarse stems were left after five days, and in the second instance the greater "woodiness" of the stems, the greater proportion of which would have been main stems as opposed to younger secondary stems in the case of the lower density plots.

Although Figure 3.2 does not show this very well, the

leaf component appeared to be eaten first at all stages of growth, and what was left after the second or third day of grazing was, in most cases, almost certainly petiole, or, especially at the later stages of growth, older less palatable leaves.

The nitrogen concentrations were initially lower at the higher density in all but the green pod grazed lupins. At the first two stages of growth this difference disappeared after the first two or three days, but at the secondary stage the concentration was lower at the lower density after the first day. There was very little difference between the two densities at the green pod stage. Overall, those recorded at the higher density were slightly higher than those recorded with bitter *L. angustifolius* at similar growth stages (Anon., 1938), but not as high as those observed in the trial described in Chapter Two. At the lower density, the nitrogen concentrations were much higher than those recorded by Anon. (1938) at the first three stages of growth, but very similar at the green pod stage. Nitrogen concentration at the pre-flower stage, in this trial, was higher at both densities than that found by Davis and Offutt (1975) in *L. albus*, but at the later stages was slightly lower, and slightly higher in the high and low densities respectively.

From these results, it would appear that plant density is an important factor to be considered when looking at forage nitrogen concentration. Increasing density to maximize dry matter production, as suggested earlier, may adversely affect the quality of the feed in terms of nitrogen and thus protein available, especially if plants are grazed at the pre- or primary flower stages.

Results of a trial conducted by Andrews and Ørskov (1970) suggested that the optimum dietary protein concentration for growth ranged from 12.5 to 17.5 per cent for lambs with liveweights between 20.0 and 35.0 kg (Table 3.5). For 25.0 kg lambs the optimum crude protein concentration was given as 15.0 per cent. In the present trial, crude protein concentrations were only over 15.0 per cent on the first three days of grazing in the pre-, primary and secondary flower treatments (both densities) and the first two days of the green pod grazed treatment (again for both densities). At lower levels of digestible energy intake, however, optimum protein concentrations for growth tend to decrease (Andrews and Ørskov, 1970), implying that protein concentrations could well have been still acceptable at later stages of each grazing period.

Table 3.5: Optimum dietary crude protein concentration for growth of weaned lambs.

Liveweight (kg)	Optimum Crude Protein concentration (per cent)
20	17.5
25	15.0
30	12.5
35	12.5

From Andrews and Ørskov (1970).

Optimum concentrations also decrease as animals increase in liveweight (Table 3.5), so that at the green pod stage, with the lambs at about 30 kg, a protein concentration as low as 12.5 per cent was acceptable. This was the case, at both densities, over the first three days of grazing at this stage.

Digestibility of the fodder was, as in the trial described in Chapter Two, lower than expected, considering the high digest-

ibility of *L. angustifolius* obtained by Clarke (unpub.) at similar stages of growth. It was, however, higher in this trial at the pre-flower stage than at a similar stage in the previous trial (Chapter Two), and slightly higher (at the high density only) than that recorded in *L. albus* (Davis and Offutt, 1975) at pre-flowering. At the later stages of growth, digestibility was similar to that of the previous trial, but lower than that of *L. albus* (Davis and Offutt, 1975). The exception was at secondary flowering, at which stage the digestibility at day 0 was higher than at both the previous (primary flower) and green pod growth stages, and almost identical to the *L. albus* figure, at both densities. This might be explained by the presence of flowers on most secondary branches together with young green pods on the primary stems, at a stage where the stem was not too "woody" and where leaf fall had not yet begun.

The *in vivo in vitro* correlation of .991 was high and the standard error of 1.61 reasonably low. Although this agrees with the high correlations obtained by Tilley and Terry (1963), O'Shea and Wilson (1965), Wedin *et al.*, (1966) and Ademosum *et al.* (1968), it must be remembered that only two animals were used in the present trial, which was conducted over a relatively short period. The results obtained, therefore, should be regarded with some caution.

The daily metabolizable energy allowances for growing lambs recommended by M.A.F.F. (1975) are given in Table 3.6. As the energy value of the feed increases from 8 MJ kg⁻¹ to 12 MJ kg⁻¹, the total energy intake requirement decreases, dropping from 7.4 to 6.6 MJ day⁻¹ for a 25.0 kg lamb and 8.2 to 7.4 for a 30.0 kg lamb, both increasing in liveweight at a

Table 3.6: Recommended daily ME allowances (MJ day^{-1})
for growing lambs.

Live-weight	Energy value of food (MJ kg^{-1} DM)	Rate of Gain (g day^{-1})						
		50	100	150	200	250	300	350
25 kg	8	7.4	9.9	12.7	-	-	-	-
	10	6.9	9.0	11.2	13.4	15.7	14.8	-
	12	6.6	8.3	10.2	12.0	14.0	13.3	-
30 kg	8	8.2	10.9	13.8	-	-	-	-
	10	7.8	9.9	12.2	14.6	17.0	-	-
	12	7.4	9.2	11.1	13.1	15.1	17.2	19.3

From M.A.F.F. (1975)

rate of 50 g day^{-1} .

At only the pre-flower stage was the energy value of the feed near the 12 MJ kg^{-1} figure (11.74 MJ kg^{-1}). The animals at this time would have been in the lighter weight category, as they averaged just over 26 kg. Total metabolizable energy available should have allowed the lambs to grow at about 100 g day^{-1} for four days. This assumes 100 per cent utilization of the feed, but actual utilization was only about 50 per cent over the four days. On the other hand, the higher energy portion of the feed would have been grazed first and the energy level of the feed left was declining. The lower limit of 8 MJ kg^{-1} was reached by day four at both densities. At the other growth stages the lower limit was reached earlier, by the end of day three for both densities grazed at either primary or secondary flower stages, by day two in the high density green pod grazed plots, and after only one day at the lower density of this growth stage.

The animal data recorded in this trial was not intended to give detailed information on the growth rate of the lambs. The average growth rate of about 97 g day^{-1} cannot be related to the potential growth rates that are indicated by the energy values obtained. The fact that the lambs gained weight over the whole trial period, in spite of being forced to eat low value feed on the last two or three days of each grazing period, is the only evidence that can be taken from this trial to indicate the value of the crop in terms of energy value.

However, it appears that although the overall dry matter yield and metabolizable energy available increases as the plant ages, growing lambs should be grazed at the earlier stages of growth. If they are grazed at the later stages,

then it should be only for a short period, leaving the feed of lower energy value for another class of stock with lower energy requirements, for example, dry ewes.

3.5 CONCLUSION

Although the highest totals of dry matter, protein and metabolizable energy were available from this December sown lupin crop at the green pod stage, it is suggested that this is not the ideal stage at which it should be grazed with lambs, if a high growth rate is required. Highest protein concentrations and energy value in terms of MJ ME kg⁻¹ were, however, available at the pre-flower stage, and although these had declined by the primary flower stage they were still at an acceptable level for reasonable lamb growth rate. For older or dry stock, requiring lower protein concentration and energy value, the crop would probably be better grazed at a later stage where more total feed is available.

The effect of density was most apparent at the earlier growth stages especially in the pre-flower grazed treatment. More dry matter was produced, but this had a lower protein concentration and marginally lower metabolizable energy value. Again, this would be more important if growing lambs were grazed on the crop compared with other classes of stock.

Lupins grazed at the pre- or primary flower stage, therefore, could play a definite role on Canterbury farms for lamb fattening, particularly where grain crops are also grown, and the lupins can be used in rotation to restore soil fertility.

CHAPTER FOUR

REGROWTH POTENTIAL OF SPRING-SOWN SWEET LUPINS
(*Lupinus angustifolius* CV. UNIHARVEST) AFTER GRAZING

4.1 INTRODUCTION

It has been generally assumed that green lupins are a "single grazing" crop with little or no potential regrowth. The poor regrowth of the crop appears to have limited its use as a greenfeed, especially in Australia.

Light grazing of bitter cultivars at an early stage of growth is possible without reduction of seed yield; as much as 50 per cent of the autumn sown New Zealand Bitter Blue crops grown in Canterbury in the 1940's and 1950's were grazed prior to being shut up (Anon., 1942; Whatman, 1959; Claridge, 1972; Stoker, 1974). However, it has been recommended that sweet cultivars should not be grazed at all before the end of flowering, as this would result in reduction of both total dry matter production and seed yield (Gladstones, 1959, 1967b, 1969c, 1970b; Garside, 1975). Straatman *et al.* (1972) emphasized that grazing at an early stage of growth was undesirable as the growing points of the plant were eaten first and very little regrowth occurred.

Withers (1975a) showed that defoliation of lupin plants at the seven to eight leaf stage or later at the primary bud (pre-flower) stage decreased the seed yield in spite of stimulated lateral branch growth, increasing the number of lateral inflorescences. Herbert (1977b), however, found that the

absence of apical dominance caused by removal of the main stem inflorescence allowed greater production from lateral inflorescences, and that no overall reduction in seed yield occurred in either *L. angustifolius* cv. Unicrop or *L. albus* cv. Ultra. During the later stages of the grazing trial described in Chapter Three, it was observed that the plots grazed at the earlier stages of growth were beginning to regrow, and that a substantial amount of dry matter was being produced. It was realized that, with the likelihood of regrowth occurring after grazing, the versatility of the crop would be improved. A seed crop could be taken, or further grazing would be possible. With the latter in mind, the plots were resampled for measurement of dry matter accumulation, and also for nutritive value of the forage.

4.2 MATERIALS AND METHODS

All plots grazed in the previous trial (Chapter Three) which showed any signs of regrowth, were resampled at 40 and 61 days post-grazing, and the following measurements were made:

(i) Dry Matter and Proportion of Plant Components

For each plot, four 0.25 m² quadrats were cut, and material bulked. Each sample was weighed and the dry matter concentration calculated as for the grazing trial material (Chapter Three). From this dry matter value the amount of dry matter which was left after the animals were removed was subtracted, to give the amount of regrowth. The amount of dry matter left after grazing at the primary flower stage and regrowth at 58 days is shown in Plates 7 and 8. The sample material was divided into various plant components, and their proportions were obtained.



Plate 7

Low density plot (60 plants m^{-2}) of lupins (*Lupinus angustifolius* cv. Uniharvest) after having been grazed for five days at the primary flower stage.



Plate 8

Regrowth at 58 days from a low density plot (60 plants m^{-2}) of lupins (*Lupinus angustifolius* cv. Uniharvest) after having been grazed for five days at the primary flower stage.

(ii) Digestibility

The digestibility of the regrowth (whole plant) was measured *in vitro* as described in Chapter Two.

(iii) Nitrogen and Protein Concentration

Nitrogen concentration was measured, and the protein content calculated as described previously (Chapter Two).

(iv) Metabolizable Energy

The metabolizable energy of the feed available was calculated as in Chapter Two.

No statistical analysis of regrowth data was carried out.

4.3 RESULTS AND DISCUSSION

4.3.1 *Description of Regrowth*

Regrowth only occurred in plots which had been grazed at the pre-flower or primary flower stage, with only a few individual plants showing any signs at all of regrowing in plots which had been grazed at the two later stages. These results are similar to those obtained in the early work on bitter lupins (Anon., 1942; Whatman, 1959), (although the grazing treatment carried out in the present trial could not be described as light), but contradicted those of Straatman *et al.* (1972). They reported that the growing points appeared to be eaten first when the crop was grazed, allowing no further growth. In the present trial, the regrowth appeared to be mainly from secondary branches which formed at both upper and lower stem nodes, with tertiary branching occurring in many plants after the 40 day sampling date. This tertiary develop-

ment was more noticeable in the lower density (60 plants m^{-2}) treatment. This confirms the work of Withers (1975a) and Herbert (1977b) who both, in seed yield studies, observed stimulated lateral branch development after early defoliation or removal of the main stem flower.

Flowering, and apparently normal pod set, occurred on the secondary branches, and at 61 days flowers had formed on many of the tertiary branches. Again this was more apparent at the lower plant density. Seed would probably not have matured as, by the time this stage was reached, it was early winter (mid-May) and it was unlikely that seeds would have ripened.

Good falls of rain occurred on 19, 21 and 22 February, two, four and five days after the animals had been removed from the plots which had been grazed at the pre-flower stage (Figure 2.1). This may have been a factor influencing the regrowth potential. Soil moisture levels would still have been reasonable after the end of the primary flower grazing period, and rain fell again on 10 March, 17 days after regrowth commenced in this treatment.

The mean minimum temperature was between 8° and 10°C in the period immediately following pre-flower grazing, and about 10° following grazing at the primary flower stage. Temperatures did not fall appreciably until the second week of April, which was towards the end of the regrowth period (Figure 2.1).

4.3.2 *Dry Matter*

Forty days after grazing at the pre-flower stage, dry matter present in these plots (Table 4.1) was 116.8 g m⁻² at the lower plant density, and 326.2 g m⁻² at the higher (100 plants m⁻²). By 61 days, this had increased to 555.0 and 828.2 g m⁻² respectively, much higher than the 390.5 and 523.0 g m⁻² present in these plots when originally grazed 67 days after sowing. A similar trend was evident in those plots grazed at the primary flower stage, with 382.8 and 442.0 g m⁻² being obtained from the low and high density plots respectively after 40 days of regrowth, and 741.0 and 714.0 g m⁻² respectively after 61 days.

Total dry matter (grazed plus regrowth) was very similar (Figure 4.1) in three treatments:

- . Higher density, grazed at the pre-flower stage (just over 1 350 g m⁻²).
- . Higher density, grazed at the primary flower stage (just under 1 340 g m⁻²).
- . Lower density, grazed at the primary flower stage (just over 1 300 g m⁻²).

Total dry matter from the lower density pre-flower grazed treatment was just under 950 g m⁻², marginally less than the dry matter without regrowth obtained from both densities grazed at the green pod stage.

4.3.3 *Proportion of Plant Components*

At 40 days after grazing, the stem component was fairly high (above 60 per cent in all four treatments and as

Table 4.1: Dry matter, digestibility and metabolizable energy concentration of regrowth from lupins (*Lupinus angustifolius* cv. Uniharvest) grazed at the pre-flower or primary flower stage.

Density plants m ⁻²	Stage of Growth at which grazed	Days Post- grazing	DM g m ⁻²	Digestibility (per cent)	Metabolizable energy MJ kg ⁻¹
60	Pre-flower	40	116.8	66.4	9.76
		61	555.0	71.0	10.47
	Primary flower	40	382.8	60.2	8.88
		61	741.0	61.0	8.99
100	Pre-flower	40	326.2	68.5	10.08
		61	828.2	73.7	10.87
	Primary flower	40	442.0	64.1	9.46
		61	714.3	67.2	9.80

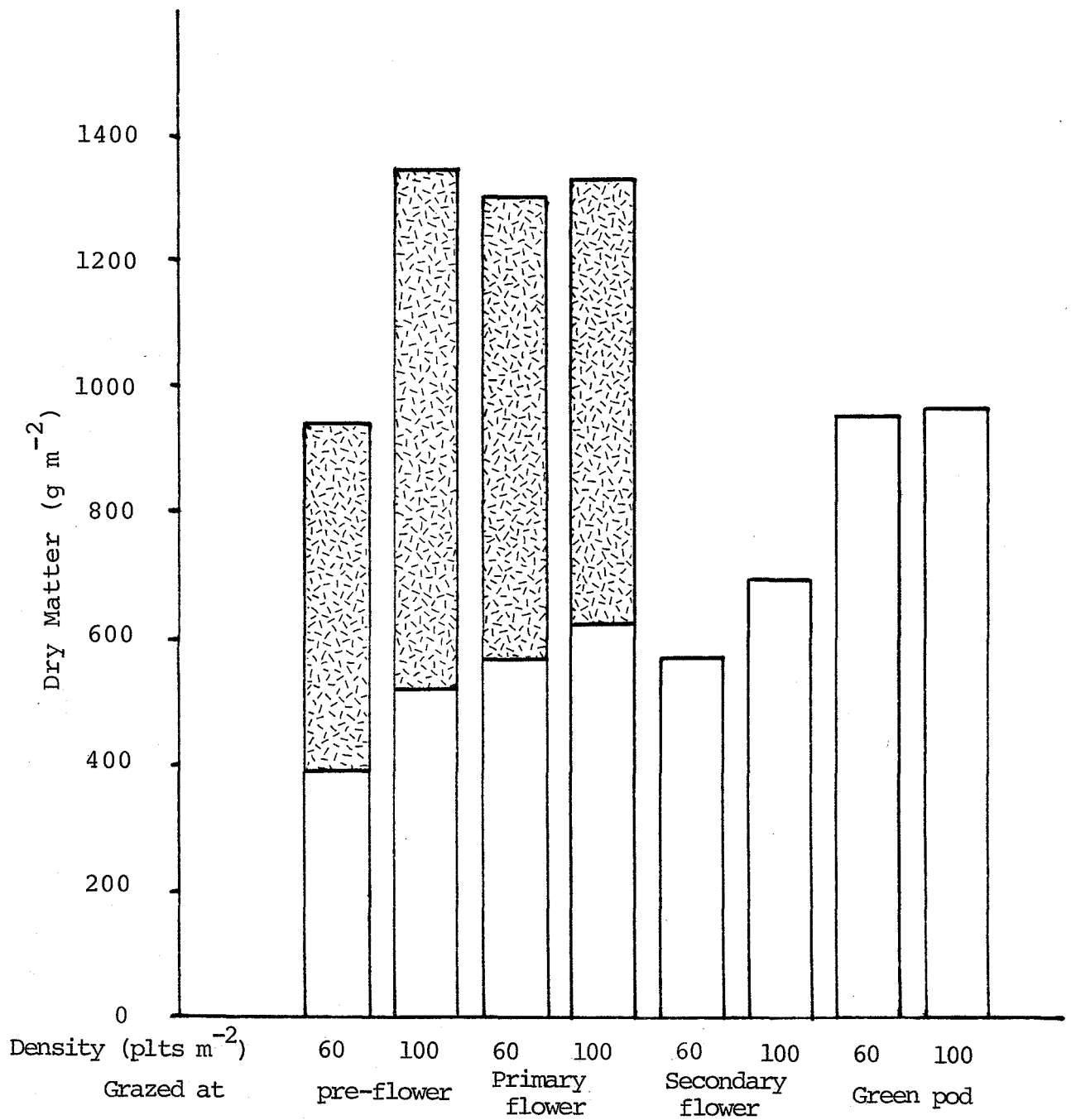


Figure 4.1: Total dry matter available from *L. angustifolius* cv. Uniharvest grazed at four stages of growth (two densities), including regrowth (shaded area) at 61 days after grazing.

high as 67 per cent in the lower density plots grazed at the pre-flower stage) in comparison with both the original plant material and 61 day regrowth (Figure 3.2 and Table 4.2).

The reasons for this were that there was a large proportion of main stem with few leaves in relation to the developing secondary branches, and also that there were still a few plants in the stand which was sampled that had not regrown. After 61 days most of these had died away, and by this time the proportions of plant components were very similar to those of the original pre-grazed material.

The proportion of reproductive parts at 61 days in all treatments was high, especially the lower density plots grazed at the primary flower stage. The 14 per cent recorded in this one treatment was higher than that recorded at either the secondary flower or the green pod stages of grazing. This result appears to confirm the work of Herbert (1977b) who found that seed yield was not decreased by removal of the main stem, rather than that of Withers (1975a) in which yield was depressed by defoliation at an early growth stage in spite of good secondary branch growth.

4.3.4 *Digestibility and Metabolizable Energy*

Digestibility of the regrowth material (Table 4.1) was generally lower at 40 days than that of the original pre-grazed plants. For the lower density plots the values were 66.4 and 60.2 per cent at the pre- and primary flower grazed stages respectively, compared with just under 74 and 75 per cent in the ungrazed material. For the higher density plots the values were 68.5 and 64.1 per cent compared with 80.0 and just over 75 per cent in the original pre-flower and primary

Table 4.2: Proportion of plant components in regrowth of lupins (*Lupinus angustifolius* cv. Uniharvest) grazed at the pre-flower or primary flower stage.

Density plants m ⁻²	Stage of Growth at which grazed	Days Post- grazing	Proportion of Component (per cent)		
			Leaf	Stem	Reproductive
60	Pre-flower	40	33.9	64.0	2.1
		61	49.2	39.6	11.2
	Primary flower	40	29.4	67.1	3.5
		61	38.2	47.8	14.0
100	Pre-flower	40	36.1	60.7	3.2
		61	43.0	47.2	9.8
	Primary flower	40	35.1	63.1	1.8
		61	40.6	47.7	11.7

flower grazed treatments. In those plots grazed at the pre-flower stage, digestibility of regrowth at 61 days was very much higher than at 40 days, 71.0 and 73.0 per cent for the lower and higher densities respectively. Although digestibility increased in the primary flower grazed treatments, from 60.4 and 64.1 (low and high density respectively) at 40 days after grazing to 61.0 and 67.2 per cent at 61 days after grazing, the differences were small, and probably not significant at the lower density. The increase in digestibility as the regrowth aged can be explained by the high proportion of stem present at the earlier sampling date, especially the old dying stalks, which would have had a very low digestibility.

The metabolizable energy concentration was highest ($10.87 \text{ MJ ME kg}^{-1}$) in the pre-flower grazed high density plots at 61 days of regrowth (Table 4.1), and these plots had the highest total ME available (9.0 MJ m^{-2}). This was a direct result of both the high dry matter at this time and the high digestibility of these plants at 73.1 per cent (Table 4.1). When the metabolizable energy available at grazing was added to that available in regrowth, the highest total metabolizable energy (15 MJ m^{-2}) was recorded from the above treatment (Figure 4.2). Just under 13 MJ m^{-2} was present in the primary flower grazed treatment at both densities, and about 10 MJ m^{-2} was recorded in the lower density pre-flower grazed plots. This was still higher than either of the other two grazing treatments for both high and low density.

4.3.5 *Nitrogen and Protein*

Nitrogen, and therefore protein, concentrations were fairly low compared with the original material. In the

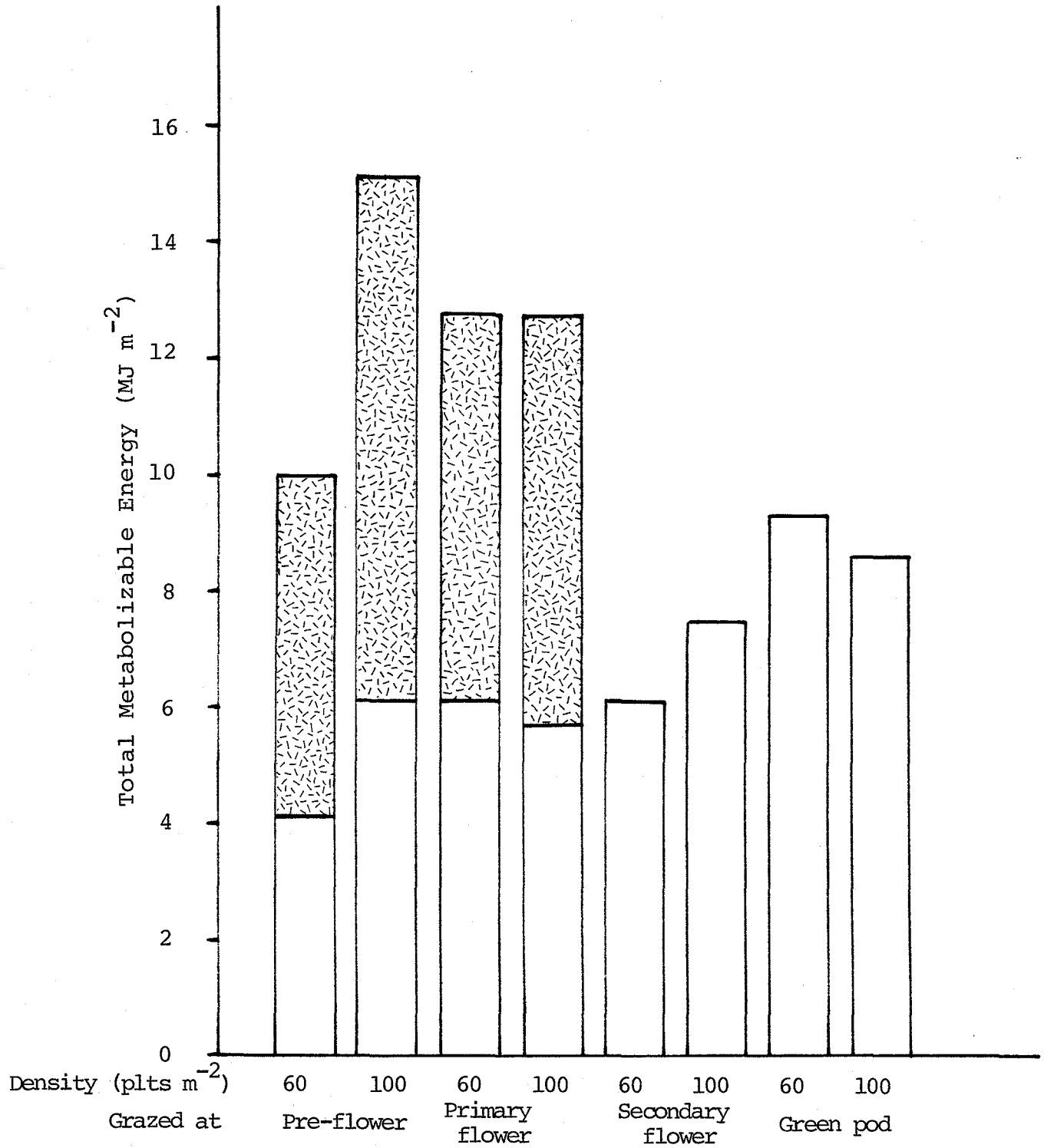


Figure 4.2: Total metabolizable energy available from *L. angustifolius* cv. Uniharvest grazed at four stages of growth (two densities), including regrowth (shaded area) at 61 days after grazing.

lower density, in spite of an increasing ratio of leaf and reproductive parts to stem, the nitrogen concentration tended to fall as the regrowth aged (Table 4.3). The expected rise in nitrogen concentration occurred in only the pre-flower grazed higher density treatment (1.9 per cent at 40 days to 3.8 per cent at 61 days of regrowth). The high concentration in this treatment resulted in 31.47 g m^{-2} of nitrogen being available from regrowth material, and, when added to that available at grazing, the total was nearly 49 g m^{-2} (Figure 4.3). This was much higher than that from either of the primary flower grazed plots. Total nitrogen available from grazing and regrowth in the pre-flower grazed lower density plots was less than that available from the higher density plots grazed at the green pod stage with no regrowth.

4.4 SUMMARY AND CONCLUSION

Regrowth of lupins only occurred in those plots which had been grazed at the pre- or primary flower stage. Of these, the higher density ($100 \text{ plants m}^{-2}$), pre-flower grazed treatment was the best in terms of both dry matter accumulation and nitrogen and protein content. Digestibility of these plants was higher, as was the metabolizable energy available in these plots.

This treatment also produced the highest total dry matter, metabolizable energy and nitrogen over the whole trial period. The higher dry matter available at grazing in the primary flower grazed treatment for both densities compensated somewhat for the lower dry matter production during the regrowth period, but the lower digestibility and nitrogen concentration of the regrowth decreased the total amounts of metabolizable energy and

Table 4.3: Concentration and total available nitrogen and protein in regrowth of lupins (*Lupinus angustifolius* cv. Uniharvest) grazed at the pre-flower or primary flower stage.

Density plants m ⁻²	Stage of Growth at which grazed	Days Post- grazing	Nitrogen		Crude Protein (N x 6.25)	
			Per Cent	Total g m ⁻²	Per Cent	Total g m ⁻²
60	Pre-flower	40	2.97	3.47	18.56	21.68
		61	2.55	14.15	15.94	88.47
	Primary flower	40	2.63	10.07	16.44	62.93
		61	2.58	19.12	16.13	119.52
100	Pre-flower	40	1.90	6.19	11.88	38.75
		61	3.80	31.47	23.75	196.70
	Primary flower	40	2.25	9.94	14.06	62.15
		61	2.65	18.92	16.56	118.29

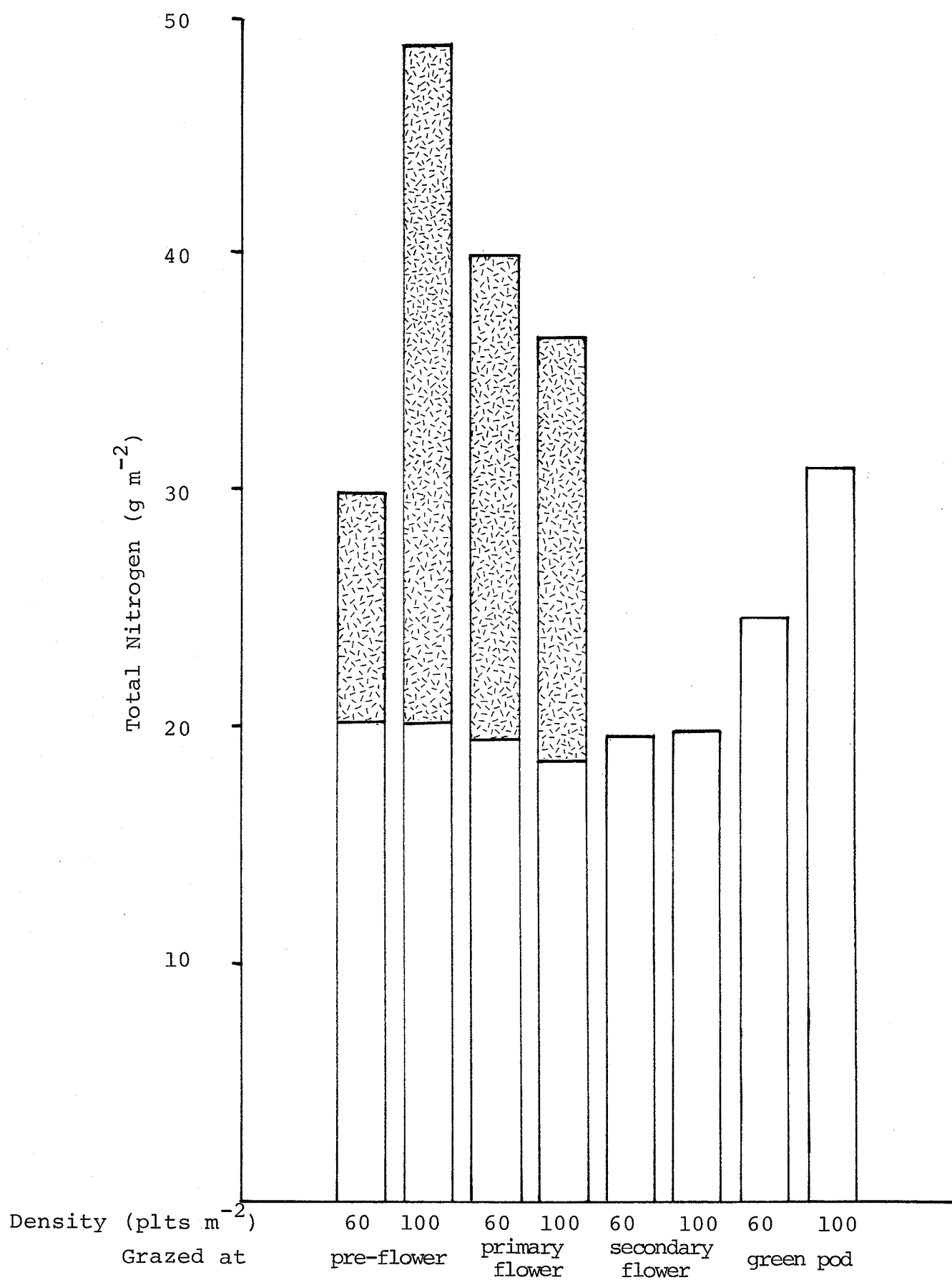


Figure 4.3: Total nitrogen available from *L. angustifolius* cv. Uniharvest grazed at four stages of growth (two densities), including that of regrowth (shaded area) at 61 days after grazing.

nitrogen available.

An amount equivalent to over 13 500 kg DM ha⁻¹ with an average nitrogen concentration of 3.6 per cent and metabolizable energy content of 11.11 MJ kg⁻² was produced in total. This was in a growing period of just under four and a half months with a density of 100 plants m⁻², grazed at the pre-flower stage.

Although very little work seems to have been published on regrowth of the crop after grazing, the observations made in this trial suggest that it is definitely possible to obtain good dry matter yields from lupins following grazing at the pre- or primary flower growth stages. This possibility makes the crop much more versatile.

After an early grazing, the crop could well be utilized at a later date for fattening "tail-end" lambs, or used as a flushing feed for ewes in the autumn. In no literature studied, during the preparation of this thesis, has any reference been made to lupins containing the high phyto-oestrogen concentrations which make it unwise to use lucerne-based pastures for pre-tup flushing.

If further feed is not required, it may be possible to take a seed crop. Although Withers (1975a) found seed yield to be decreased after defoliation of the plants at a very early (seven to eight leaf) or at the bud stage, work of Herbert (1977b) suggested that this might not be the case, and as normal pod set appeared to be taking place in the trial reported here, a reasonable seed yield could have been expected. This point is worth further investigation. The main disadvantages would be the extra length of time that the crop would be in the ground, and also that there may not be time for seed to ripen.

Early frosts, occurring at flowering, could also reduce seed yields markedly. Earlier sowing of the crop (September or October rather than mid-December as with this trial) may overcome these problems to some extent and, if a spring sown crop followed the lupins in rotation, the extra length of time the crop is in the soil would be no great problem either. It is possible that irrigation might be required after grazing if sufficient rain does not fall following grazing, and soil moisture is low.

A "single grazed" crop may well be considered uneconomic, in view of the extra costs of cultivation and sowing, but it is unlikely that if two grazings (or one grazing plus a light seed crop) were possible that this would be the case, even if irrigation was required.

CHAPTER FIVE

GENERAL DISCUSSION

Although lupins have been used in several countries as a forage for sheep, their use in New Zealand has been fairly restricted, especially in more recent times, in spite of their being a legume, and thus able to restore nitrogen to the soil (Rhodes, 1976). The trials described in the previous chapters have shown that the crop has considerable potential as a summer forage crop in Canterbury. Dry matter yield was especially promising. A maximum yield of 987.4 g m^{-2} without irrigation was obtained in the first trial (Chapter Two) at 150 days after sowing. This was at a stage where leaf drop was almost complete, and the plants were fairly well dried off, at which time most of the dry matter was in the form of seed.

The highest dry matter recorded in the grazing trial (Chapter Three) was recorded in the high density plots ($100 \text{ plants m}^{-2}$) at the green pod stage (980 g m^{-2}), but it was found that a much higher yield could be obtained if the crop were grazed at the pre- or primary flower stage and then allowed to regrow for at least 60 days (Chapter Four). Peak dry matter production obtained was 1350 g m^{-2} (from the pre-flower grazed plots at a density of $100 \text{ plants m}^{-2}$) equivalent to 13500 kg ha^{-1} . New Zealand lupin forage yields reported from other trials have been very variable. Macmillan and Brown (1973) and Knight (1980, pers. comm.) both obtained very low yields from sweet lupins. However, on the other hand, Herbert (1977a)

showed that the crop had the potential to yield up to 20 000 kg DM ha⁻¹ (without regrowth) under favourable conditions when irrigated. Yields obtained from early experiments with sweet *L. angustifolius* (Allison and Thurston, 1952; Greenall, 1956; van Stevenick, 1956) were generally lower than those recorded here, although yields from bitter cultivars have generally been higher (van Stevenick, 1956). Overseas work has also shown that there is considerable variation in lupin forage yield (Edwardson and Corbett, 1959; Nel, 1965), although comparisons from country to country are difficult to make with many possible factors being involved, including soil type, climate and plant pests and diseases.

When comparing the yield of lupins obtained in these trials with those of other commonly used summer fodder crops, it is clear that the crop can be considered as a viable alternative, even when unirrigated. Although yields were less than the summer production of lucerne when grown under favourable conditions (Wier *et al.*, 1960; O'Connor *et al.*, 1968; Vartha and Allison, 1973; Hoglund *et al.*, 1974), they were higher than in many other situations especially the lucerne yields obtained on unirrigated land reported by Iverson (unpub.) and Vartha (unpub.) (both cited by Vartha, 1971) and where disease and insect damage is a problem (Burnett *et al.*, 1978; Dunbier *et al.*, 1979b; Harvey, 1979a, b; Kain *et al.*, 1979a). The forage yields obtained also showed that the crop has the potential to outyield the summer production from mixed pasture (O'Connor *et al.*, 1968), and crops such as kale and rape under South Island conditions (Macmillan and Brown, 1973; Mortlock, 1975).

Although from an economic point of view a perennial crop such as lucerne or pasture is preferred, especially with increasing costs of cultivation, the potential yield shown in the two trials described here indicate that where an annual fodder crop can be used, possibly within a cropping rotation, that because of their dry matter production, lupins should be considered.

In the trials reported here, both nitrogen (protein) concentration and *in vitro* digestibility measurements were made on the lupin forage. Although Sullivan (1974) suggested that nitrogen or protein concentration was not a very accurate method for prediction of nutritive quality (in terms of digestibility) especially in legumes, adequate protein levels are important in the diet of young growing animals, and the method is relatively simple.

Peak protein concentration (calculated by multiplying nitrogen concentration by 6.25) was obtained in plants at the very early stages of growth and was 28.75 per cent 45 days after sowing. The concentration then declined over the plant's life at a rate of 0.15 per cent per day to 12.8 per cent just prior to harvest at 162 days. The protein concentration of the forage at the pre- and primary flower stages in the grazing trial ranged from 17.3 to 23.75 per cent before grazing. These values can be compared with the crude protein concentration of grasses which vary between 17.5 and 22.0 per cent depending on management (M.A.F.F., 1975); perennial ryegrass after flowering at 11.6 per cent (M.A.F.F., 1975); white clover at commencement of flowering at 23.7 per cent (M.A.F.F., 1975); and of lucerne which has been shown to be very variable in forage protein concentration. M.A.F.F. (1975) showed that protein concentration

in lucerne declined from 25.3 per cent at the vegetative (pre-flower) stage to 20.5 per cent at the bud stage and to 17.1 per cent at flowering. Although Mowat *et al.* (1965) found lucerne leaves to have a protein concentration as high as 30 per cent, much higher than that of lupin leaves recorded in the present trial, the average over the whole plant was just over 20 per cent. At very young growth stages, Terry and Tilley (1964) found a protein concentration of nearly 40 per cent in lucerne, whereas Ellis Davies *et al.* (1966) found that it averaged only 17.6 per cent over six stages of growth.

Maximum total protein in the forage was available in the present trial at 150 days after sowing (Chapter Two), which also coincided with peak dry matter production. As a protein concentration of 15.0 per cent is considered to be optimal for live-weight gain in 25.0 kg lambs (Andrews and Ørskov, 1970) the plant should possibly be grazed before the 150 day stage. However, protein concentration was only slightly under 15 per cent, and with heavier lambs for which the optimum protein concentration is lower, grazing could have taken place at the peak dry matter and total nitrogen stage.

In the grazing trial (Chapter Three), protein concentration of the forage was adequate for animal growth over the first three days of grazing at the pre- and primary flower stages, and over the first two days of grazing at the green pod stage (at a stocking rate equivalent to 2 000 ha⁻¹). Protein concentration in the lupin regrowth at 61 days of age was between 16 and 24 per cent suggesting that this material also should be suitable as a lamb fattening feed if required, or for flushing of ewes, prior to joining, where a high rate of liveweight gain is important. The nitrogen concentrations in the lupins recorded in

this grazing trial were slightly higher than those recorded in Canterbury by Anon. (1938) using bitter *L. angustifolius* at similar growth stages, and although initially higher, were, at the later stages, the same as those recorded by Davis and Offutt (1975).

In terms of protein concentration therefore, lupins at the earlier stages of growth, compare favourably with ryegrass and white clover pasture, and also with lucerne, especially once the lucerne has commenced to flower. Forage protein concentration is generally well over the levels recommended by Andrews and Ørskov (1970) for rapid liveweight gain in lambs.

In vitro digestibility of plant material was measured in both trials (Chapters Two and Three). In the first trial, peak digestibility at just under 65 per cent, occurred at day 125, but was fairly constant before this (varying between 60 and 65 per cent). It then declined rapidly after this date. This value was much lower than might have been expected when considering the very high digestibilities (of over 90 per cent) that were obtained by Clarke (unpub.), but agreed with values for both sweet *L. angustifolius* and *L. albus* (Allison and Thurston, 1952; Davis and Offutt, 1975).

Higher forage digestibility was recorded in the grazing trial (Chapter Three) especially at the pre-flower stage where the forage was over 80 per cent digestible at the higher density (100 plants m⁻²) before grazing. Much work on the digestibility of pasture species and lucerne has been reported. Lucerne has been found to have a digestibility varying between 84 and 63 per cent (Terry and Tilley, 1964) or 78 to 73 per cent (Mowat et al., 1965) as regrowth ages. Under Canterbury

conditions, Cosgrove (1978) found that the plant was over 80 per cent digestible at a stage where grazing could be contemplated, with respect to dry matter accumulation, but Thom (1978) reported that at very low dry matter accumulation after cutting, digestibility was only 73 per cent, and that this declined to 62 per cent as dry matter accumulation increased. The average digestibility of white clover has been reported as 76 to 77%, although at early stages of growth it was as high as 82 per cent (Ellis Davies *et al.*, 1966) and whole plant digestibility of perennial ryegrass ranged between 69 and 83 per cent (Terry and Tilley, 1964) with varying age and stage of growth.

In only the early growth stages of the grazing trial were lupins shown to have as high a digestibility as good lucerne, but if the potential of over 90 per cent digestibility in *L. angustifolius* obtained by Clarke (unpub.) could be expressed, at plant densities that were economical, the crop would have a definite advantage as a lamb feed over other summer forages.

In a small scale trial, *in vitro* digestibility of the forage was found to be very highly correlated with *in vivo* measurements (described in Chapter Three). These results conform with other published work (Tilley and Terry, 1963; O'Shea and Wilson, 1965; Wedin *et al.*, 1966; Ademosum *et al.*, 1968).

The digestibility of a forage is important, but the metabolizable energy (ME) available must also be considered, especially when the forage is being fed to young growing animals. Both the ME concentration of the forage and total available ME were calculated in the two trials. In the first trial (Chapter Two) peak total ME occurred at about the same stage (150 days) as peak dry matter accumulation, and maximum

nitrogen availability. The highest ME concentration in the forage was, however, at the early stages of growth, at which stage the value was 9.36 MJ kg^{-1} . The values recorded in the two trials were very similar to the ME concentrations for other green legumes and, with few exceptions, higher than those of most pasture grasses (M.A.F.F., 1975). In the same way as nitrogen concentration, there are limits to ME concentrations that are required for a feed to be acceptable to stock. The value required depends on the average weight of the animals and also on the rate of liveweight gain that is to be achieved (M.A.F.F., 1975). The concentration of ME was suitable at all stages of growth in the first trial, and at the beginning of each of the grazing periods in the grazing trial. It was shown in the grazing trial, however, that at the later stages of the plants' development, ME concentration drops rapidly, after the leaves and pods have been grazed, so that with less than 50 per cent utilization of the crop, ME concentration can fall below levels suitable for fattening lambs at a reasonable rate.

The animal data recorded in this trial was not detailed and was not intended to provide information on actual live-weight gains from feeding lupins. Early New Zealand work on this aspect is restricted to that reported by Anon. (1938), Anon. (1942) and Lancaster and Adams (1943), where bitter, or only the very early sweet cultivars, were used. Recent Western Australian work reported appears to be restricted to dry standing crops or stubbles and to lupin seed rations. The trials reported here have shown that large amounts of dry matter, with good digestibility, high nitrogen (protein) concentration and acceptable ME levels, are available, that lambs graze the crop readily and these animals gained weight at a reasonable

rate over the whole trial period in spite of being forced to eat lower quality feed towards the end of each grazing period. It is suggested that a much more detailed trial should be carried out to measure the rate of liveweight gain on lupins. The level of utilization of the crop that can be obtained would be one of the more important aspects of such an experiment. This would be especially important when considering the regrowth potential of the crop. It could well be that a lower utilization of the crop, or grazing over a longer period at a lower grazing pressure, might affect the amount of regrowth produced. Further, it may also be possible, as suggested by the results obtained in the low density plots grazed at the pre-flower stage, to over-graze, and so prevent or slow regrowth. This should be considered if a mob of some other class of stock is used to "clean up" after lambs have had the best grazing.

Plant density is another aspect of growing lupins for forage which requires further investigation. The effect of plant population on yield and nutritive value could not be defined from the results obtained from the grazing trial. Certainly it appears from the results obtained that at earlier growth stages, dry matter production is higher at a higher density, but that nitrogen concentration is depressed. As long as the nitrogen concentration is high enough to make the feed acceptable, the extra dry matter available should more than compensate, implying that more total protein is available per unit area. However, in the trial described here (Chapter Three), although the seeding rate was doubled, plant density was less than doubled (60 plants m^{-2} and $100 \text{ plants m}^{-2}$), and the dry matter production only increased by 25 per cent in the

higher density plots at the pre-flower stage, and by less than this at the primary flower stage. The extra cost of doubling the seeding rate may therefore not be justified by this result. However, the effect of density on regrowth of the plants grazed at the pre-flower stage (very much more regrowth occurred in the higher density plots) should be noted (Figure 4.1), but there could be many reasons for this large difference, including the fact that lower density plots were grazed very hard over the grazing period, and might have taken longer to recover.

Digestibility of the forage appeared to be unaffected by plant density, although it is possible that the very much higher digestibilities shown by Clarke (unpub.) were obtained from plants sown at a density higher than that of either of the two trials described here.

Further work using a range of densities is also, therefore, suggested. Apart from the economic aspect of increasing or decreasing density, other factors such as possible increased problems with weeds at lower densities, as happened in two of the plots of the trial described in Chapter Two, must also be considered.

From the two trials described, it has been established that the recommended time to graze a green lupin crop is at the pre- or primary flower stage, both in terms of nutritive value and maximum total dry matter production (allowing for regrowth). Recommended utilization is not so easy to define, but it is suggested that if grazing with young weaned lambs, the animals should not be left in the crop after the stage at which most of the leaves and young tender parts of the stem have been removed. This would mean a utilization of less than 50 per cent, even at the early growth stages, and as low

as 15 or 20 per cent at the later (secondary flower or green pod) stages. After this, protein concentration is lower, and both digestibility and consequent metabolizable energy concentration are declining. The residue can be fed to other classes of stock in which high rates of liveweight gain are not so important. However, as mentioned previously, making another mob "clean up" might well cause damage to the plants and lower their regrowth potential.

Lupins could definitely have a place on farms in Canterbury. They would fit logically into the types of cropping rotations practised, by most cropping farmers, or possibly into a pasture renewal situation as suggested in Chapter Two. In a cropping rotation, between cereal crops, nitrogen would be restored to the soil, especially if the crop was grazed twice rather than taken for seed. The major possibilities for the crop demonstrated by the trials described here are:

- . The crop could be sown in spring or early summer and grazed by weaned lambs at the pre-flower stage.
- . Regrowth after the above grazing could be then utilized for later lambs, possibly as flushing feed for ewes, or could be taken for seed if the crop had been planted early enough.

Irrigation might have to be used if there were insufficient rain after grazing. Other possible uses include making hay from the crop. However, as is the case in South Africa, (Straatman *et al.*, 1972), problems might well arise in drying the forage without excessive leaf loss occurring. This would be especially the case with *L. angustifolius* cultivars. Silage would be less risky, but this does not appear to be a popular method of feed conservation in

the Canterbury area. Later sowing as an autumn and early winter greenfeed is another possibility, but again irrigation might be required if dry conditions occurred after sowing. This would not be as a lamb fattening feed, but more as a feed for flushing. Very little work on this aspect has been published. Western Australian work has shown that ovulation rates can be increased markedly if ewes are fed lupin grain before tupping (Lightfoot and Marshall, 1974; Marshall and Lightfoot, 1974; Kenney, 1975; Knight *et al.*, 1975; Brien *et al.*, 1976; Lightfoot *et al.*, 1976; Brien *et al.*, 1977), but there appears to have been no work published in which green lupins have been fed at this time. From the trials described here, there appears to be no reason why the crop cannot be used, and further work along these lines is suggested.

There are, however, several possible disadvantages that may be associated with the crop. Seed is sometimes difficult to obtain in quantity, and is relatively expensive. Both trials showed that poor seedling emergence could occur in poorly structured soils. In the first trial, emergence was slow and weeds became a bad problem in some plots. Even under favourable conditions, final densities in the grazing trial were much lower than originally intended, and although weed control was unnecessary in this grazing trial, it would have been advisable in the other.

Although the organism causing lupinosis, *Phomopsis leptostromiformis*, has not as yet been isolated in New Zealand, the possibility of this disease restricting the use of lupins as a forage in this country in the future, as it has in both South Africa and Western Australia (Marasas, 1974) should not be disregarded. Close (1980, pers. comm.) has stated that there is no reason

why the fungus should not survive under Canterbury conditions, and although green lupins are considered to be reasonably safe, problems could well arise with the grazing of regrowth, in which old dying stems still remain, and stubbles.

Although Harris (1980, pers. comm.) had no trouble with aphids in his trial on insects which infest lupins, conducted in the same year as those reported here, aphids, and the viruses they transmit, might also become a problem as they have done in lucerne and some pea crops.

In spite of these problems, lupins appear to have considerable potential as a forage. The two trials reported here have shown that they are capable of yielding well, and they produce a highly nutritious feed especially suitable for young lambs. If regrowth can be ensured (even if this means irrigating), the lupin crop compares favourably with other greenfeeds and would be a useful addition to any cropping rotation because of its ability to fix nitrogen.

CONCLUSION

The experiments reported here have shown that sweet lupins (*L. angustifolius* cv. Uniharvest) have the potential to yield well under Canterbury conditions and that they are capable of outyielding the more traditional summer forages used for lamb fattening, such as lucerne and ryegrass/white clover-based pastures, under some circumstances. Digestibility of the crop was shown to be good, protein levels high and the overall nutritive value found to make the crop an acceptable alternative summer greenfeed.

ACKNOWLEDGEMENTS

In the course of this project, I have become indebted to many people, and I would like to express my gratitude to the following:

Mr George Hill, for his supervision of the project, and for his advice and encouragement in the preparation of this thesis.

Professor A.R. Sykes, Mr Terry Hughes and laboratory staff of the Animal Sciences Group, for use of facilities and equipment for digestibility determinations.

Dr Noel Porter and staff of the Applied Biochemistry Division, D.S.I.R., for nitrogen analysis, and for use of freeze drying facilities.

Mr Gerry Meijer and staff of the Field Service Centre, for their help, especially with fencing and animal work.

Waree Piyawongsomboon, for her valuable help with drawing figures.

Malcolm Macfarlane, for photography.

My parents and Godmother, for many hours of correcting and proof-reading of the thesis.

Staff and students of the Plant Science, Farm Management and Rural Valuation and Biochemistry Departments for their advice and encouragement.

Mrs Kathy Brown, for typing this thesis.

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