THE NUTRITIONAL VALUE OF RUSSELL LUPIN (*Lupinus polyphyllus x Lupinus arboreus*) FOR SHEEP

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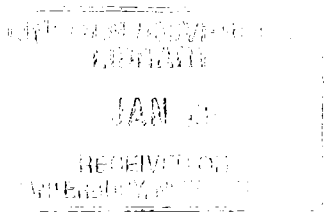

Abstract of a thesis submitted in partial fulfilment of the requirements for the degree of M.Agr.Sc. at Lincoln University, New Zealand.

THE NUTRITIONAL VALUE OF RUSSELL LUPIN (*Lupinus polyphyllus x Lupinus arboreus*) FOR SHEEP

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Two field trials were conducted consecutively in Canterbury, at Lincoln University. In the first experiment, spring regrowth of Russell lupin (*Lupinus polyphyllus x L. arboreus*) was cut at three weekly intervals to determine changes in nutritive value with plant maturity. Six harvests were made between 5 October 1989 and 18 January 1990. Measurements included dry matter (DM) yield per plant and plant parts, nitrogen (N) and neutral detergent fibre (NDF) concentration, and *in vitro* cellulase DM and organic matter (OM) digestibility.

Whole-plant DM yield for the six cuts increased from 40 to 160 g plant $^{-1}$ (or 4 to 16 t ha^{-1}). Up to pod formation the DM yield of Russell lupins was largely petioles and leaves. The N concentration in total DM decreased from 4.5 to 2.4 % with maturity; corresponding values for NDF were 24.1 to 46.2 %. This was due to both changes in the proportion of plant components and changes in N and NDF concentration within components. The N concentration in individual plant parts generally declined over time.

The *in vitro* cellulase DM and OM digestibility declined from 76.5 to 56.0 % and 81.4 to 54.9 %, respectively. Unlike most other pasture species, the *in vitro* cellulase DM and OM digestibilities of Russell lupin showed a slow, quadratic ($P<0.001$, $R^2 = 0.94$) decline with maturity. The high digestibility of Russell lupins together with their high DM yield gave a very high yield of digestible DM (DDM) and digestible OM (DOM). The DDM yield of Russell lupins showed two peaks; the first, at 89 g plant^{-1}, at full bloom and the second, at 91 g plant^{-1}, at the dry pod stage. Although the two DDM yields were similar, (i) the second peak had three times more DDM from dead matter, (ii) 49 and 20 % of the DDM (of peak I and II respectively) consisted of plant parts with >80 % digestibility, and (iii) 0 and 50 % of the DDM (of peak I and II respectively) consisted of plant components with <60 % digestibility. This trial showed that Russell lupins can produce highly digestible DM with a high N content over most of their growth.

In the second experiment, autumn sown (March, 1990) Russell lupins were grazed (Nov., 1990 - Jan., 1991) by two-tooth Coopworth ewes (plot size 418 m^2, 20 sheep $plot^{-1}$) at full bloom, green pod and dry pod stages. The objectives were: (i) to distinguish between the two stages of peak DDM yield in terms of acceptability to sheep, per cent utilisation and amount of regrowth and determine the optimum stage to graze the lupins, and (ii) to study preference of sheep among different plant components of Russell lupins.

There was no apparent difference between the three stages of growth with respect to acceptability, for average DM disappeared per sheep increased with allowance. Sheep selected against stems, but showed strong preference for leaves; defoliation of other parts increased as the proportion of leaves in total herbage decreased. As opposed to earlier reports, there was significant consumption of both green and dry pods. Per cent utilisation was 89, 80 and 75 % for lupins grazed at full bloom, green pod and dry pod, respectively.

Total regrowth DM (residue + current growth) yield was 6960, 3774 and 2282 kg ha^{-1} for Russell lupins grazed at full bloom, green pod and dry pod stage, respectively. However, the difference between full bloom and dry pod in terms of estimated annual harvestable (i.e. by sheep) DM yield, which respectively was 6990, 6490 and 7410 kg ha^{-1} for lupins grazed at full bloom, green pod and dry pod stage, was not as marked. Therefore, it was concluded that the optimum stage for grazing will depend on the feed requirement plan of the individual farmer. Farmers have the option of leaving the lupins standing till late in the season without marked loss of quality, or graze them early for better autumn regrowth.

Key words: *Russell lupin, dry matter yield, nitrogen, neutral detergent fibre (NDF), in vitro cellulase digestibility, digestible dry matter, selection, optimum stage, regrowth, utilisation.*

CERTIFICATE

This is to certify that the work reported in this thesis was planned, executed and described by Soressa M. Kitessa under my supervision.

A Nicol HPG. Hill

George Hill, 7.2.92

Supervisor

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CHAPTER ONE

GENERAL INTRODUCTION

Unlike most developed countries, New Zealand agriculture has relied on clover and other nitrogen fixing legumes to provide the substantial inputs of nitrogen required to build or sustain soil fertility. It has been estimated that less than two per cent of New Zealand total nitrogen requirement is applied through fertiliser N (New Zealand Fertiliser Statistics, 1986). Pasture improvement in New Zealand has relied on introduction of vigorous legumes (e.g. white clover) after correction of soil nutrient deficiencies through commercial fertilisers. However, decline in farm returns and removal of fertiliser price and transport subsidies since 1984 (New Zealand Fertiliser Statistics, 1986) has made such an improvement scheme unprofitable to many farmers, especially high and hill country farmers. Therefore, farm advisors and scientists have been looking for alternative methods of improving pastures.

In 1972 Epstein suggested developing plants whose mineral nutrition was suited to the soils in which they were grown rather than changing the nutrient status of soils to suit the plants. Recently, the Grasslands Division, DSIR, has undertaken a breeding programme to produce a white clover with improved phosphate nutrition (Dunlop *et al.*, 1988). However, it is not easy to produce a cultivar whose mineral nutrition has been intentionally improved, and the task may take a very long time.

Another approach is the use of legume species adapted to conditions prevailing in hill country farms. One such species is Russell lupin (*Lupinus polyphyllus x Lupinus arboreus*), which has proved to be a vigorous, persistent, perennial legume, well adapted to the high country environment, where phosphate is universally limiting, soil pH is generally low, and soil aluminium level is high (Scott, 1989). Studies conducted so far, by DSIR and Lincoln University, focused mainly on the productivity and persistence of Russell lupin

under grazing (Scott and Covacevich, 1987), their establishment requirements (Tesfaye, 1989; Wangdi, 1990) and the effect of forms of phosphate and pH on its growth and nutrition (Miller, 1989). No study has yet characterised the change in DM yield, chemical composition, and digestibility of the plant with maturity. There is hardly any information on the pattern of its defoliation and changes, if any, in its acceptability with maturity.

Therefore, two consecutive field experiments were initiated with the following general objectives:

1. To illustrate the changes in yield, composition and digestibility of Russell lupins as they progress to maturity,
2. To determine the amount of harvestable (i.e. through grazing) yield produced at different growth stages, and
3. To indicate the optimum stage to graze these lupins based on the yield of digestible nutrients, acceptability to sheep and amount of autumn regrowth.

CHAPTER TWO

REVIEW OF LITERATURE

2.1. GENERAL HISTORY OF LUPINS

There have been a number of reviews of the use of lupins for forage and grain. Gross (1986) reviewed the evolution of the genus *Lupinus*, and their natural geographical distribution in the Old and New World. Gladstones (1970) provided a comprehensive review of the global distribution of different lupin species, their cultural requirements and use for livestock feed. Burtt (1981) presented an updated review on the same subject, with an in-depth coverage of lupin use in New Zealand. The chemical composition and nutritive value of lupin seeds (Hill, 1977), the use of lupins for sheep (Hill, 1988, 1990), poultry, swine, cattle, deer, goat, fish and human nutrition (Hill, 1986, 1990) have also been reviewed. The following sections present the origin of lupin cultivation and general trends in the use of lupins as forage for animal feeding and factors governing these trends.

2.1.1. Origin of cultivation

The name *Lupinus* is derived from *Lupus*, Latin for wolf, probably to reflect their growth in rough and wild places (Gladstones, 1976). The time and place of the first cultivation of lupins in the Old World is obscure. Many consider Egypt to be the place of origin of lupin cultivation where they may have been grown from as early as 2000 B.C. (Gladstones, 1970). However, some argue that the Egyptian name for lupin, *termis* is derived from the Greek word *thermos* suggesting Greece was the place of origin (Aguilera and Trier, 1978). In the New World, the Andean regions of Peru are considered the origin of lupin cultivation where signs of cultivation date as far back as 2000 B.C. (Gross, 1986).

Large-seeded lupin species, the source of present and potential crop varieties, with the exception of *L. mutabilis*, originated in the Mediterranean basin and north and central Africa (Gladstones, 1970). They were used extensively as green manure. After treatment to remove alkaloids, seeds were used for human consumption by the poor and for stock feed (Gladstones, 1970, 1976). Writers as early as Hippocrates mentioned the use of lotions prepared from lupin seed for beautifying the face. There are now a wide variety of annual and perennial lupins used for grain and/or forage production in different parts of the world.

2.1.2. Recent trends in lupin cultivation

Towards the end of the 18th century there was increased interest in the cultivation of lupins which decreased during the 1860's due to the availability of cheap nitrogen fertilisers and alkaloid poisoning problems (Gladstones, 1970; Burtt, 1981; Hill, 1988). However, lupins continued to be used in Germany mainly for green manuring, and at the end of the 19th century the area under lupins still exceeded 300 000 ha (Hanlet, 1960, cited by Gladstones, 1970).

Interest in lupins increased again when in the early 1920's Baur (1931, cited by Gladstones, 1970) postulated a hypothesis that alkaloid-free mutants might occur in lupins as in other legume genera, which was pursued by von Sengbusch (1931, cited by Gladstones, 1970) who in 1928-29 successfully selected the first alkaloid-free lupin and thereby laid the foundation for modern lupin breeding. Simultaneously, selection for non-shattering (of pods) also began in 1929 and a non-shattering strain was successfully found, 10 million plants later, in the mid 1930's (von Sengbusch, 1938, cited by Gladstones, 1970). Before the 1939-45 war, cultivation of alkaloid-free lupins was confined almost entirely to North Germany where the area under lupin was about 78 000 ha in 1938 (Gladstones, 1970).

Since the development of sweet varieties of lupins there has been a global increase in lupin cultivation; the area sown in lupins rose from 667 000 ha in 1948/52 to 1 073 x 10^3 ha in 1985 (Williams, 1986). The expansion of lupin cultivation was particularly high in Australia; the area under lupins increased from a mere 2 000 ha in 1961/65 to 606 000 ha in 1985 (Williams, 1986) which exceeded the sum total for the rest of the world in the same year by 77 %. The increase in lupin cultivation in Australia, particularly *L. angustifolius* was due to rigorous research work which managed to successfully combine: sweetness, permeable seed coat and non-shattering pods (Burtt, 1981). The area sown in lupins in 1988 was 1 015 x 103 ha which slightly decreased in 1989 to 849 x 10^3 ha (Australian Bureau of Statistics, 1989/90). Preliminary evaluation of lupins for introduction into Britain as an alternative oil and protein grain has also given promising results (Williams, 1979; Sheldrick *et al.* 1980).

2.1.3. Use of lupins in New Zealand

During the 1930's, after the use of rape (*Brassica napus*) as a supplementary fodder in summer had declined in popularity due to its susceptibility to aphid attack, bitter *L. angustifolius* became a popular summer greenfeed in Canterbury (Anon., 1938, 1942; Allison and Thurston, 1952). In 1936/37 about 80 % of the total area sown to lupins for sheep fattening in New Zealand was grown in Canterbury (Anon.,1942). Borre, a soft-seeded sweet cultivar of *L. angustifolius*, was the cultivar commonly used for this purpose (Allison and Thurston, 1952, Greenall, 1956). Lupins did not tolerate the wetter and heavier soils of Southland and trials on the pumice soil of the Central North Island were unsuccessful (Burtt, 1981). The area sown in lupins peaked at 4 000 ha in 1950 after which it declined.

Increasing problems with lucerne (Burtt, 1981), a competitor with lupin as a summer forage, the recent banning of DDT use on species susceptible to insect damage, the

increasing popularity of organic farming and the loss of subsidies in fertilisers for hill country farmers are just some of the reasons to reconsider the potential of both sweet and bitter lupins for ruminant feeding. To date, there have only been five annual species used to any great extent, namely, *L. angustifolius, L. albus, L. luteus* and *L. cosentinii* which are described by Gladstones (1970) and *L. mutabilis* described Gross and von Baer (1977).

Russell lupin has shown some potential for use as forage on some hill country sites in New Zealand. The following section introduces this plant and presents some of its features that may justify its incorporation in the New Zealand farming system.

2.1.4. The Russell lupin

2.1.4.1. Origin

The Russell lupin is a herbaceous perennial, which dies back to a stout crown each winter (Horn and Hill, 1982). It grows up to 1.5 m tall and has long leaves (each with 9 to 16 leaflets) and very short stems, which are inconspicuous during vegetative growth. It has flowers with a wide variety of colour, i.e. blue, white, red, pink, orange and yellow as well as various combinations and shades of these colours (Horn and Hill, 1982).

The exact contribution of genetic material from the parental lines which produced the Russell lupin is not known. It is generally believed that *Lupinus polyphyllus* Lindl. is the major parental line with *L. arboreus* Sims. and *L. nootkatensis* also contributing a few traits (Dunn, 1984). Tesyaye (1989) can be consulted for the origin and morphological features of these parental lines. *L. polyphyllus*, from which Russell lupin was mostly derived, was introduced to Britain as a potential horticultural plant by Douglas in 1826 (Scott, 1989). George Russell widened the originally predominantly blue-and-white coloured flowers of the plant by hybridisation with the tree lupin (*L. arboreus*). The plant as it now exists was released commercially as an ornamental in the mid 1930's (Scott, 1989)

and received widespread recognition including a gold medal from the Royal Horticultural Society for its colourful flowers. The morphology of the Russell lupin in general and the specific morphological characteristics of a collection of Russell lupin accessions has been well documented by Tesfaye (1989).

2.1.4.2. Introduction to New Zealand

The Russell lupin was brought into New Zealand gardens shortly after its release in Europe (Scott, 1989). The first major sowing in the high country was 8-10 kg of seed broadcast on bare roadside soils in about 1952 on the Sawdon Station section of the Tekapo/Burkes Pass road in the Mackenzie Basin of the South Island (Scott, 1989). Until the late 1980's most work with Russell lupins in New Zealand had been on its potential for revegetation. The plant has a capacity to grow and persist well under adverse soil conditions (see Section 2.1.5).

Studies conducted so far at Lincoln University, New Zealand, have dealt with glasshouse (Tesfaye, 1989) and field (Wandgi, 1990) establishment of Russell lupins, the effects of soil pH and phosphate nutrition on Russell lupin growth (Miller, 1989), and seasonal variation in the alkaloid content of Russell lupins forage (Gibbs, 1988; Savage *et al.*, 1990). The first major investigation of the potential of Russell lupins as a forage was started in 1982 at the Grasslands Division DSIR trial site at Mt John Station, Lake Tekapo, in the Mackenzie Basin. The main findings of experiments conducted at that station are summarised below.

(1). Among 24 species tested, Russell lupin was the species best able to utilise lower fertiliser rates, and was the highest producing of these species at all but the highest of five superphosphate levels (0, 50, 100, 250 and 500 kg ha-1) (Scott and Covacevich, 1987).

(2). Although the lupin produced high yields under lax grazing, it was also shown that it could be grazed to ground level and recover (Scott, 1989).

(3). In mixtures with grasses and other legumes, sheep selected against Russell lupin, but consumption increased with stocking rate (Scott and Covacevich, 1987).

(4). Young flowers were eaten first but all parts were acceptable to stock during spring and autumn (Scott, 1989).

These studies have indicated that the Russell lupin has the potential to become a major forage legume on moist, acid, loose-textured soil in higher rainfall areas where only low to moderate fertiliser rates could be afforded (Scott, 1989), i.e. under a combination of conditions to which many legumes are not suited. However, these observations can only be used as preliminary guidelines. Firstly, the relative importance of species in Scott and Covacevich's work was based on subjective ranking to which no statistical significance can be attached. Secondly, the studies did not indicate the percentage DM utilised per plant or per unit area. Thirdly, the seasonal acceptability trends were not supported by data to show that consumption of Russell lupins or their individual plant parts, say in summer was significantly lower than in spring and/or autumn. Therefore, there is a paucity of information on the dry matter yield, stock acceptability and nutritive value of Russell lupins.

2.1.5. Important agronomic features of lupins

Features of lupins which can be exploited in pastoral farming include efficiency of nitrogen fixation, performance under poor soil fertility, especially low phosphorus, resistance to pest damage, resistance to frost (which varies with species), and improvement of soil fertility when used in rotation with other crops. These characteristics are discussed below.

1. Nitrogen fixation. Like other legumes, lupins can obtain their N requirement through symbiotic association with N-fixing *Rhizobium*. Annual N fixation by *Lupinus* species is estimated to range from 145 to 208 kg N ha^{-1} with an average of 176 kg N ha^{-1} (Nutman, 1976). The high N yield of lupins can be exploited by using them in rotation with grasses or cereal crops. Rhodes's (1980) experiment on a Templeton silt loam in Canterbury provides a good example. He showed that:

(1). The amount of N fixed by *Lupinus angustifolius* cv. Uniharvest (183 kg ha^{-1}) was more than double the amount fixed by *Pisum sativum.*

(2). Tama ryegrass (*Lolium multiflorum*) yield from plots previously in lupins (3 680 kg DM ha^{-1}) was higher than the yield from plots previously sown to peas (2 850 to 3 290 kg DM ha^{-1}).

(3). The N concentration in Tama ryegrass was higher after Uniharvest lupin than after peas.

Similarly, Mock (1986) demonstrated that where lupins preceded wheat on a mildly alkaline sandy loam soil of north west Victoria, there was no yield response to application of N (0, 10, 20, 40 and 80 kg/ha). Sandberg and Gadgil (1984) also showed that most, if not all, of the N required for *Pinus radiata* forest development on sand dunes was derived from symbiotic N fixation the perennial tree lupin (*Lupinus arboreus*. Sims)

2. Growth under adverse soil conditions. Lupins have been known to grow under suboptimal soil fertility. Arnold and associates (1975) obtained 9 t/ha of lupin (*L. angustifolius*) DM on soils that produced only 3 to 4 t/ha of pasture (Arnold *et al.* 1975). Dry matter yields as high as nearly 20 t ha^{-1} have been recorded from irrigated *L. angustifolius* (Herbert and Hill, 1978). The main features of lupins with respect to productivity under adverse soil conditions are listed below.

(a). Lupins are not only tolerant to low soil phosphate levels, but are also capable of utilising soil phosphate which is unavailable to most other plants (Miller, 1989; Borie, 1990). Borie (1990) listed four probable root adaptations of lupins growing on P-deficient soils: (i) root excretion of acid substances, (ii) deep roots and other geometry of rootlets, (iii) exudation of root phosphatases, and (iv) formation of mycorrhizal associations.

(b). Lupins may have the potential to mobilise unavailable P in excess of their own requirement (Borie, 1990).

(c). On deep sandy sites, lupins can also extract potassium which is less available to cereals (Gladstones *et al.*, 1964; Rowland *et al.*, 1986). In some areas this increased the soil K by 50 kg ha^{-1} (Baylis and Hamblin, 1986).

(d). Their massive root system improves soil structure and aids erosion control on loose-textured soils by increasing the soil organic matter content which forms and

stabilises aggregates (Rowland *et al.*, 1986). On compacted soils, their deep penetrating roots ameliorate the effect of compacted soils for succeeding cereal crops replacing the need for deep tillage. Henderson (1989) estimated that the 'biological plough' effect of lupins on compacted soils improved wheat yield by about 100 kg ha^{-1}.

(e). Lupins can tolerate low soil pH (Davis, 1981; Baylis and Hamblin, 1986; Miller, 1989), but do not flourish when soil acidity is due to poor drainage (Anon.,1942).

(f). Lupins tolerate toxic levels of aluminium usually associated with low pH soils (Scott and Covacevich, 1987).

(g). Some lupins accumulate Manganese at levels (5 000 to 16 000 ppm) which would be considered toxic to other plants (Reay and Waugh, 1981; Gardner *et al.* 1982). Gardner *et al.* (1982) suggested that manganese accumulation was probably related to physiological processes that increase phosphorus uptake from neutral or acid soils.

3. Drought tolerance. Lupins are tolerant to drought. This is principally due to the ability of their roots to penetrate rapidly and deeply into the soil rather than to xerophylly or other physiological forms of drought resistance (Gladstones, 1970). Turner and Stern (1986) also stated that osmotic adjustment is not the likely adaptive mechanism to water stress in commercial lupins grown in Western Australia.

4. Frost tolerance. Lupins are resistant to frost in the pre-flowering state (Gladstones, 1967), and sowing date can be arranged so flowering does not coincide with frost. Huyghe (1988) suggested that a large root, especially a large root parenchyma, is required for cold resistance as the root parenchyma cells of winter type white lupins *L. albus* had thicker cell walls.

5. Resistance to insect damage. Bitter lupins are considerably resistant to pest damage, and can be used as a 'break' crop in rotations (Mock, 1986). Mock (1986) showed that wheat infection with *Gaeumannomyces graminis* on plots previously sown to lupins was half the level of infection on plots previously sown to barley.

Considering all these benefits of lupins one would wonder whether they deserve their current minority status both as a grain and a forage legume. This argument can be further supported by considering the nutrient content and digestibility of lupins. Due to

limited information on perennial lupins most of the discussion in the following sections is based on annual species.

2.1.6. The nutritional quality of lupins

2.1.6.1 Nitrogen concentration

Lupins produce DM of high nitrogen concentration which together with their high DM yield gives a very high herbage N yield per ha. In most cases the protein content of lupin herbage DM is greater than 15 % (Davis and Offutt, 1975; Sheldrick *et al.* 1980; Burtt, 1981). More interestingly, in some species (e.g. *L. albus*) the N concentration remains high as the lupins progress to maturity (Davis and Offutt, 1975; Sheldrick *et al.*, 1980).

2.1.6.2. Dry matter digestibility

Most lupins produce highly digestible dry matter, especially in their vegetative stage. Even at the latest stage of maturity most lupins are more than 50 % digestible (Sheldrick *et al.*, 1980; Burtt, 1981; Anslow *et al.* 1983). Some species, e.g. *L. albus*, have shown an absence of decline in digestibility (Davis and Offutt, 1975) or even enhanced digestibility (Sheldrick *et al.*, 1980) with the onset of reproductive development, which is opposite to what usually occurs in other pasture plants. Moreover, Offutt and Davis (1973) stated that not only did the crude fibre content of sweet white lupin increase at a slower rate than in lucerne (*Medicago sativa*) but also the nutritional quality of the fibre declined more slowly. The interesting feature of the lack of rapid deterioration in quality with the onset of maturity is that it provides the option of using the plants late in the season without sacrificing herbage quality.

There does not appear to be any report on the site of digestion of protein or efficiency of utilisation of ME of lupin forage. Most of the reports in these areas focus on lupin grain fed as supplement which is outside the scope of this report. However,

considering the presence of alkaloids, and most probably tannins, lupin forage may not undergo excessive degradation in the rumen.

2.1.7. Forms of lupin feeding

Lupins can be used as green herbage, hay or silage. In addition, unharvested dry standing lupins and/or lupin stubble are popular summer feeds for sheep and cattle in Australia (Thatcher, 1982). The value of dry standing lupins and lupin stubble is beyond the scope of this review. The reader is referred to other papers regarding the value of dry standing lupins (Carbon *et al.*, 1972; Arnold and Charlick, 1976; Morcombe *et al.* 1987) and lupin stubble (Marshall *et al.*, 1976; Croker *et al.*, 1979a, 1979b; Kenney and Roberts, 1987; Oldham and Wilkins, 1988).

2.1.7.1. Green lupins

Reports from Australia concentrate mainly on the value of lupins as a dry standing summer feed or as stubble. There is little published information on the nutritive value of green lupin herbage. In New Zealand bitter lupins were popular summer green feed during the 1930's (Anon., 1938). For instance, a liveweight gain of 193 g/head per day was achieved by Corridale wether lambs grazing lupins; those grazing rape gained only 158 g/head per day (Anon., 1942). It was also shown that ewes grazed on lupins were in good condition (gaining 10 kg over 2 months) and had the best average birth weight of lambs (Anon.,1938).

Recently, Burtt (1981) evaluated the nutritive value of *L. angustifolius* cv. Uniharvest at four growth stages. The results are summarised below.

(1). At all growth stages leaves were preferentially grazed, followed by flowers and pods.

(2). The amount of residue left after grazing was 2 to 3 t/ha and showed the a tendency to increase with maturity.

(3). Sheep liveweight gain was estimated at about 97 g/day although the duration of grazing was not long enough to generate acceptable liveweight gain data.

(4). No health problems were reported from sheep used in the study.

Generally, for better regrowth, grazing before the end of flowering is recommended, because sweet lupins recover poorly from cutting or grazing (Gladstones, 1970) and bitter lupins will have high alkaloid content in their vegetative parts at earlier stages (Wink and Hartmann, 1981). However, Burtt and Hill (1990b) obtained better regrowth from *L. angustifolius* grazed at pre-flowering stage than that grazed at primary flower stage.

2.1.7.2. Lupin hay and silage

Lupins are generally unsatisfactory as a hay crop (Gladstones, 1970). In species like *L. luteus* their thick fleshy stems cause difficulties in drying, while in others (e.g. *L. angustifolius*) leaf drop leads to loss of quality (Gladstones, 1970). Lupin hay from non-shattering varieties can be made after plants are fully mature and fed whole or after grinding. Making lupin hay has shown promising results in preventing lupinosis (a mycotoxicosis caused by consumption of lupins infected with *Phomopsis* species (Van Warmelo *et al.*, 1970), or at least reducing the risk (Allen *et al.*, 1977a; Allen *et al.*, 1978; Allen and Wood, 1979). Hay making provides farmers who do not harvest their lupins for seed with a way of utilising lupins as summer feed while significantly reducing the risk of lupinosis.

As with hay making, lupins are not the best crop for silage making. They tend to be too woody at the stage when they produce optimal DM for silage making. However, *L. luteus* can be used up to quite an advanced stage of maturity, and does not shed its leaves (Gladstones, 1959). Where there is an epidemic of lupinosis, cutting lupins for silage also gives the opportunity to use lupins before their infection with the causative fungus reaches toxic level.

In summary, lupins can be grazed green if grazing is delayed until the plants finish their main growth (towards end of flowering). The thick woody stems of lupins and leaf drop problems make lupins less attractive for both hay- and silage-making.

2.1.8. Limitations in feeding lupins to stock

Published descriptions of lupin poisoning as early as the 19th century distinguished two types of poisoning caused by *Lupinus* species: alkaloid poisoning and lupinosis (Bennetts, 1957). Anti-nutritional factors in lupins other than alkaloids are considered to be at too low a level to have serious consequences (Williams, 1984).

2.1.8.1. Toxicity of lupin alkaloids

Lupin alkaloids belong to the quinolizidine alkaloid (QA) group (Cromwell, 1955; Waller and Nowacki, 1978; Wink 1987b). The chemical properties and structural details of QA's are discussed elsewhere (Cromwell, 1955; Nowacki and Waller, 1975; Wink, 1987b) . Both their bitterness and toxicity are derived from their chemical structures (von Baer and Feldheim, 1982). Consequently, the poisonous properties of lupins are expected to vary with both the total quantity and the kind of alkaloids present. Before considering the issue of toxicity, a brief look at the synthesis and movement of these alkaloids may help in understanding the strategies of grazing management that can be used to avoid this toxicity.

Alkaloid synthesis is genetically controlled and carried by a dominant gene (von Sengbusch 1931, cited by Gladstones, 1970). All quinolizidine alkaloids are derived from lysine through a decarboxylation product, cadaverine (Nowacki and Waller, 1975; Waller and Nowacki, 1978; Wink, 1987b; Hartmann, 1988). All lupin alkaloids are synthesised in the green parts of the plants, particularly in the leaf chloroplast (Waller and Nowacki, 1978; Wink and Hartmann, 1981; Wink, 1987a; Hartmann, 1988). Alkaloid synthesis has not been shown to occur in seeds, at least those of *L. albus* and *L. angustifolius* (Williams and Harrison, 1983).

Lupin alkaloids are mainly accumulated in the vacuoles and epidermis and are transferred to pods and seeds at maturity. Williams and Harrison (1983) observed that at maturity seeds contained more alkaloids than the total present in other above-ground tissues and that alkaloids in the vegetative parts were at the threshold which differentiates sweet and bitter genotypes (Williams and Harrison, 1983). At the ripe-seed stage, between 80 and 95 % of the total alkaloids in the plant has been transported into the seeds, which possibly accounts for the loss of alkaloids in vegetative parts (Williams and Harrison, 1983). Therefore, as far as grazing is planned to coincide with the stage of growth at which alkaloids are low in vegetative tissues, alkaloid content may not be a total handicap to lupin utilisation, even in bitter lupin species.

Lupin toxicity due to alkaloid content is of two types: (a) toxicity due to high total alkaloid content, and (b) toxicity due to specific teratogens. The former occurs when animals feed on bitter lupins in which the alkaloid concentration usually exceeds about 3 % DM (Waller and Nowacki, 1978). The development of sweet lupin varieties has reduced the total alkaloid content in commercial lupins to less than 1 % DM, and many reports indicate a lack of chronic damage to sheep due to a regular intake of small doses of lupin alkaloids (Culvenor and Petterson, 1986).

Toxicity due to specific individual teratogenic lupin alkaloids is very common in cattle grazing rangelands in the USA (Keeler, 1982). Anagyrine, a teratogenic lupin alkaloid which causes crooked calf disease (Keeler, 1973a,b), is widely present in some American species (Davis, 1982; Davis and Stout, 1986). However, none of the teratogenic species are grown in New Zealand or Australia. Keeler and associates (1976) stated that as long as grazing is adjusted to avoid the period when alkaloids are high in the vegetative parts of lupins and/or the period when pregnant cows are susceptible to the toxin, teratogenic lupins can also be used for grazing. Therefore, it does not appear that the presence of alkaloids would be an unavoidable limitation for the use of lupins.

2.1.8.2. Ovine Lupinosis

The disease lupinosis poses a considerably greater problem to the use of lupins for stock feeding than alkaloids, especially in Australia. Lupinosis is a mycotoxicosis caused by a group of toxins called phomopsins (Culvenor and Petterson, 1986), produced by *Phomopsis leptostromiformis* (Kuhn) Bubak (van Warmelo *et al.* 1970). It is a hepatic abnormality due to interference of the phomopsins with fat transport and cell division (Petterson *et al.*, 1979; Horwood, 1987). Various studies have shown abnormalities in copper and zinc metabolism of animals affected by lupinosis (Croker *et al.* 1979a,b). There is also a condition known as lupinosis associated myopathy- a white muscle disease observed in sheep with normal liver selenium levels (Allen *et al.*, 1977b; Allen, 1978). A detailed account of the latter can be seen in Costa *et al.* (1986). There is no report on the occurrence of lupinosis in New Zealand other than the two cases reported by Brash (1943).

The disease is discussed here with emphasis on its potential to limit lupin utilisation and ways of countering its incidence. Details on chemical and structural properties of the toxic principles (Edgar and Culvenor, 1985; Culvenor and Petterson, 1986), on gross and histological symptoms of lupinosis (Croker *et al.*, 1978; Petterson *et al., 1979*; Allen, 1986; Horwood, 1987) are presented elsewhere. However, a brief discussion on the route of infection of lupins is presented to help in understanding some of the control and prevention measures suggested.

Lupinosis is a problem where lupins are grazed as dry standing summer feed or when sheep are grazed on lupin stubble. This is because, although infection of lupins (via spores) occurs throughout the growing season (Allen *et al.* 1985), the fungus persists only on senescent tissue (Allen *et al.* 1980). The fungus appears to produce toxin after the death of the lupin plant (Allen *et al.* 1985). The symptoms on green stems are purplish-black lesions which become apparent after stems die (Cowling *et al.* 1988).

The risk of lupinosis depends on the total amount of toxin consumed, the time over which it is consumed and the size of individual daily doses (Petterson *et al.*, 1987). The rate of absorption relative to excretion may be a limiting factor (Petterson *et al.*, 1987). Sheep require a daily intake of phomopsin greater than 25 $\mu g\ kg^{-1}$ liveweight for clinical

lupinosis to occur (Croker and Johns, 1985). Extended low intake of phomopsin can lead to progressive liver damage that significantly reduces life span (Peterson, 1986).

The major prevention procedures recommended are: (i) to graze lupins early in summer, because toxicity increases as the summer progresses (Anon., 1980), (ii) to avoid conditions which force sheep to eat dead stems, e.g. high stocking rates, especially more than 30 sheep/ha, and one water point in a large paddock (Croker *et al.*, 1979a, 1979b; Anon., 1980), (iii) to graze high risk lupin paddocks with adult sheep rather than weaners (Allen *et al.* 1978; Allen *et al.* 1985), (iv) to avoid feeding hungry sheep on lupin stubble, (v) to give sheep grazed on dry lupins an access to consumption of non-lupin material (Anon., 1980), (vi) to cut lupins for hay or silage where lupinosis is an epidemic (Morcombe *et al.*, 1986), (vii) to use lupins in mixture with other crops (e.g. oat-lupin mixture), (viii) to burn lupin stubble to break the infection cycle, (ix) to treat stubble with an alkali (Phomopsin A is hydrolysed and completely destroyed in 0.2 M NaOH within 24 hrs (Allen *et al.* 1986a)), (x) to dose sheep with zinc (0.5 g per day or more) to reduce their susceptibility to lupinosis (Allen and Masters, 1980; Allen *et al.*, 1986b), (xi) to spray lupins with fungicides (Wood *et al.*, 1975), and (xii) to use lupins resistant to infection by the causal fungus (Gladstones, 1982; Cowling *et al.*, 1986a, 1986b, 1987).

The foregoing paragraph has shown the various possibilities for using even lupins susceptible to infection by *Phomopsis* with minimal risk of lupinosis. The efforts of Australian workers, resulting in resistant varieties have reduced the fear of lupinosis and its threat to lupin expansion. In conclusion, neither alkaloid poisoning nor lupinosis appear to be serious limitations to the extensive use of lupins for animal feeding. Research into the development of *Phomopsis* resistant lines does not appear to be far away from development of *Phomopsis*-free lines. However, it is worth noting how much scope there is to use bitter lupins or those susceptible to *Phomopsis* through good management without loss of animals to either alkaloid poisoning or lupinosis.

How does Russel Lupin fit in.

2.2. Evaluation of forages

2.2.1. Choice of pasture evaluation method

Many pasture evaluation experiments involve a series of harvests. Pasture research requires extensive replication in space and time. Exhaustive evaluation of perennial species may require close observation over a period of at least five to six years (Chamblee, 1962; Shaw *et al.*, 1976). Furthermore, as the productivity and persistence of some species (e.g. legumes) is greatly affected by grazing, it is important to graze as well as harvest such species by cutting, even in screening experiments.

Economically important characters sought in pasture plants include: aggressiveness and persistency, ability to withstand grazing, restoration of soil fertility, ability to produce a high yield of acceptable forage, leafiness and duration of vegetative growth, absence of toxic compounds, ease of establishment whether by seed or vegetatively, ease of gathering seed or reproductive material, winter hardiness and in case of legumes, the ability to nodulate readily with either introduced or native *Rhizobium* (Davison, 1959; Shaw *et al.*, 1976). A full description of all desirable attributes is rarely possible and the scientist has to choose those most appropriate to the objectives of the particular investigation.

Ideally, these attributes are assessed under grazing and the nutritive value of a herbage is measured in terms of the yield and quality of livestock products obtained from animals grazing that herbage. Although this approach more closely reflects the commercial value of pasture plants, a fully replicated grazing trial is extremely costly and it has its own particular problems. Therefore, many pasture evaluation experiments have had to rely on information generated from small-plot experiments.

Small-plot experiments are useful where it is desirable to evaluate a large number of lines or species which vary in their growth habit, rate of growth, or time of maturity, and where plots are small because of seed scarcity or other factors. They produce a large amount of valuable information rapidly and cheaply. However, extrapolation from small-plot experiments to grazing conditions requires considerable caution and skill.

Small-plot experiments are broadly divided into three categories (Chamblee, 1962). These are, in order of increasing difficulty of execution, cutting only (no animals present), experiments with common grazing, and experiments with individual grazing of plots.

a. Cutting only (no animals present). In cutting experiments, dry matter yield is estimated from a series of cuts on small plots (10 m^2, 2 - 5 replicates). Cutting experiments may provide the final answer when dealing with problems which can be resolved without using grazing animals. Such problems include: date and rate of seeding, seedbed preparation methods, seed placement, methods of seeding, plant spacing, chemical weed control, irrigation, and inoculation procedures with legume bacteria (GRI, 1961; Shaw *et al.*, 1976). The main disadvantage of cutting experiments is that cutting simulates only one aspect of grazing, i.e. defoliation (Chamblee, 1962; Watkin and Clements, 1978).

b. Experiments under common grazing. The grazing of a series of plots at the same time by the same sheep is a simple way to graze small-plot experiments. The main assessment is still made on the herbage; any animal measurements are supplementary to this. The use of animals as a means of defoliation will minimise the disparity between mowing and grazing. Common grazing is undesirable in fertiliser trials because of the possible transfer of fertility when high yielding plants or those with a greater proportion of legumes are grazed with low yielding plots. In addition, common grazing of pasture plots often leads to differential intensity and/or severity of defoliation of plots where species or varieties of contrasting palatability, stage of growth and nutritive value are grazed together.

c. Individually grazed plots. In this system each plot is fenced off and is grazed independently. As with common grazing, evaluation is not based on measurement of animal output. This method develops a sward which is closely related to that developed under practical farming conditions. The experimental design is less expensive than grazing trials where evaluation is based on meat, milk or wool production. For example, an experiment to compare eight pastures at stocking rates of 2 - 3 animals ha^{-1} with two replications requires only 2.2 ha, while a full animal production experiment using three animals per herd would require 40 ha of land and 18 times as much seed (Shaw *et al.*, 1976). Individually grazed small plots are particularly valuable at advanced stages of species and

mixture testing, and in intermediate stages of testing management procedures (Shaw *et al.*, 1976). It is also useful in studying rate of intake, site of digestion and selective grazing of plant species or components.

To summarise, it is not possible to prescribe a 'best' method for any given experiment. The choice of method will depend on the kind of pasture, the growth form of the species, the time, labour and facilities available, the precision required, and the particular facets of pasture performance under study. If resources are not limiting, evaluation of pasture plants based on animal products provides the best option as the primary criterion of the value of a grazed pasture is the production of livestock products. However, where large scale grazing experiments cannot be justified for various reasons small-plot experiments can provide adequate information on the potential productivity and nutritive value of forages.

2.2.2. The need to use animals in pasture evaluation

Even at preliminary stages of pasture evaluation it is important to use animal grazing. This is because grazing involves animal influences that cannot be simulated by mowing. These include selective grazing, the return of nutrients in faeces and urine, and influences exerted through treading (trampling and soil compaction) (Watkin and Clements, 1978). These influences are discussed further in the following sections.

a. Selective grazing. A feature of grazed pasture is that defoliation is uneven due to selection. Hodgson (1979, 1990) provided the following distinction between preference and selection. **Preference** is the discrimination which would be exhibited between the components of a sward if all were available without restriction, while **selection** is a measure of the choice demonstrated in practice. Therefore, the composition of the diet selected reflects preference modified by the limitations to the opportunity for preference which occur in the field (Hodgson, 1990). For example, the chance of a preferred component being selectively grazed will be less if it is distributed in the base of the sward. Both selection and preference are relative terms.

Many authors have attempted, albeit without much success, to explain why a certain plant component or species is eaten in preference to another one. The main problem

is that the selection of a component could be due as much to its position in the sward canopy as to active selection by the grazer (Hodgson, 1982). On artificial turfs, Black and Kenny (1984) distinguished ease of harvest as the main driving force behind selective grazing. However, the valid application of this to animals grazing natural swards remains questionable.

The state of knowledge regarding selection by grazing animals is that:

1. The green leaf content, the nutrient concentration and the DM or OM digestibility of the diet selected are almost invariably greater than those of the sward as a whole (Hodgson, 1982).
2. The diets of grazing animals consistently contain more leaf and live material, and less stem dead material than that of the vegetation on offer (Arnold, 1981). Sheep show greater preference for clover than grass (Hodgson, 1990).
3. Touch, taste and smell are the sensory organs used in selective grazing (Arnold, 1966,1981).
4. Selectivity is reduced when the animal is hungry; hunger may lower either the taste or smell thresholds of rejection (Arnold, 1981).
5. The levels of herbage mass and allowance affect selectivity through their effect on opportunity for selection (Arnold, 1981).

b. Nutrient Return

The grazing animal returns dung and urine to the sward. Frame (1976) estimated that grazing animals return 70 - 90 % of ingested nutrients as excreta. Dung and urine returns are uneven, being greater near or at camping sites, in the vicinity of shelter, watering points and gateways (Gillingham, 1980). The lack of dung and urine return in cutting trials can be overcome, at least partially, by returning clippings after mowing, and/or applying excreta to cut swards, but these approaches have inherent difficulties and do not simulate the patchy return of nutrients.

c. Influence of treading

Treading by sheep and cattle can directly reduce pasture growth through damage to plant growing points and photosynthetic tissue, or indirectly through soil compaction and puddling (Watkin and Clements, 1978). It also causes a reduction in acceptance of herbage due to soiling by mud and fouling by dung. Reduction in pasture yield due to treading increases with stocking rate and depends on pasture species, weather and soil water content (Curll and Wilkins, 1983). Richards *et al.*, (1976) suggested that only at high levels of herbage production and associated high stocking rates would treading damage outweigh the beneficial effects of excreta return. The results of Curll and Wilkins (1983) show that even at extremely high stocking rates, the benefits of excreta return can more than compensate for yield reductions caused by treading. Moreover, "hoof cultivation" undoubtedly aids in establishment, tillering and growth of some pasture species. Close-knit, densely-tillering swards are less prone to treading damage than plants with other growth habits.

The net effect of grazing depends on the balance between the effect of the return of nutrients in excreta, which tends to increase yield, and that of treading and other sward damage, which tends to reduce yield. For grass swards, under low to medium fertility, return of excreta will have a benefit greater than the deleterious effect of grazing and hence grazed herbage will give a higher yield than that defoliated by cutting. When soil fertility is not limiting, swards under grazing will be subject to treading and bruising with little or no additional compensating benefit and yield will thus be reduced by grazing (Curll and Wilkins, 1983).

2.2.3. Indices of nutritive value

The term 'nutritive value' is defined as the animal response per unit feed intake (Ulyatt, 1981). The nutritive value of a herbage depends on its digestibility and the efficiency with which the digested nutrients are converted to animal products (Poppi, 1983). Digestibility is the parameter most commonly used to measure the nutritive value of feeds

because it shows wide variability between feeds. It represents the total amount of nutrients per unit of feed intake made available to the animal through digestion (Poppi, 1983). During the early stages of pasture evaluation there will not be enough feed to carry out replicated *in vivo* digestibility trials. Consequently, the level of some chemical components, such as crude protein and cell wall, and *in vitro* digestibility methods have been used as indices of the nutritive value of forage. The main advantage of these methods is that they are rapid and cost effective.

2.2.3.1. Chemical components

In the past 50 years regressions have been derived relating *in vivo* digestibility of feed dry matter, organic matter, or energy to one or more chemical components in the feed such as protein, fibre or lignin. This is because the digestibility and intake of forages is markedly influenced by their chemical composition, particularly the structural cell wall material they contain. However, chemical indices do not give a direct estimate of nutritive value, rather they rely on a statistical association between the content of analysed components and forage quality.

Chemical factors in pasture plants that may influence the nutritive value of pasture may be categorised into: (a) fractions that are essential nutrients for the rumen microbes and the host animal (protein, water soluble carbohydrates, starch and mineral elements), (b) chemical fractions that are related to the quantity and composition of fibre in the plant (cellulose, hemicellulose, lignin, silica and elastin), and (c) toxic factors (e.g. alkaloids) (Minson, 1982). Cell wall constituents are the fractions commonly used as an index of the nutritive value of pasture plants. The protein content is also measured if the plants contain the critical amount of protein required for ruminant nutrition. These components are briefly discussed below. The reader is referred to Cruickshank (1986) for a review of other components.

a. Cell wall constituents

The cell wall is the structural part of the plant. It is mainly composed of cellulose, hemicellulose, lignin, cutin, Maillard products and other indigestible substances (Van Soest, 1982). Van Soest divided cell wall constituents into partially available (cellulose and hemicellulose) and totally unavailable components (lignin, cutin, elastin and silica). Conceptually, the potentially digestible fibre (PDF) and cell contents soluble in neutral detergent solution (SOL) of any forage have a digestibility of 100 % and are the only digestible energy available to ruminants (Girard and Dupius, 1988).

Neutral detergent fibre (NDF) consists of all cell wall components, mainly cellulose, hemicellulose, lignin and insoluble ash. Acid detergent fibre (ADF) is NDF less those components which are soluble in acid detergent solution. It mainly consists of lignin, silica, cellulose and insoluble ash (Van Soest and Wine, 1967; Van Soest, 1982). The difference between the two is used to estimate the amount of hemicellulose (van Soest, 1982). Hemicellulose estimates based on the difference between ADF and NDF has been shown to include some cell wall protein (Marten, 1981).

Since cell contents have similar availability across different feed types, the cell wall constituents, NDF and ADF, are employed as predictors of the nutritive value of forage. Generally, the rate and extent of cell wall lignification with plant maturity is lower for legumes than grasses (Buxton and Russell, 1988), and total NDF may provide sufficient indication of changes in the nutritive value of legumes.

b. Protein content

The minimum crude protein (CP) content (defined for most feeds as N % x 6.25) required for maintenance for ruminants is 9% CP (ARC, 1980). Minson (1982) stated that appetite will be depressed, and intake will be less than expected from consideration of physical composition if the CP content of pasture falls below 6 - 8 %. Legumes have a relatively constant N content due to their ability to fix atmospheric nitrogen (Minson, 1976).

Usually there is a strong correlation between the crude protein content and the digestible CP content of forages (Sullivan, 1964; Milford and Minson, 1965; Stallcup and Davis, 1965). However, it has now been established that the site of digestion of protein, as influenced by its degradability, is a better indicator of the value of herbage N than the total crude protein content or the digestible CP content (MacRae and Ulyatt, 1974; ARC, 1984). However, where during evaluation, assessment of the site of protein digestion is too costly, per cent crude protein may provide some indication of the nutritive value of herbage, especially for legumes which in some cases possess tannins which protect their protein against excessive degradation in the rumen.

The main limitation of the use of chemical components as indices of nutritive value is that almost any component, even lignin, seldom has a consistent association with digestibility (Van Soest, 1982). The digestibility of the cell wall is regulated more by the intrinsic character of its components, and no single chemical component is able to describe the breakdown of cell wall by rumen bacteria (Van Soest, 1982). Therefore, *in vitro* digestibility assays, which closely approximate the actual digestion process in the rumen have been developed.

2.2.3.2. Digestibility

There is generally a positive relationship between voluntary intake of feed, probably the most important factor determining the level of animal production, and its digestibility. Therefore, digestibility has been widely used as an indicator of the nutritive value of pasture plants. Two related techniques have been developed to determine *in vitro* digestibility of feeds. These are: the two-stage *in vitro* rumen fermentation procedure pioneered by Tilley and Terry (TT) (1963) and, its modification, the pepsin-cellulase technique, developed by Jones and Hayward (1975). Both methods are described below.

a. *In vitro* rumen liquor fermentation

The early history of the development of this technique is reviewed by Johnson (1963, 1966). The Tilley and Terry (1963) *in vitro* procedure involves incubation of a 0.5 g sample of forage, ground to pass through a 1 mm screen, in strained rumen liquor for 48 hrs, followed by further digestion in pepsin for 48 hrs. The procedural details of the method are described elsewhere (Tilley and Terry, 1963). This technique enabled: (i) to study simultaneously many variables governing the digestibility of forages, (ii) the estimation of the digestibility of small samples (e.g. botanical components and plant parts) insufficient for analysis by *in vivo* digestion.

This technique is considered superior to all the laboratory techniques used to determine the digestible energy potential of forages, and has shown consistency with *in vivo* digestibility (Pace *et al.*, 1984; Coelho *et al.*, 1988). This is because, the micro-organisms can, to some extent, multiply and adapt their population to specific feed types as in actual *in vivo* digestion (Goldman *et al.* 1987). However, there may be some *in vivo* processes which are not adequately simulated by the *in vitro* technique. For instance, the method relies upon complete removal of the micro-organisms from the host animal, which entails accumulation, instead of absorption, of metabolic end-products, and the probable development of a population of micro-organism not characteristic of the population in a functioning rumen. It also does not allow for the effects of level of intake and associated factors on herbage digestibility.

The principal problem in using the rumen liquor technique is that it involves a tedious procedure of obtaining inoculum, the need for fistulated animals for supply of rumen liquor, and, above all, the variability of the liquor and the associated low reproducibility among laboratories. Therefore, Jones and Hayward (1975) proposed a two-stage pepsin-cellulase method which replaced rumen liquor by fungal cellulases and abolished the need for fistulated animals for rumen liquor supply.

b. Cellulase solubility methods

Jones and Hayward (1973) first found a correlation between the solubility of grasses in a crude preparation of cellulase from *Trichoderma reesei*, also known as *T. viride*, and their *in vivo* DM digestibility. Later, Jones and Hayward (1975) observed a marked improvement in the correlation due to pretreatment of the herbage with acid pepsin. They actually showed that digestibility determined by the pepsin-cellulase technique had a greater correlation with the *in vivo* digestibility of the samples than digestibility determined by the Tilley and Terry (1963) method. Hence, they proposed their two-stage pepsin cellulase technique as being more rapid, convenient and precise for the prediction of *in vivo* digestibility than the *in vitro* Tilley and Terry (1963) method.

After finding weakness in the Jones and Hayward (1975) technique in estimating *in vivo* digestibility of feeds relatively high in starch, Dowman and Collins (1982) proposed the incorporation of a starch hydrolysing step. Roughan and Holland (1977) proposed a method which uses a neutral detergent pretreatment instead of pepsin. Comparison of this method with the above enzymatic methods and the Tilley and Terry (1963) method indicated that it has the advantage of taking less time and is to be preferred in predicting the digestibility of feeds high in starch (Dowman and Collins, 1982).

A European *in vitro* ring test (with 52 participating laboratories) (De Boever *et al.*, 1986) which compared Tilley-Terry, pepsin-cellulase, and NDF-cellulase methods, reported that the enzymatic methods predicted the *in vivo* digestibility of 6 concentrates with greater accuracy than the Tilley and Terry (1963) method, mainly due to the low reproducibility of the latter. Presumably commercial cellulase enzyme will be more uniform among laboratories than rumen liquor collected at different laboratories.

In conclusion, pepsin-cellulase techniques predict forage digestibility as well as *in vitro* rumen fermentation methods. On feeds of very low digestibility their accuracy might be low because they don't permit adaptation of micro-organisms, or the selection of species which are capable of degrading certain cell wall constituents.

There are now commercially available fungal cellulases for *in vitro* digestibility assays. Onozuka SS (P1500) is a cellulase extracted from *T. viride* and has both

cellulase and hemicellulase activity. Currently, Onozuka SS has been replaced by Onozuka 3S which has twice the activity of Onozuka SS (McLeod and Minson, 1980).

2.2.3.3. Validity of indices of nutritive value

Prediction equations, whether based on chemical components or on *in vitro* or cellulase digestibility, are derived from samples cut to ground level and fail to accommodate the selective nature of animal grazing. As stated earlier, animals, through selective grazing, consume a diet with considerably greater digestibility and nutrient content than the sward. From a sward of 60 % average digestibility, cattle selected herbage of 70 - 74 % digestibility (Raymond and Terry, 1966). Furthermore, plants of similar digestibility can differ considerably in nutritive value. Minson (1981) found that plants selected on the basis of the same DM digestibility or pepsin DM solubility can differ in intake by as much as 37 %. Ulyatt (1970) found difference in OM intake of up to 177 g day^{-1} between feeds of similar *in vitro* digestibility. Laredo and Minson (1973) indicated that, at similar digestibilities, the mean intake of leaf fractions of tropical grasses was 46 % higher than that of the stem.

Even at similar intake and digestibility, herbages give different animal output due to differences in site of digestion and nutrient release. Digestibility coefficients, which relate feed value to the difference between intake and undigested residue expressed as a per cent of intake, cannot distinguish the proportion of nutrients which disappear in different sections of the gut (ARC, 1984); neither can they explain why feeds of similar digestibility exhibit difference in intake. The release of nutrients from microbial and post-ruminal digestion depends on the extent of digestion in the respective parts of the digestive tract. Both indoor feeding (Beever *et al.*, 1980, Beever *et al.*, 1986a) and outdoor grazing (Ulyatt *et al.*, 1980; Beever *et al.*, 1986b) experiments with cattle have shown greater duodenal flow of non-ammonia nitrogen (NAN) per unit ME intake on white clover than ryegrass of similar digestibility. Similarly, Beever *et al.* (1978) and MacRae *et al.* (1985) observed greater incremental apparent absorption of NAN per unit of ME intake above maintenance on spring-harvested (2.1 g/MJ) than on autumn-harvested grass (0.6 g/MJ per day).

Hence, chemical indices, *in vitro* and *in vivo* digestibility trials can only be a guide to the potential value of a feed. They are appropriate at the initial screening stage or mid-way in the evaluation process when it is necessary to go beyond a simple DM yield measurement. The final evaluation requires long-term grazing trials where the value of the feed will be determined and compared on animal output per head or unit area of land.

CHAPTER THREE

3. EXPERIMENT I: YIELD, COMPOSITION AND *IN VITRO* DIGESTIBILITY OF RUSSELL LUPINS (REGROWTH TO MATURITY)

The literature review has invoked some peculiar features of lupins with respect to their dry matter yield and forage quality. As mentioned in the general introduction no published work has characterised the yield, composition and digestibility of Russell lupins or other perennial lupins as they mature. Tesfaye (1989) reported annual and seasonal DM yield of Russell lupins. He indicated that spring regrowth yield was higher than autumn regrowth; 70% of spring regrowth plants produced 175-375 g DM per plant while 80% of autumn regrowth plants produced 13-63 g DM per plant. The maximum DM yield per plant was 750 g, which was mainly from spring regrowth. His study was not aimed at determining changes in yield and nutritional quality of Russell lupins.

Therefore, an experiment was set up with the following main objectives.

1. To study the changes in DM yield until maturity of spring growth Russell lupins.
2. To determine the protein and fibre content of the DM yield of Russell lupins over time.
3. To determine the *in vitro* digestibility of the Russell lupin DM over time.
4. To determine the stage of maximum DM yield and maximum nutrient yield to identify the optimum stage to harvest or graze the plant.

3.2. MATERIALS AND METHODS

3.2.1. Experimental site.

The trial was conducted in Canterbury in the South Island of New Zealand (43° 38'S.) at Iverson Field, Lincoln University, on a Wakanui silt loam soil of high fertility. The paddock was in perennial ryegrass (*Lolium perenne*)/ white clover (*Trifolium repens*) pasture in 1986, rape (*Brassica napus*) in 1986/87 and was sown in naturalised New Zealand Russell lupins (Connie lupins) in December, 1987 by Tesfaye (1989). The lupins were grazed by sheep in June and December, 1988 and again in June 1989.

3.2.2. Experimental layout.

The lupins used in this study were the spring regrowth of plants grazed in June, 1989. The design was a randomised complete block with 7 replicates and 10 planned harvest dates on a paddock of 0.25 ha. Each replicate was 9 by 40 m and contained 10 plots each of which contained 10 plants in two rows. Each plot in a replicate was randomly assigned to a harvest date using random numbers. Harvests were made at three-week intervals starting on 5 October, 1989. Lupins had reached dry pod stage by the sixth harvest on 18 January, 1990 and two weeks later most plants died of root rot (*Phytophora* sp.) thus reducing the number of harvests to six.

Ten weeks after the start of the trial weeds between rows were mowed with a lawn mower while those between plants were removed by hand using a sickle.

3.2.3. Measurement of dry matter yield

At each harvest the mean DM yield per plant was recorded on 70 plants cut to ground level by using a grass cutter. All freshly harvested samples were weighed and the dry matter per cent was determined by drying two plants from each replicate to a constant weight at 70° Celcius in a forced draft oven for a minimum of 48 hours. A further random sample of two plants were dissected from each replicate to determine the contribution to the total DM yield from plant parts. Plants were dissected into stem, petiole (leaf stalk), leaf (lamina), flower (the inflorescence), pods, and dead matter. The dead matter included dead stem, petiole and leaf found in or at the base of the canopy, and wilted flowers and shattered pods fallen of the plants.

The dry matter per cent of each plant part was determined by drying duplicate 5-g samples at 70° C for 48 hours. The proportion of a specific plant part in the total DM at each harvest was estimated by multiplying whole plant fresh weight by the mean of the percentages obtained from the 14 plants dissected and by the DM% of each part. The ratio of plant parts, e.g. leaf-to-stem, was also calculated from the 14 plants dissected.

After taking 2 plants for DM analysis and 2 plants for dissection, the remaining 6 plants from one randomly selected replicate were discarded. Three compound replicates were then formed from the plants from the remaining 6 replicates by combining plants from adjacent replicates. The 12 plants in each of these compound replicates were bulked together and from each bulk sufficient samples of stem, leaf, petiole, flower, pods and dead matter were freeze-dried for analysis of their chemical composition and *in vitro* digestibility. The composition and digestibility of the whole plant was calculated from that of the individual plant parts.

In regressing chemical composition and digestibility on dry matter yield or ratio of plant parts only the yield and ratios in these three compound replicates were used.

The DM yield and ratio of plant parts in a compound replicate were obtained by averaging the values for the two replicates which formed that replicate.

3.2.4. Nitrogen content

The Kjeldahl nitrogen concentration of samples was determined on freeze-dried duplicate 0.5 g samples ground through 1 mm sieve by using a Kjeltec Digestion system (Digestion System 20, 1015 Digester, Tecator, Sweden) with a 19 : 1 K_2SO_4 : $CuSO_4$ catalyst, and an automatic distillation and titration unit (Kjeltec Auto 1030 Analyser, Tecator, Sweden). The N % was obtained by averaging results of duplicates unless they differed by more than 5 %, in which case the analysis was repeated. From each sample analysed for N per cent independent duplicate 1 g samples were dried at 100 $^{\circ}$C for 24 hours (GRI, 1961) and results were corrected for DM%. Where referred to in this thesis crude protein content was estimated by multiplying the N per cent by 6.25.

3.2.5. Neutral Detergent Fibre (NDF).

Ash free NDF of duplicate 1 g samples ground to pass through a 1 mm sieve was determined as described by Van Soest and Wine (1967). Dry matter per cent was determined on separate samples as above and results were converted to DM basis.

3.2.6. *In vitro* Digestibility.

The *in-vitro* digestibility was determined on duplicate 0.5 g samples ground to pass through 1 mm sieve by the two-stage pepsin-cellulase technique of Jones and Hayward, 1975 as progressively modified by McLeod and Minson (1978, 1980) and Clarke *et al.* (1982). Duplicate samples were incubated in 30 mls of 0.3% (w/v) pepsin (Pepsin A powder

BDH Chemicals Ltd., Poole England) solution in 0.125% HCL at 50 °C for 68 hours followed by digestion in 30 mls of buffered cellulase (Onozuka 3S cellulase, Yakult and Honsha Co., Ltd.) solution (0.025 g cellulase:0.5 g sample) at 50 °C for a further 48 hours (Clarke *et al.*, 1982). Dry matter per cent was determined as above. The organic matter content was determined by ashing dried samples in a furnace at 550 °C for 8-12 hours.

The average of duplicate samples was considered to be the digestibility of the sample unless they differ by more than 5%, in which case the analysis was repeated. A known standard was used in each run and the whole run was repeated if the value for the standard did not fall within 2% of the mean value for the corrected per cent digestibility of the standard. The dry matter digestibility (DMD) and organic matter digestibility (OMD) were corrected for *in vitro* values by using equations developed for a range of grass and legume feeds at the Animal and Veterinary Science Group laboratory, Lincoln University (Dr. D.P. Poppi, personal communication).

% Cellulase DMD corrected for *in vitro* values

[% cellulase DMD x 0.902] + 6.70

% Cellulase OMD corrected for *in vitro* values

[% cellulase OMD x 1.03] + 2.81

3.2.7. Statistical analysis.

Data were analysed by using the General Linear Model procedure (PROC GLM) of the SAS statistcal package (SAS Institute Inc., 1989). Treatment differences were tested by using least significant difference (LSD<0.05). The choice of best regression curves for prediction was made by stepwise model selection procedure (PROC STEPWISE) (Draper and Smith, 1981; SAS Institute Inc., 1989).

Statistical tests on whole plant dry matter yield and dry matter yield of plant parts were performed on log transformed data. The mean value of the raw data of these variables were used in reporting results. The standard error of the mean (S.E.M.), the least significant difference (L.S.D.) and the coefficient of variation (CV) of DM yield were obtained by back-transforming the S.E.M., L.S.D. and CV of the transformed data (Finney, 1973).

3.3. RESULTS

3.3.1. Climate data.

The mean daily temperature over the period of 1987-1990 and the long term average values for the area are shown in Fig. 3.1. The temperatures over the months during which the experiment was conducted (Oct. 1989 - Jan. 1990) were similar to those in previous years. The lowest mean monthly minimum in 1987-90, at 0.63 ° C, was in July, 1989. This was not a particularly cold temperature for July as a daily mean minimum of 0.2 ° C was recorded in 1982. Mean monthly rainfall for 1989 was generally higher than in 1988 (Fig. 3.2). The total rainfall in 1989 (634 mm) was close to 650 mm, which is the mean annual rainfall for the area.

3.3.2. Dry matter yield per plant.

The DM yield data varied over a very wide range (Appendix 1). Total DM yield per plant increased from 42 g at the first cut to 100 g at the second cut taken after the beginning of flowering after which it tended to plateau before it rose again (Fig. 3.3). Between the first and second sampling DM yield increased at 3 g plant^{-1} day^{-1}, equivalent to 300 kg ha^{-1} day^{-1} at 10 plants m^{-2}. Over the remaining sampling period DM yield increased at 0.7 g plant^{-1} day^{-1}. That is, after the lupins began to flower (at the second cut) the rate of increase in DM yield dropped by a factor of greater than four. There was no significant increase in DM yield after the third cut (full bloom stage), except at the last cut when it reached a maximum yield of 160 g per plant. When flowering began the Russell lupins had accumulated over 60 % of their maximum yield; the DM yield at full bloom was over 75 % of the maximum yield.

The distribution of plant parts differed in their absolute yield and proportion of the total DM per plant as the Russell lupins matured. Dry matter from stems increased from a negligible 0.5 g per plant at the first cut to 26 g per plant by the green pod stage (Fig. 3.4)

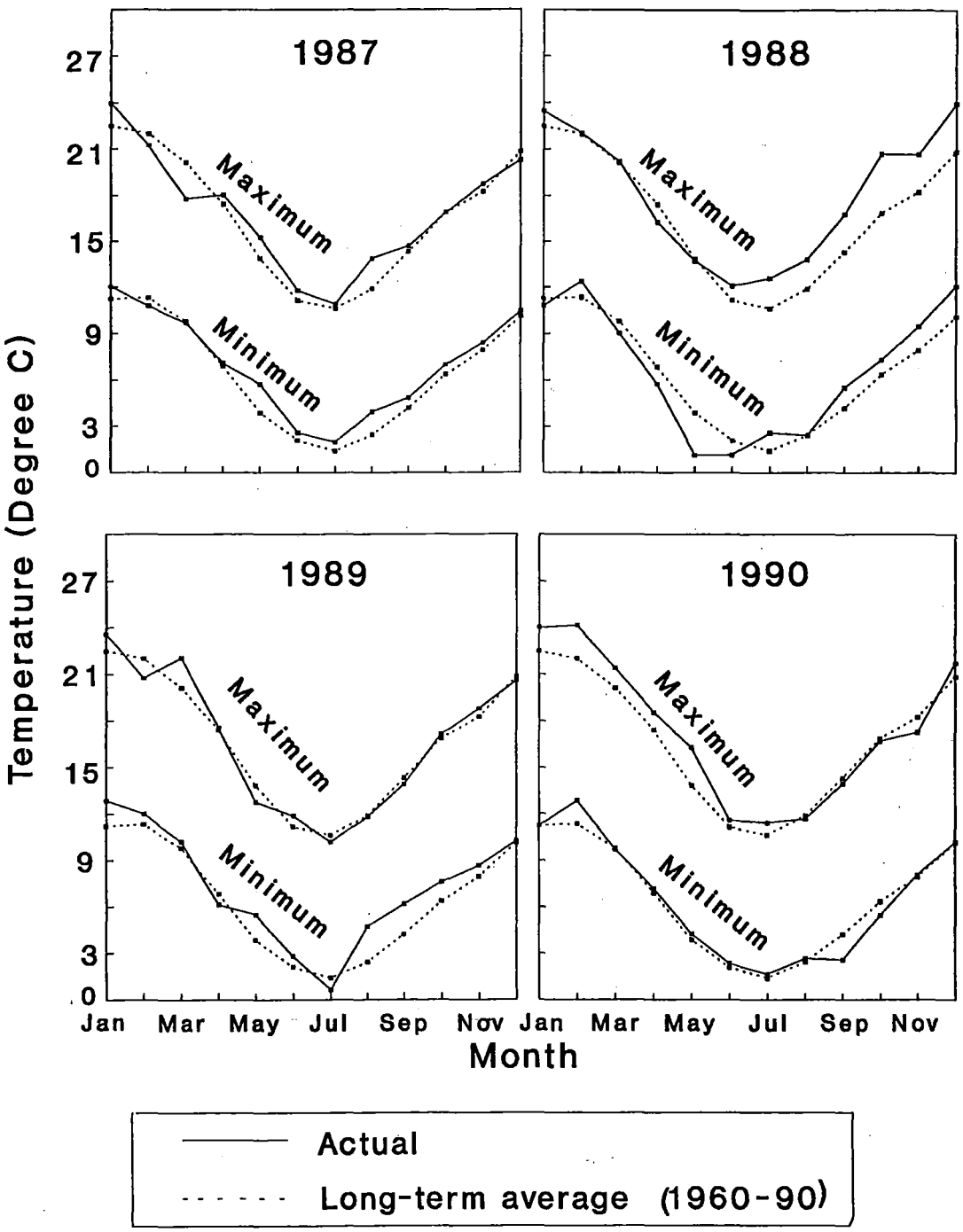

Fig. 3.1. Mean daily maximum, mean daily minimum and the long-term mean minimum and maximum temperature at Lincoln University, Canterbury (1987-1990).

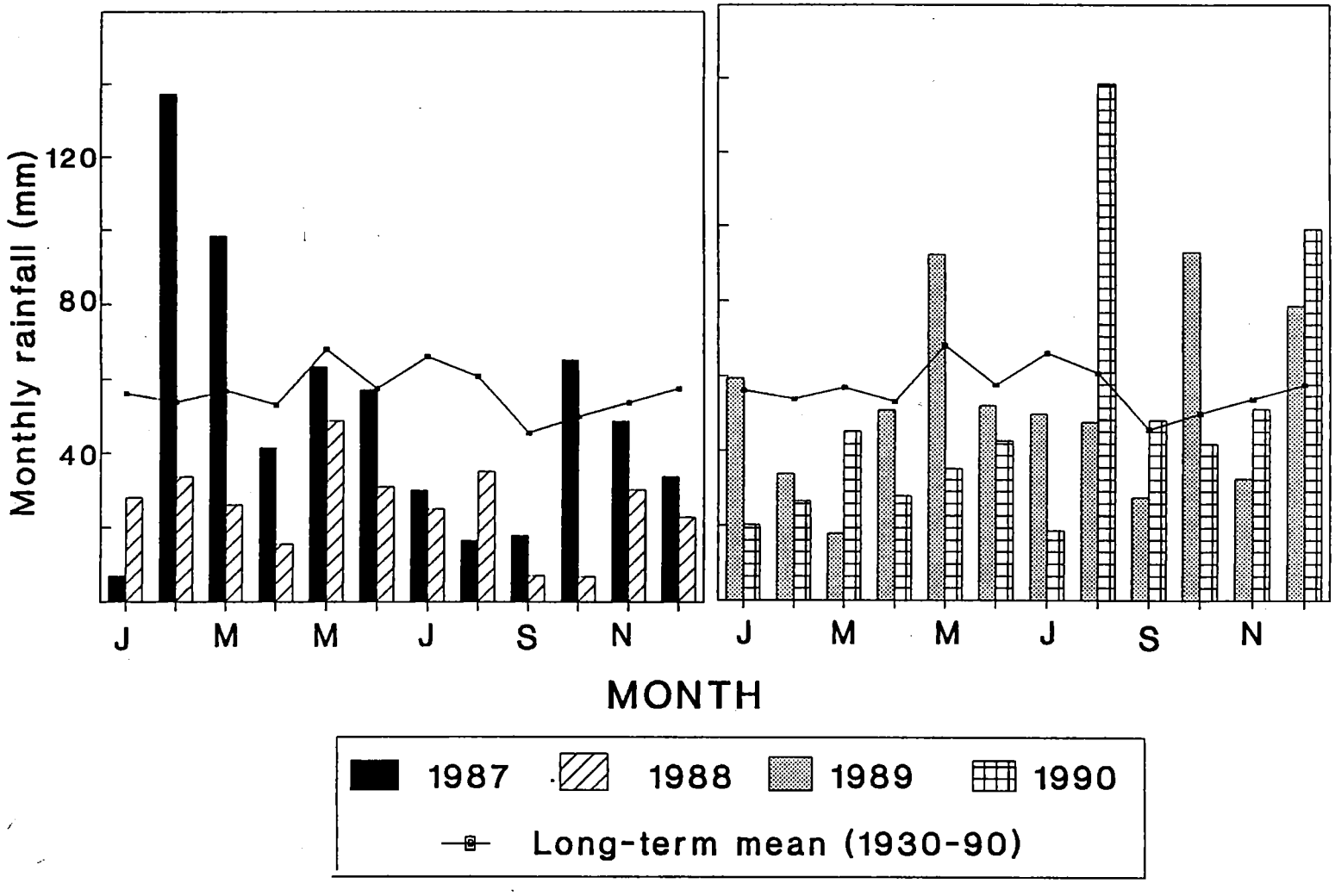

Fig. 3.2. Total monthly rainfall for the years 1987-90 and long-term average monthly total rainfall at Lincoln University, Canterbury.

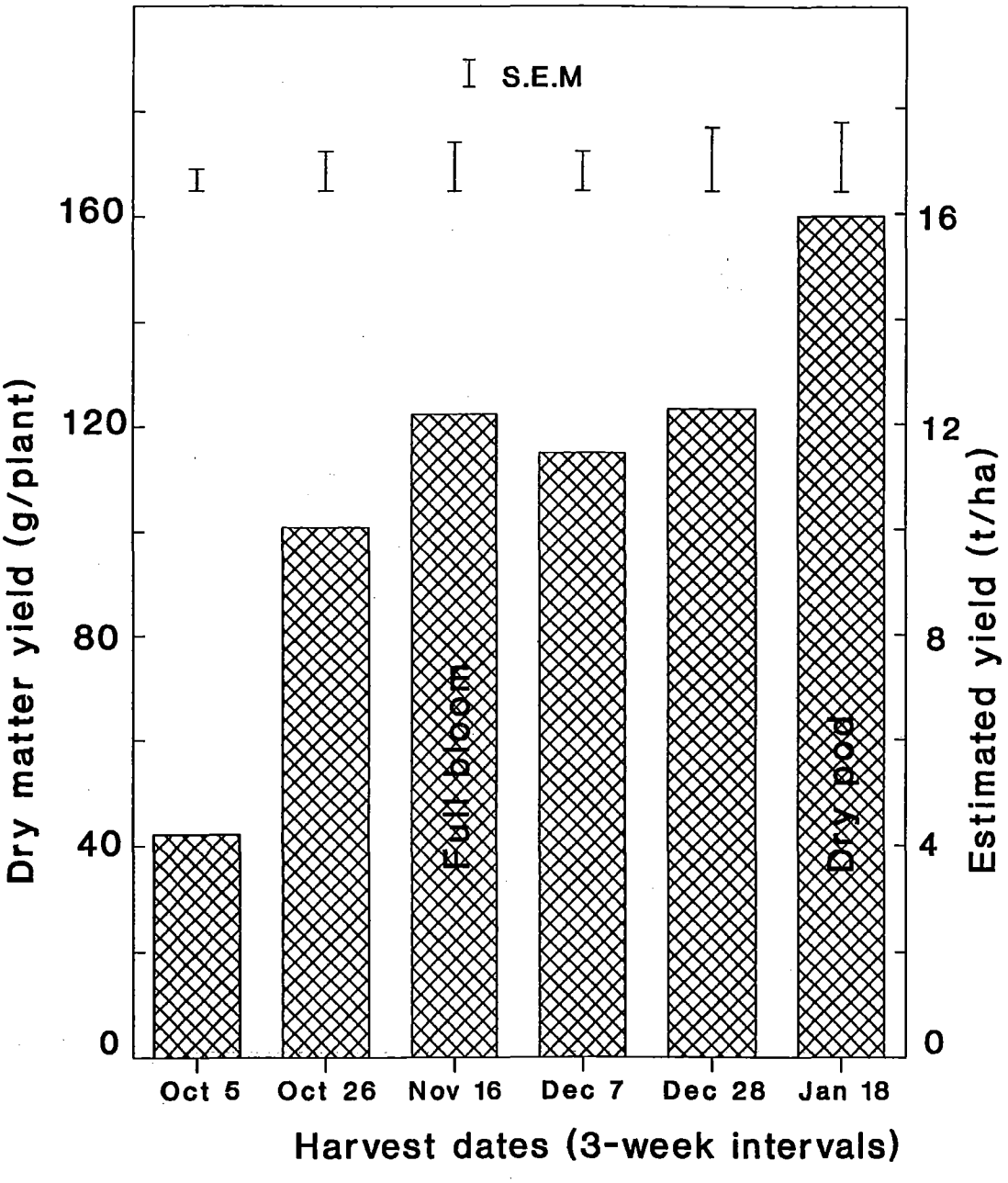

Fig. 3.3. The dry matter yield per plant of Russell lupins sampled at different growth stages.

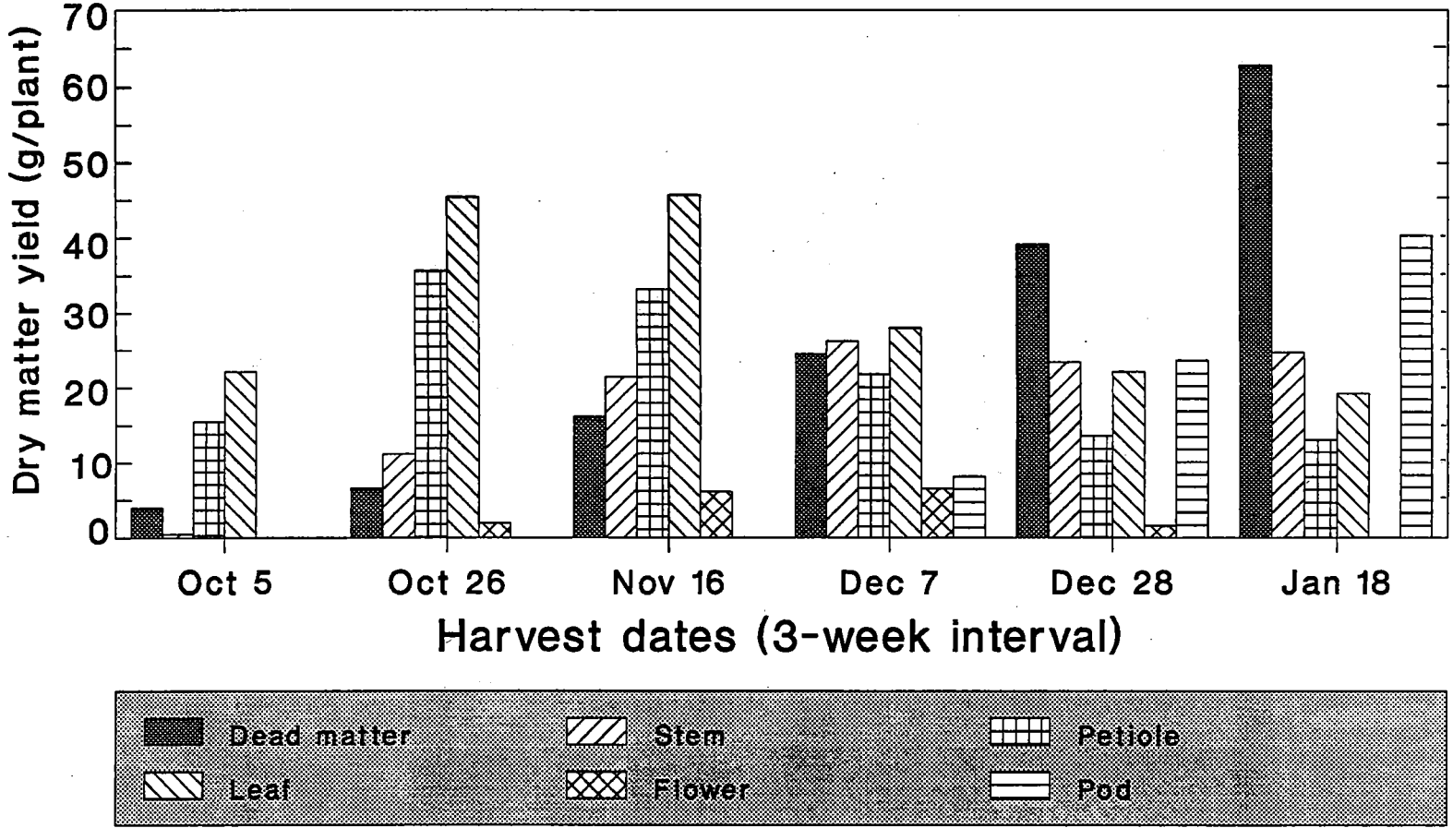

Fig. 3.4. The dry matter yield (g) of vegetative and reproductive parst of Russell lupins harvested at different growth stages (1989-90).

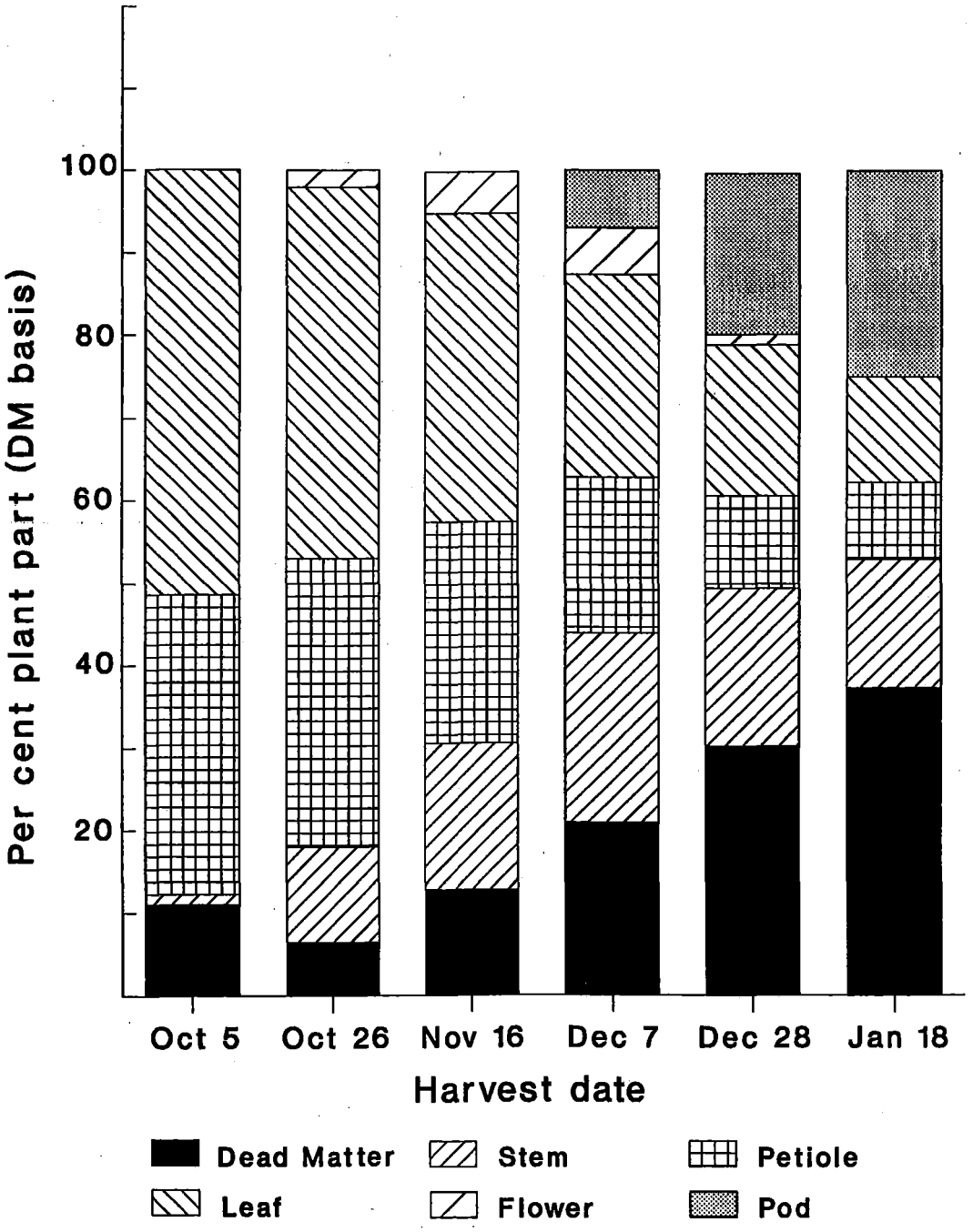

Fig. 3.5. The distribution of plant parts in the total dry matter yield per plant of Russell lupins over time (1989-90).

and this constituted 23 % of the total yield (Fig. 3.5). Petiole and leaf were the first to reach their maximum weight (at full bloom); stems reached their maximum weight three weeks later at the green pod stage (Fig. 3.4). The contribution of flowers to total DM yield was negligible; only at the third and forth cut did it slightly exceed 5% of total DM (Fig. 3.5). Maximum yield of total DM per plant was obtained at the dry pod stage when pod and dead matter were at their maximum weight. This was 9 weeks later than maximum leaf yield, and there was about 40 % of maximum leaf yield remaining.

In percentage terms, the contribution of petiole and leaf to the total DM declined with maturity while that of stem increased up to pod formation (4^{th} cut) and then declined slightly (Fig. 3.5). The proportion of pod and dead matter consistently increased with maturity, and reached 25 and 39 % of total DM yield respectively (Fig. 3.5). The leaf-to-stem ratio of Russell lupins over the six successive cuts was 44.2, 4.0, 2.1, 1.0, 0.9 and 0.8 respectively (Appendix 2).

In summary, the highest DM yield was obtained when the Russell lupins were at the dry pod stage, nine weeks after maximum leaf yield. Russell lupins had accumulated over 75 % of their maximum yield by full bloom. Dry matter yield with the highest proportion of leaf and petiole was obtained at the beginning of sampling whereas that with the highest petiole and leaf weight was obtained at the full bloom stage (i.e. six weeks later). Up to pod formation most of the DM yield of Russell lupins was from petioles and leaf. Together, petioles and leaf constituted 89, 80 and 64% of the total DM yield at the first three cuts, respectively. After pod development total DM yield of Russell lupins was largely from stems, pods and dead matter. The contribution of the inflorescence to total DM yield per plant was the lowest.

3.3.3. Nitrogen concentration

The N concentration in the Russell lupins declined with maturity and fell from 4.2 to 2.4 % (Fig. 3.6). A significant drop in Russell lupins N concentration occurred during two periods: three weeks immediately preceding the beginning of flowering and three weeks before the last sampling at dry pod stage (Fig. 3.6). However, the major drop in nitrogen

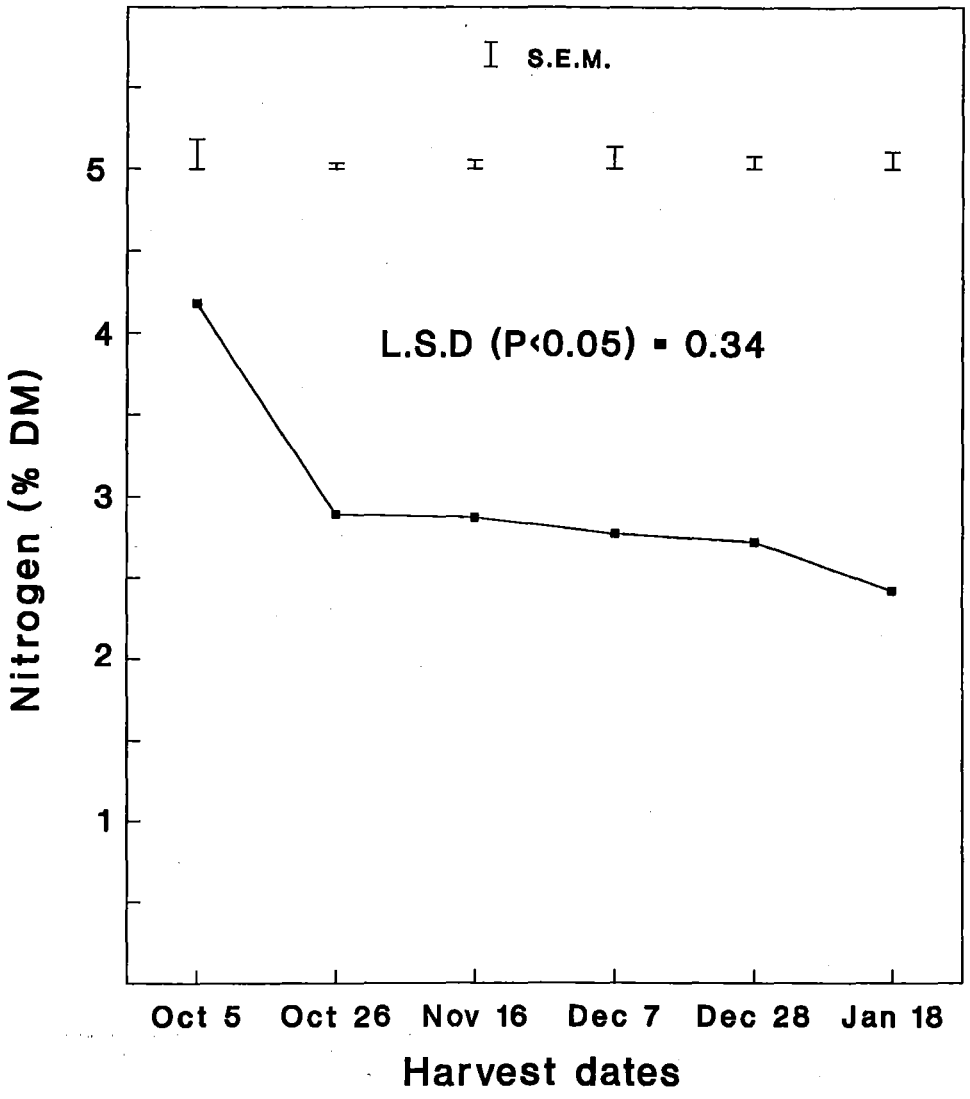

Fig. 3.6. Variation in the nitrogen per cent in the dry matter of Russell lupins harvested at different growth stages (1989-90).

concentration was during the first three weeks of sampling (about 73 % of the total decrease in N concentration). The rate of decline in N concentration for the first three weeks was 0.6 % day^{-1}; over the rest of the sampling period N concentration declined by less than one-hundredth of this rate (i.e. 0.0056 % day^{-1}). An interesting feature of Figure 3.6 was that even at the lowest mean N concentration (2.42 %), lupin DM contained more than 15% crude protein.

Whole plant N concentration of Russell lupins had an inverse relationship with total DM per plant (Equation 3.1, Fig. 3.7), i.e. it decreased as DM yield increased (Fig. 3.7).

$$\text{Whole plant N (\% DM)} = 4.43 - 0.01(\text{g Total DM}) \quad (P<0.001,\ R^2 = 0.75,\ \text{S.E.E.} = 0.31,\ n = 18) \qquad \textbf{(3.1)}.$$

The N concentration in plant parts showed different trends with plant maturity (Fig. 3.8). The N concentration in stems, leaf and pods showed a significant linear decline, while that of petiole showed a quadratic decline with harvest time (Table 3.1). The daily rate of decrease was highest for petiole N; stem and leaf N decreased at a similar rate which was slightly higher than pod N (Table 3.1). However, the predicted N concentration at the last cut was higher in leaves (2.57 %) than in stems (1.24 %); the highest predicted N concentration at the last cut was in pods (3.43 %).

Table 3.1. Regression of the N concentration (y) in different plant parts of Russell lupins on harvest time (x, days).

Plant part	Curve	Intercept	Coefficients		R^2	Sign.$^{\theta}$
		a	b_1	b_2		
Stem	Linear	3.76	-0.024	-	0.78	***
Petiole	Quadratic	2.95	-0.052	0.0004	0.41	**
Leaf	Linear	4.77	-0.021	-	0.74	***
Pod	Linear	5.02	-0.015	-	0.73	**

$^{\theta}$Significance of regression: ** = at P<0.01, *** = at P<0.001

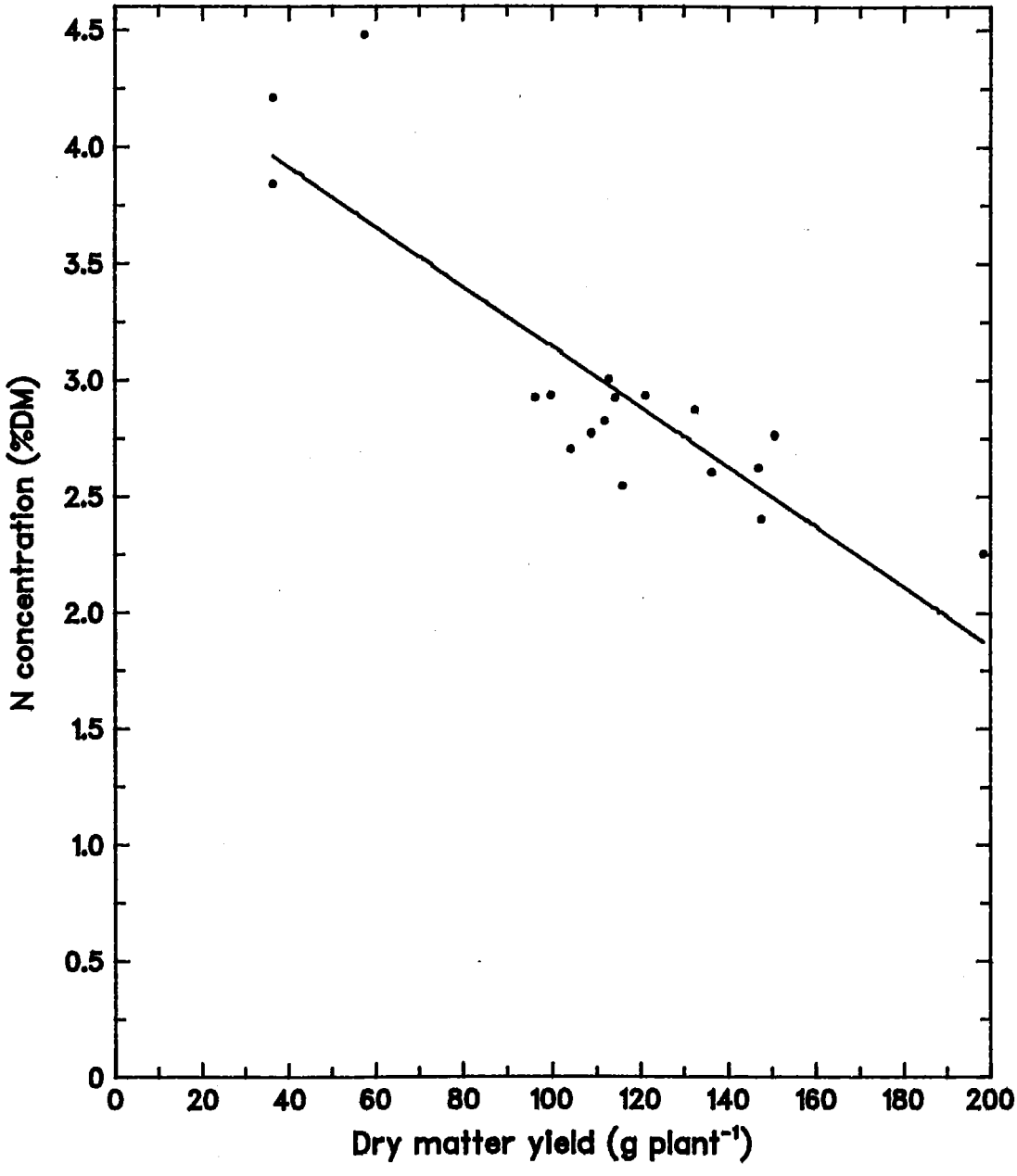

Fig. 3.7. The regression of N concentration (y) in Russell lupins on DM yield per plant (x) ($y = 4.43 - 0.01x$ $P<0.001$, $R^2 = 0.75$).

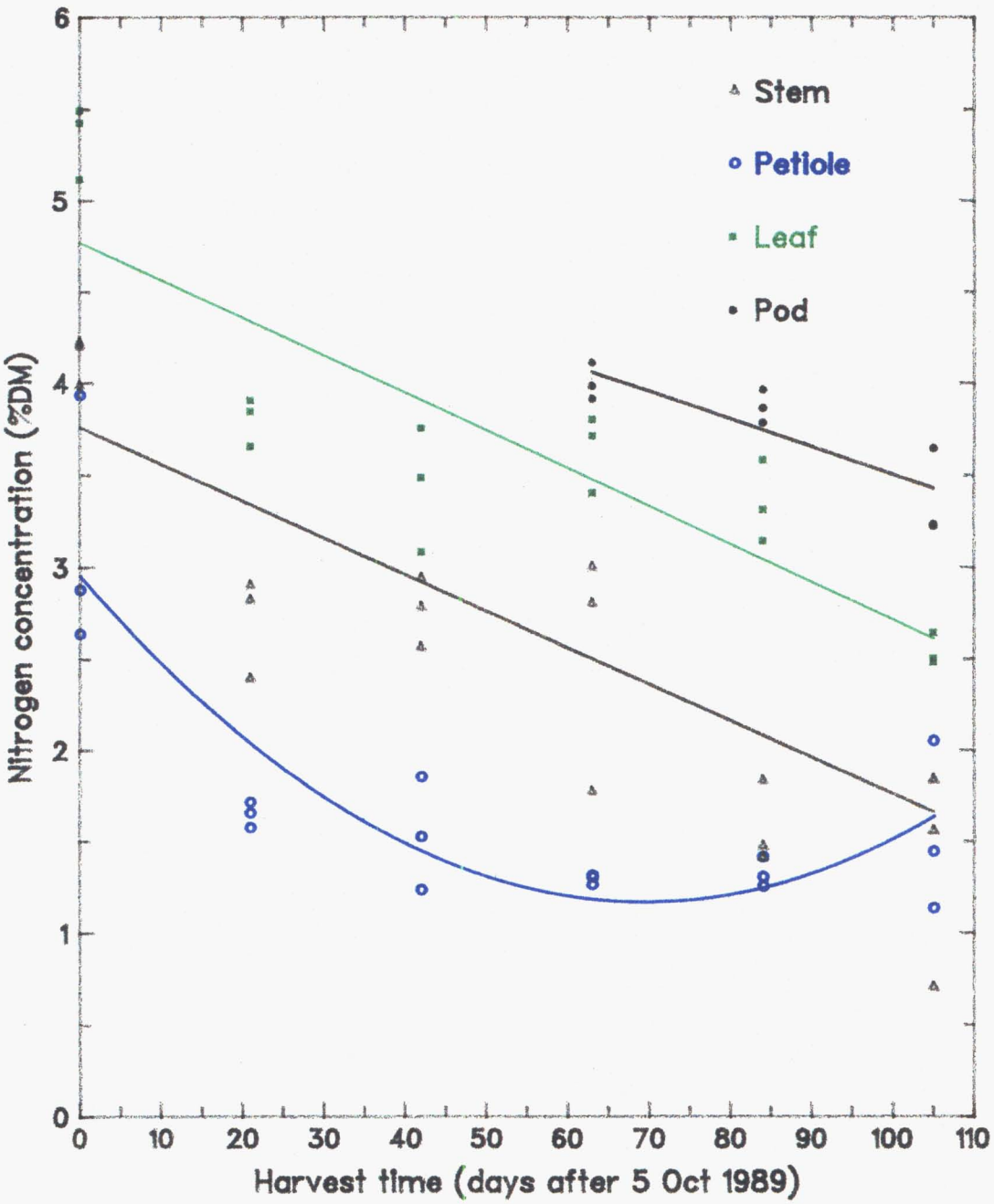

Fig. 3.8. Regression of N concentration (y) in Russell lupin stems ($y = 3.76 - 0.02x$ $P<0.001$ $R^2 = 0.78$), petioles ($y = 2.95 - 0.052 + 0.0004x^2$ $P<0.001$ $R^2 = 0.74$), leaves ($y = 4.77 - 0.14x$ $P<0.001$ $R^2 = 0.74$) and pods ($y = 5.02 - 0.015x$, $P<0.01$ $R^2 = 0.73$) on harvest time (x, days from the beginning of grazing).

The N concentration in flowers and dead matter had no significant relationship with harvest time. There was relatively little change in the N concentration in the DM of floral parts; it ranged 4.5 to 5.2 %. The dead matter, which was mainly fallen petioles and leaves, had a surprisingly high N concentration which ranged from 2.2 to 3.4 %.

3.3.4. Nitrogen yield

Nitrogen yield followed the trend of DM yield, i.e. it increased significantly up to the third cut and then showed no significant change until the last cut when it rose again (Fig. 3.9). Like DM yield (Fig. 3.3), the lowest (1.8 g) and highest (3.9 g) N yield per plant occurred at the first and sixth cuts, respectively (Fig. 3.9). At 10 plants m^{-2} the maximum N yield per plant was equivalent to 39 g N m^{-2} (or 390 kg ha^{-1}). By full bloom the Russell lupins had accumulated 91 % of this maximum N yield.

Of the individual plant components (up to pod formation, i.e. 4^{th} cut) leaves produced the highest N yield (Fig. 3.10). After pod development the N yield of pod and dead matter was higher than all other plant parts (Fig. 3.10). The contribution of stems to total N yield reached a maximum at the fourth cut. Nitrogen yield from petioles was exceeded only by that from leaves during the first two cuts, but it decreased consistently thereafter (Fig. 3.10). Despite the high N concentration of the flowers, their contribution to total N yield per plant was very low (Fig. 3.10).

3.3.5. Neutral detergent fibre (NDF) concentration

Neutral detergent fibre concentration in all plant parts increased linearly over time though the rate of increase varied among plant parts (Table 3.2). Consequently, whole plant NDF increased linearly at about 0.21 % day^{-1} (Table 3.2) and reached 46 % by the final cut. The rate of increase in NDF concentration in both stems (Fig. 3.11) and pods (Fig. 3.12) was about twice the rate in the whole plant (Table 3.2). Leaves, followed by flowers, had the lowest NDF concentration, and in both plant parts the NDF concentration increased by less than 5 percentage units over the whole period (Fig. 3.11 & 3.12).

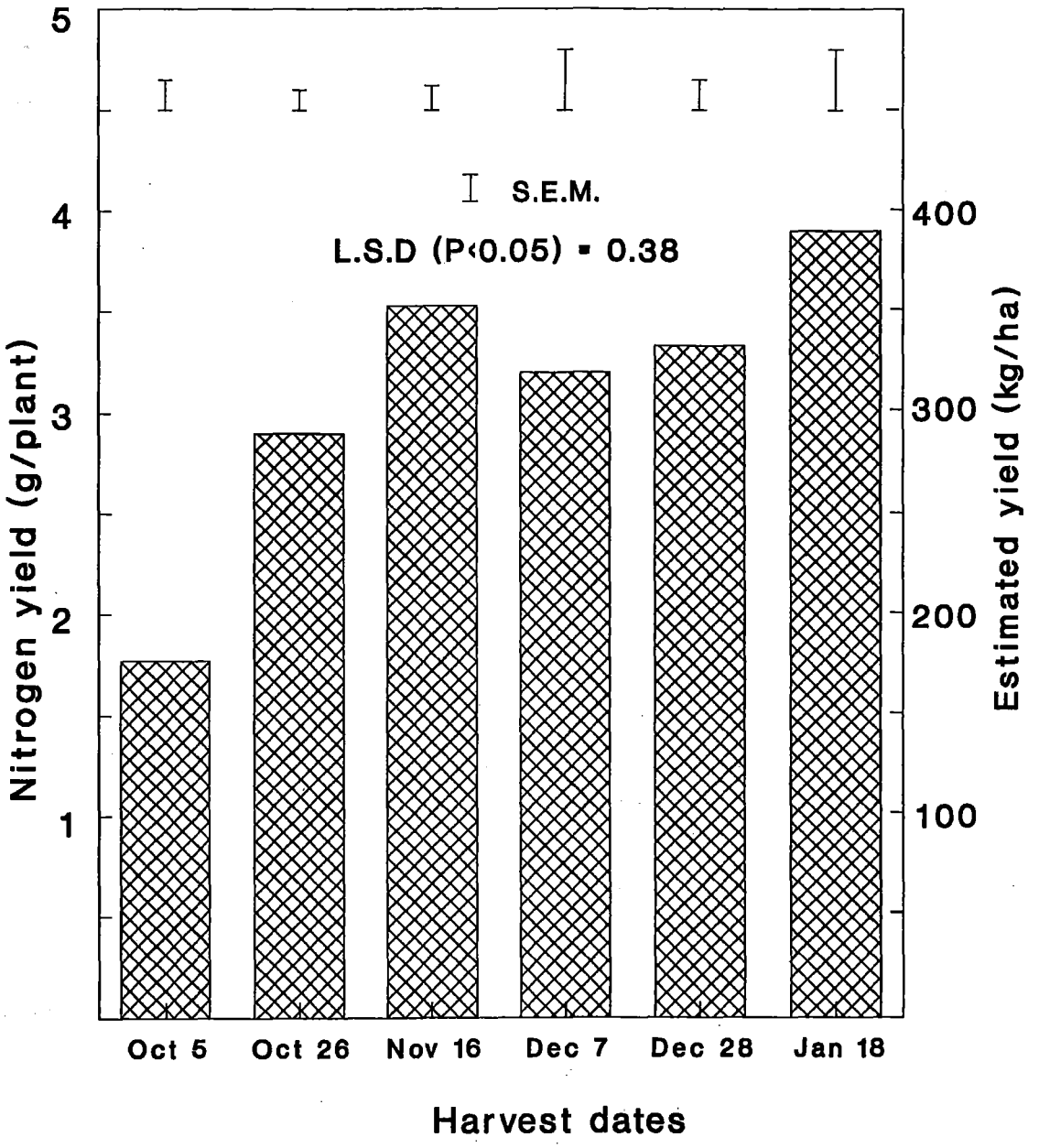

Fig. 3.9. Nitrogen yield of Russell lupins harvested at different growth stages (1989-90).

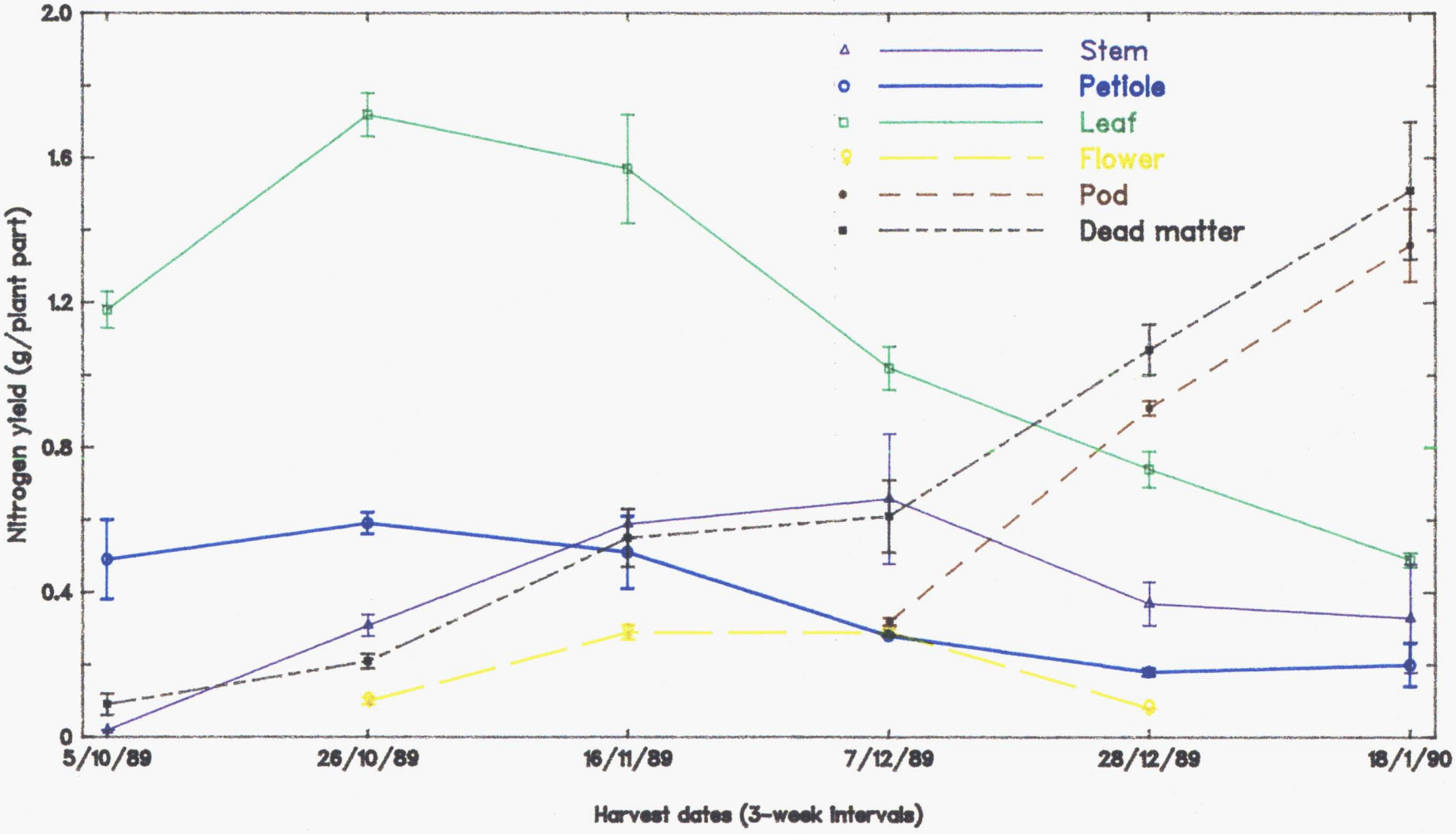

Fig. 3.10. The level of N yield obtained from different plant parts from Russell lupins harvested at different growth stages (1989-90).

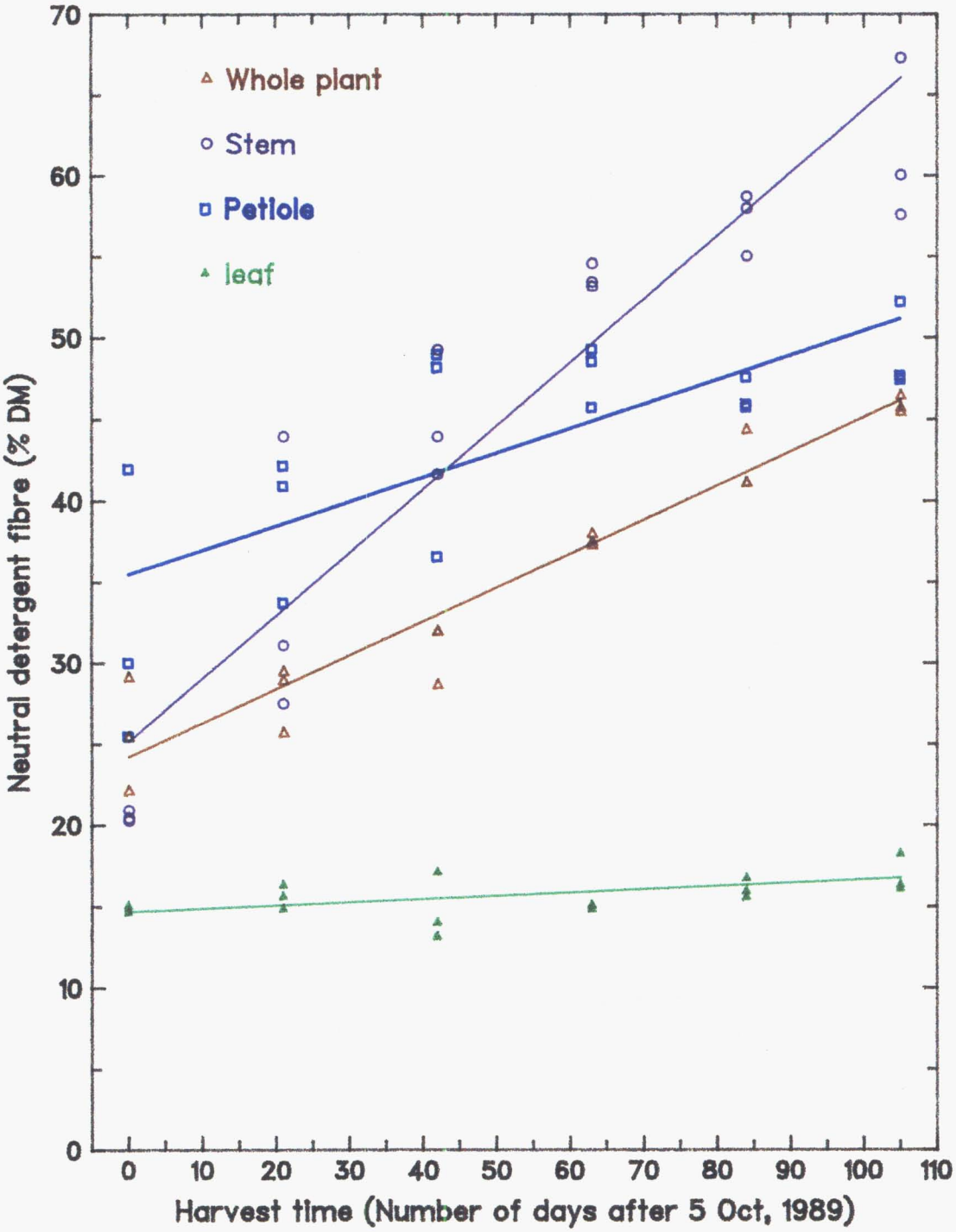

Fig. 3.11. Regression of NDF concnetration (y) in whole plant ($y = 24.14 + 0.21x$ $P<0.001$ $R^2 = 0.93$), stem ($y = 25.1 + 0.39x$ $P<0.001$ $R^2 = 0.88$), petiole ($y = 35.41 + 0.15x$ $P<0.001$ $R^2 = 0.56$) and leaves ($y = 14.63 + 0.02x$ $P<0.05$ $R^2 = 0.25$) of Russell lupins on harvest time (x, days).

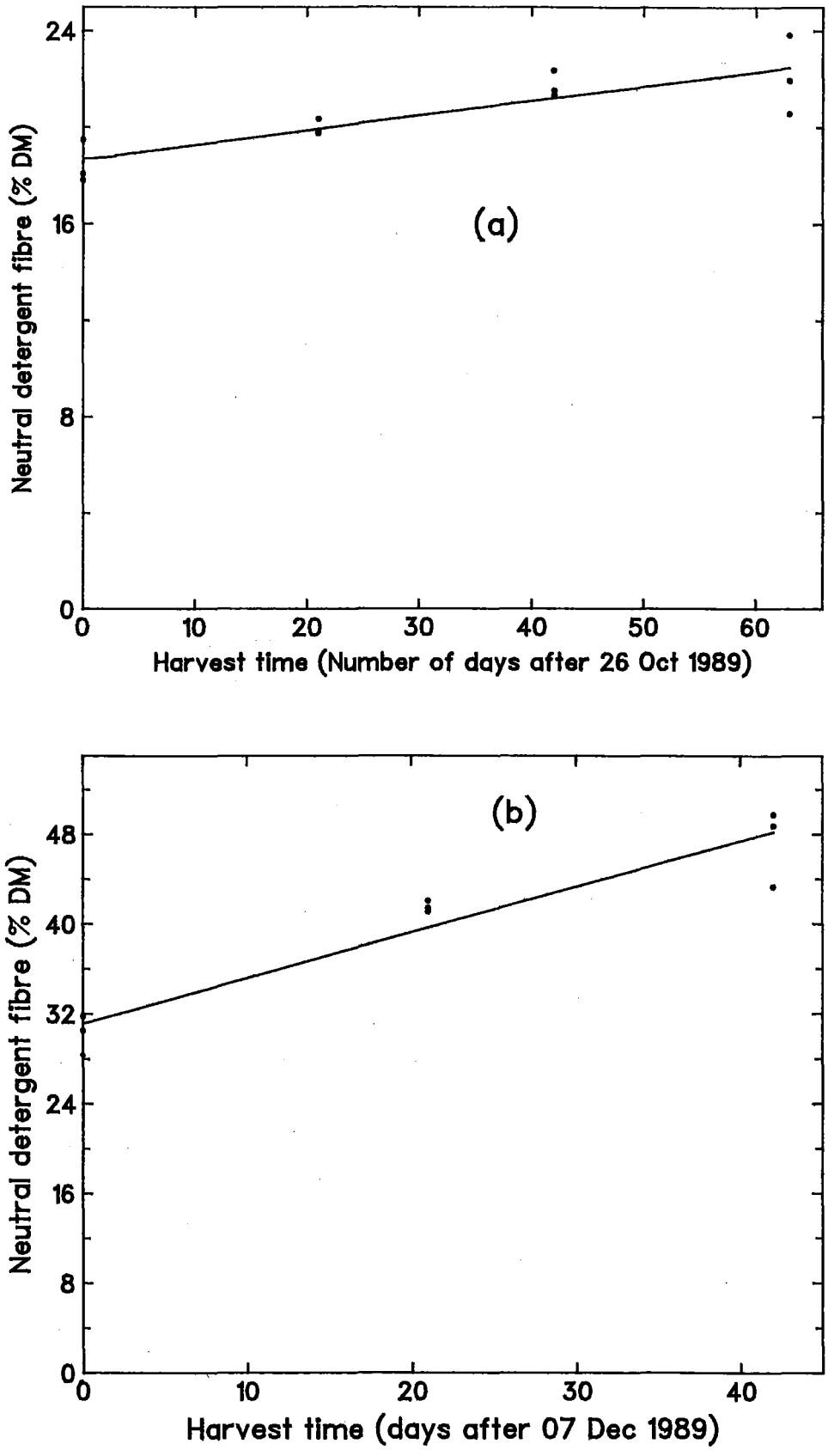

Fig. 3.12. Regression of the NDF concnetration (y) in Russell lupin (a) flowers ($y = 18.64 + 0.06x$, $P<0.001$, $R^2 = 0.73$), and (b) pods ($y = 31.06 + 0.41x$, $P<0.001$, $R^2 = 0.91$) on harvest time (x, days).

Table 3.2. Regression of the neutral detergent fibre concentration (y) in whole plant and plant parts of Russell lupins on harvest time (x, days).

Plant part	Intercept a	Coefficient b	R^2	Sign.$^{\theta}$
Whole plant	24.14	0.21	0.94	***
Stem	25.10	0.39	0.88	***
Petiole	35.14	0.15	0.56	***
Leaf	14.63	0.02	0.25	*
Flower	18.64	0.06	0.73	*
Pod	31.06	0.41	0.91	***

$^{\theta}$Significance: * = at P<0.05, *** = at P<0.001.

The dead matter NDF concentration did not show any consistent trend with maturity of Russell lupins. It ranged between 34 and 52 %.

Of the many single parameters considered for estimating whole plant NDF concentration, the ratio of leaf DM to total DM was found to be best. There was an inverse relationship, i.e. whole plant NDF concentration increased as leaf DM : total DM ratio decreased (Fig. 3.13). The regression was highly significant and accounted for 94% of the variation in whole plant NDF concentration (Equation 3.2).

Whole plant NDF (%DM) = 50.97 - 50.92 (Leaf/total DM) (P<0.001, R^2 = 0.94, S.E.E.= 1.98, n =18) **(3.2).**

3.3.6. *In vitro* Cellulase Digestibility

a. Dry matter digestibility. Whole plant *in vitro* dry matter digestibility (DMD) of Russell lupins showed a highly significant quadratic relationship (P<0.001) with maturity (Table 3.3; Fig. 3.14). By the final cut at the dry pod stage (Jan. 18) whole plant

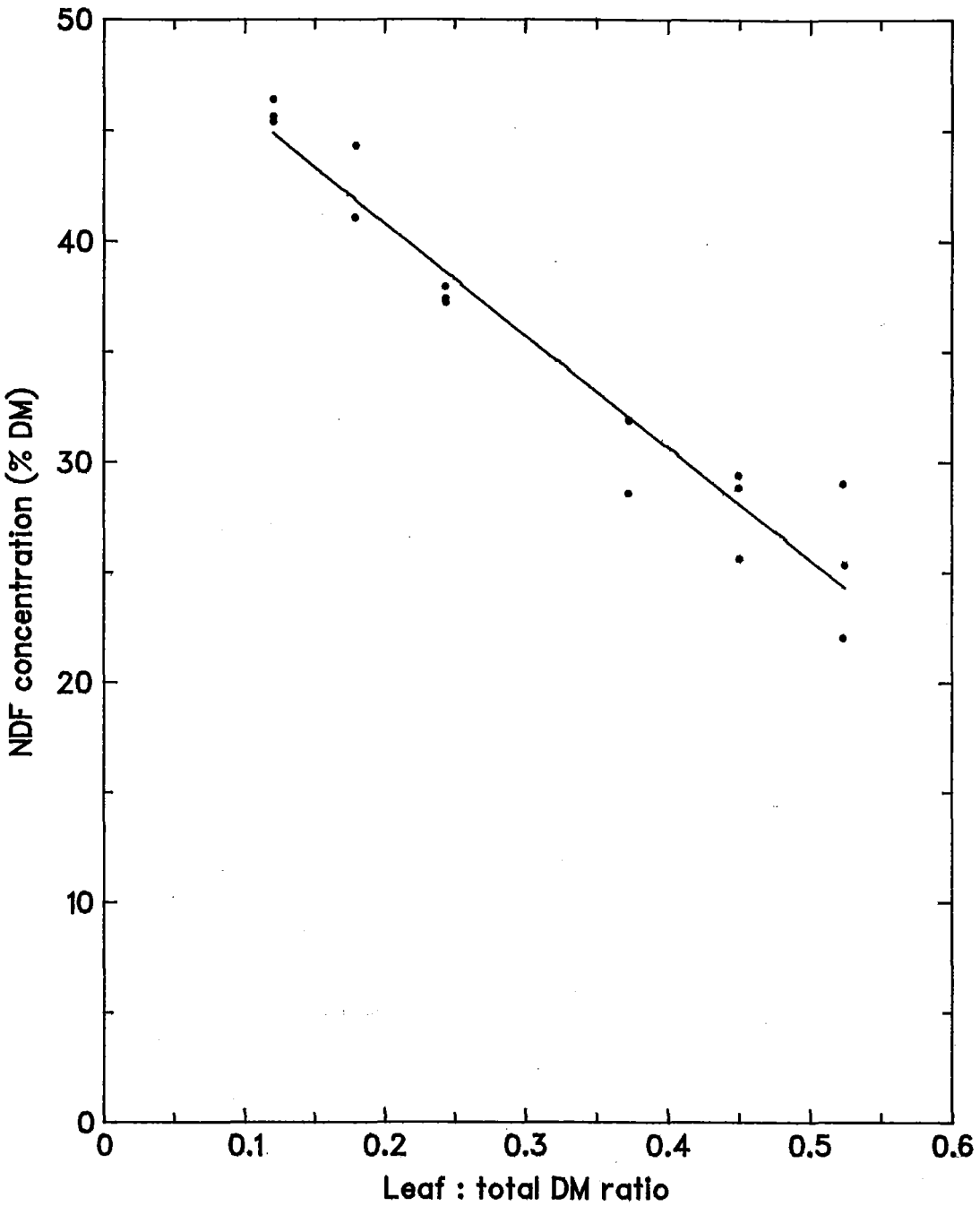

Fig. 3.13. Regression of whole plant NDF concentration on the leaf DM : total DM ratio in Russell lupins ($y = 56.97 - 50.92x$, $P<0.001$, $R^2 = 0.94$).

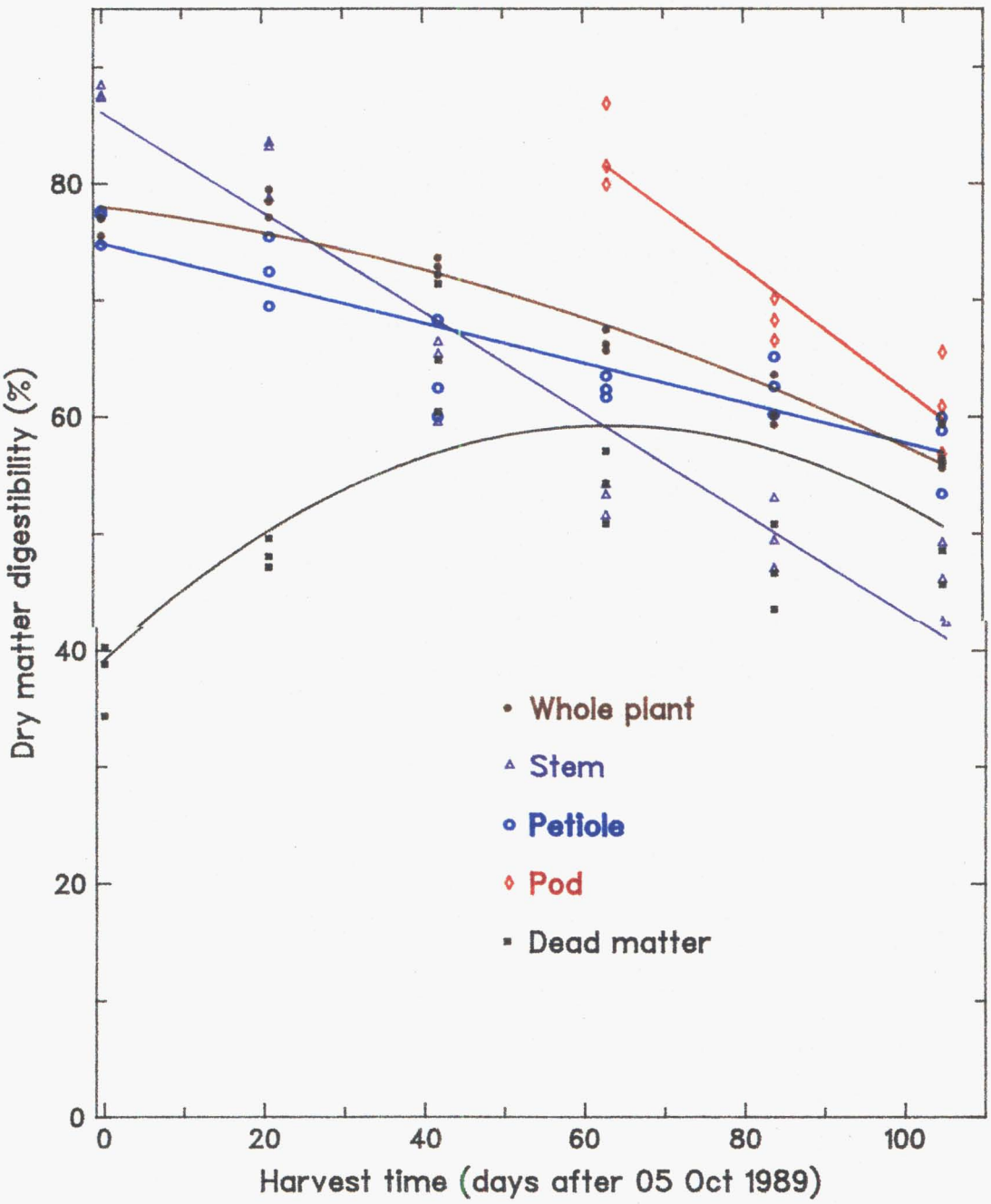

Fig. 3.14. Regression of the DM digestibility (y) of:
whole plant ($y = 76.47 - 0.09x - 0.001x^2$ $P<0.001 R^2 = 0.94$),
stem ($y = 86.12 - 0.43x$ $P<0.001$ $R^2 = 0.91$),
petioles ($y = 74.82 - 0.17x$ $P<0.001$ $R^2 = 0.79$),
pod ($y = 81.47 - 0.52x$ $P<0.001$ $R^2 = 0.88$)
and dead matter ($y = 39.16 + 0.634x - 0.005x^2$ $P<0.001$
$R^2 = 0.51$) on harvest time (x, days from the beginning of sampling).

digestibility of Russell lupins had fallen from an initial value of 76.5 to 56 %. Harvest date accounted for 94% of the variation in whole plant DMD of the Russell lupins.

Table 3.3. Regression of DM digestibility (y) of whole plant and plant parts of Russell lupins on harvest date (x, days).

Plant part	Curve	Intercept	Coefficients		R^2	Sign.$^{\theta}$
		a	b_1	b_2		
Whole plant	Quadratic	76.47	-0.09	-0.001	0.94	***
Stem	Linear	86.12	-0.43	-	0.91	***
Petiole	Linear	74.82	-0.17	-	0.79	***
Pod	Linear	104.01	-0.52	-	0.88	***
Dead matter	Quadratic	39.16	0.63	-0.005	0.51	**

$^{\theta}$Significance of regression: ** = at P<0.01, *** = at P<0.001.

The DMD of stem, petioles and pods (Fig.3.14) decreased linearly with harvest date, while dead matter DM digestibility showed a quadratic decline (Fig. 3.14). Dry matter digestibility in stems and pods decreased by about half a per cent a day (Table 3.3); the rate of decrease in DM digestibility of petioles was one-third that of pods (Table 3.3).

The DMD of leaves and flowers of Russell lupins showed very little change over time. Neither leaf DMD nor flower DMD showed a significant relationship with harvest date. The DMD of leaf material varied between 84 and 86 % while that of flowers varied between 81 and 84 %.

To summarise, across the harvest dates stem, petioles and pods showed a very large drop in their DM digestibility. In contrast, there was little change in the DM digestibility of leaves and flowers in relation to time. These caused a slow decline in whole-plant digestibility of Russell lupins. Over the whole sampling period leaves, whose digestibility stayed above 84 %, were the most digestible of all plant parts.

Within-harvest comparison of digestibility of plant parts

At the initial cut, stems had the highest digestibility though they were not significantly more digestible leaves (Table 3.4). By the second cut (when the Russell lupins began flowering) stems, leaf and flower were the parts with greater than 80% DMD. Then after the lupins developed pods, stems became the least digestible plant part, excluding dead matter (Table 3.4).

Prediction of *in vitro* cellulase dry matter digestibility

The regression of whole plant DMD on the proportion of dead matter in the total DM had the highest R^2 and lowest standard error, and was therefore the best predictor of whole plant DMD of Russell lupins. Whole plant DMD had an inverse linear relationship with the proportion of dead matter in total DM (Fig. 3.15a). The dead matter:total DM ratio explained 96% of the variation in whole plant DMD (Equation 3.3a).

$$\text{Whole plant DMD (\%)} = 81.8 - 64.64(\text{Dead matter/total DM}) \quad (P<0.001,\ R^2 = 0.96,\ \text{S.E.E.} = 1.63,\ n=18) \qquad \textbf{(3.3a)}$$

The N concentration in the DM was a poor predictor of DM digestibility (Equation 3.3b). In contrast, NDF concentration in the DM was the second best predictor of whole plant DMD (Equation 3.3c). Whole plant DMD showed a highly significant negative linear relationship with NDF concentrations in the DM (Fig. 3.15b).

$$\text{Whole plant DMD (\%)} = 43.87 + 8.32N \quad (P<0.01,\ R^2 = 0.37,\ \text{S.E.E.} = 6.65,\ n = 18) \qquad \textbf{(3.3b)}$$

$$\text{Whole plant DMD (\%)} = 103.47 - 0.997\text{NDF} \quad (P<0.001,\ R^2 = 0.92,\ \text{S.E.E.} = 2.32,\ n = 18) \qquad \textbf{(3.3c)}$$

Table 3.4. Within-harvest comparison of the mean dry matter digestibility (%) of different plant parts of Russell lupins at various growth stages (1989-90).

HARVEST	PLANT PART								
DATE	Stem	Petiole	Leaf	Flower	Pod	Dead matter	Total DMD	[1]L.S.D	[2]CV
Oct 5	87.6	76.5	84.3	-	-	37.8	76.4	3.4	2.4
Oct 26	81.7	72.4	86.2	81.3	-	48.3	78.3	4.1	3.0
Nov 16	63.6	63.5	84.7	84.0	-	65.5	72.7	2.8	5.7
Dec 7	52.9	62.5	85.1	84.0	82.7	54.0	66.4	4.0	3.2
Dec 28	49.7	62.6	85.5	83.1	68.2	46.9	60.9	3.9	3.2
Jan 18	45.8	57.4	84.2	-	61.0	50.0	57.1	7.9	7.1

[1]L.S.D. = Least significant difference at $P<0.05$.

[2]CV = Coefficient of variation (%).

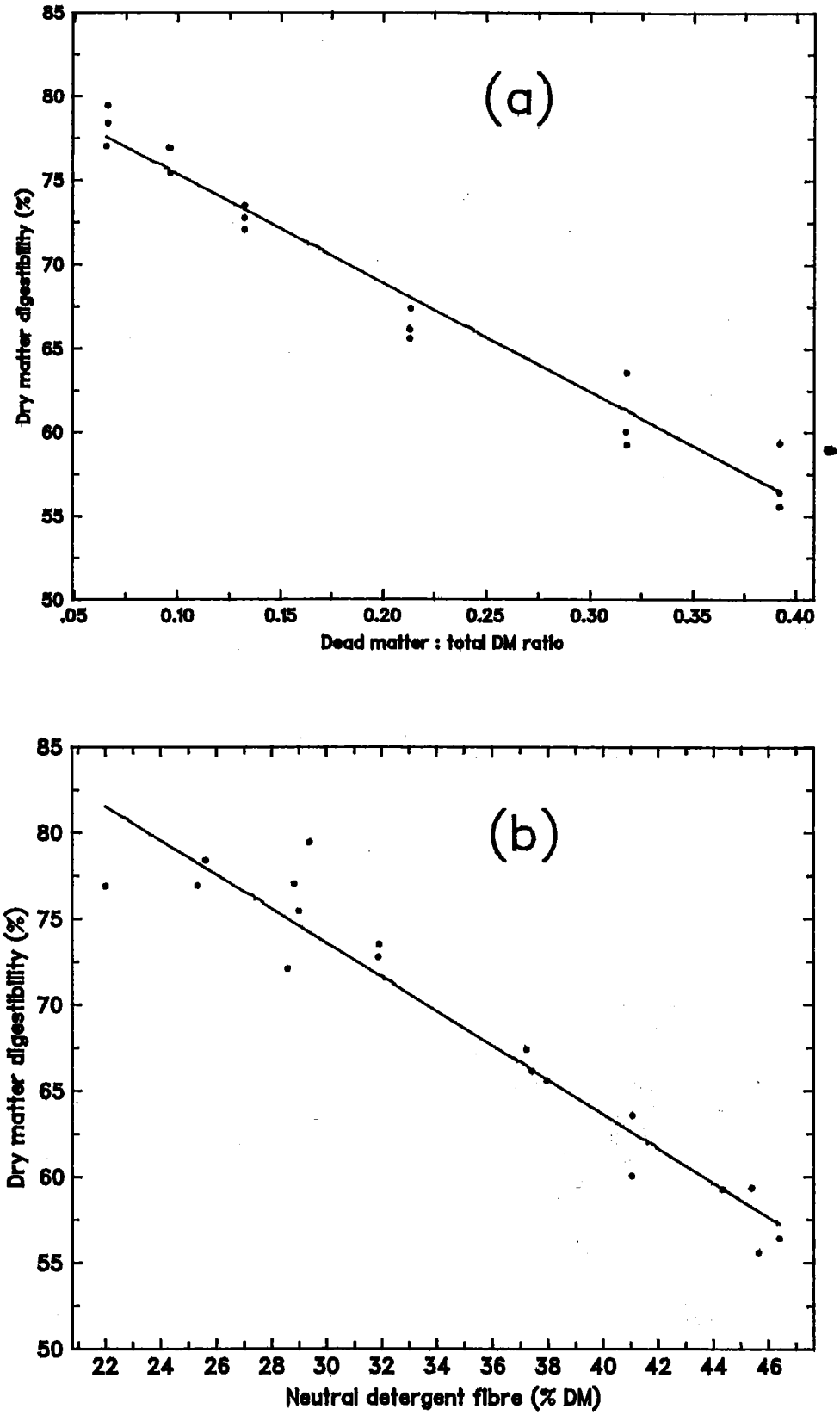

Fig. 3.15. Regression of dry matter digestibility (y) on:
(a) dead matter : total DM ($y = 81.8 - 64.64x$, $P<0.001$, $R^2 = 0.96$)
(b) NDF concentration ($y = 103.47 - 0.997x$, $P<0.001$ $R^2 = 0.92$)
in Russell lupins.

b. Organic matter digestibility (OMD). With maturity of Russell lupins the organic matter digestibility (OMD) of whole plants and plant parts showed virtually the same pattern as for DMD (Appendix 3). The OMD of leaf and flowers also appeared to be the least affected by harvest date. The comparisons of the OM digestibility of plant parts were also similar to the dry matter digestibility comparisons discussed earlier. The variables used for predicting DM digestibility were also good predictors of OM digestibility.

3.3.7. Digestible dry matter (DDM) yield

Whole plant DDM yield (g per plant) showed two peaks during the development of the Russell lupins (Fig. 3.16). Three weeks before flowering it reached 32 g DDM per plant. Three weeks later when the lupins started flowering it had more than doubled and had risen to 79 g per plant. At the third cut (Nov. 16) whole plant DDM yield had further increased significantly ($P<0.05$) to 89 g per plant (the first peak). After dropping significantly at the two subsequent cuts, whole plant DMD rose again and reached 91 g per plant at the final cut (Fig. 3.16). Digestible DM yield per plant showed a stronger correlation with DM yield per plant ($r = 0.86$) than with the digestibility of the DM ($r = -0.44$).

The contribution of plant parts to the total whole plant DDM yield varied among harvests (Fig. 3.17a). From early regrowth to the stage of pod development the majority of the DDM was in leaves and petioles. Together, leaf and petiole DDM made up 94, 82 and 67% of the whole plant DDM yield of the first three cuts (Fig. 3.17a). After the Russell lupins set pods, the contribution of leaf and petiole DDM, especially that of the petiole, to total DDM yield per plant rapidly diminished, and DDM yield from pod and dead matter assumed an increasingly higher proportion of total DDM yield (Fig. 3.17a).

Within-harvest and between-harvest comparison of the digestible DM yield of plant parts is summarised in Table 3.5. The main points will be considered briefly.

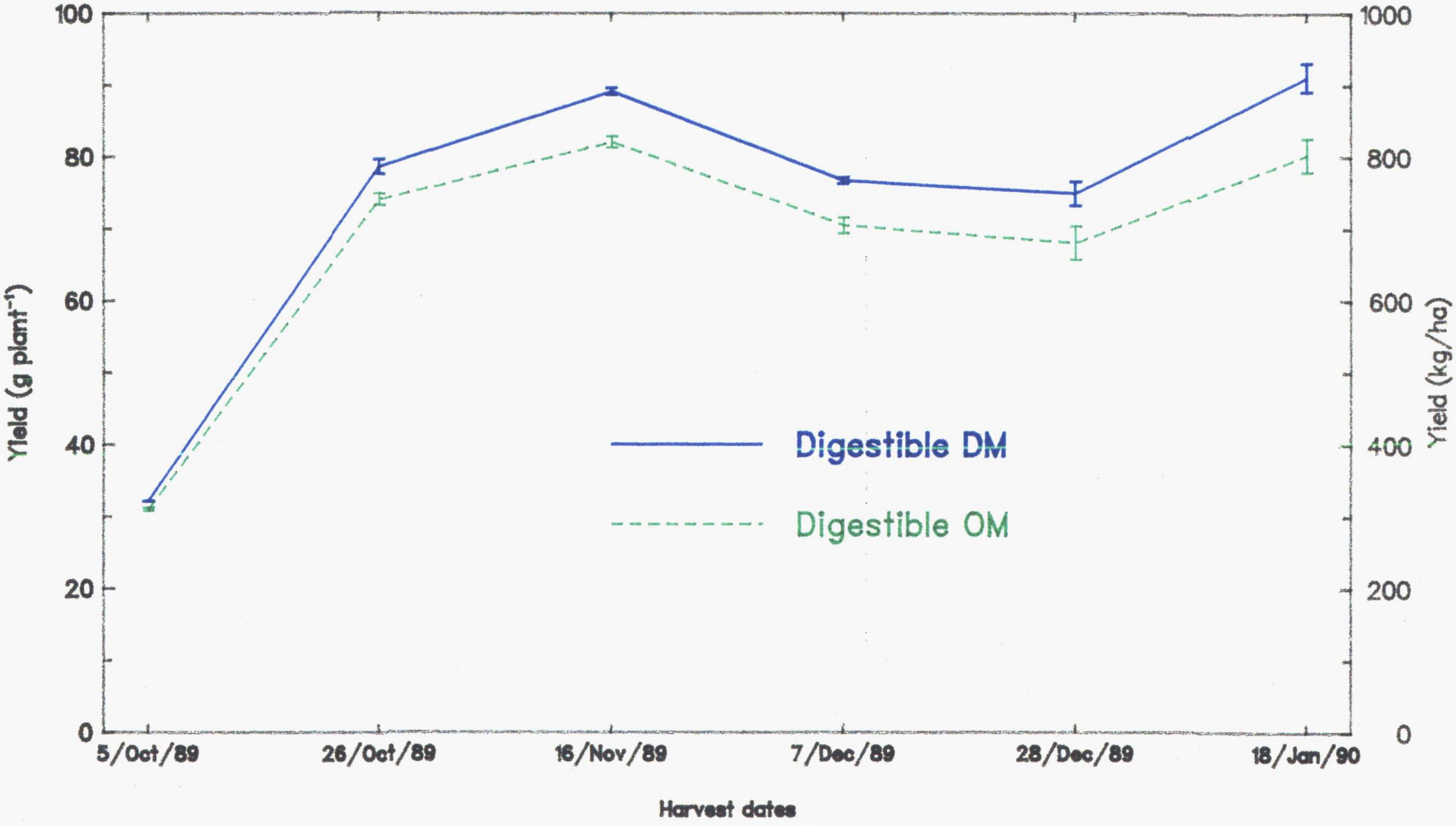

Fig. 3.16. Whole plant digestible dry matter (solid line) and organic matter (broken line) yield of Russell lupins over time (spring regrowth to maturity) (1989-90).

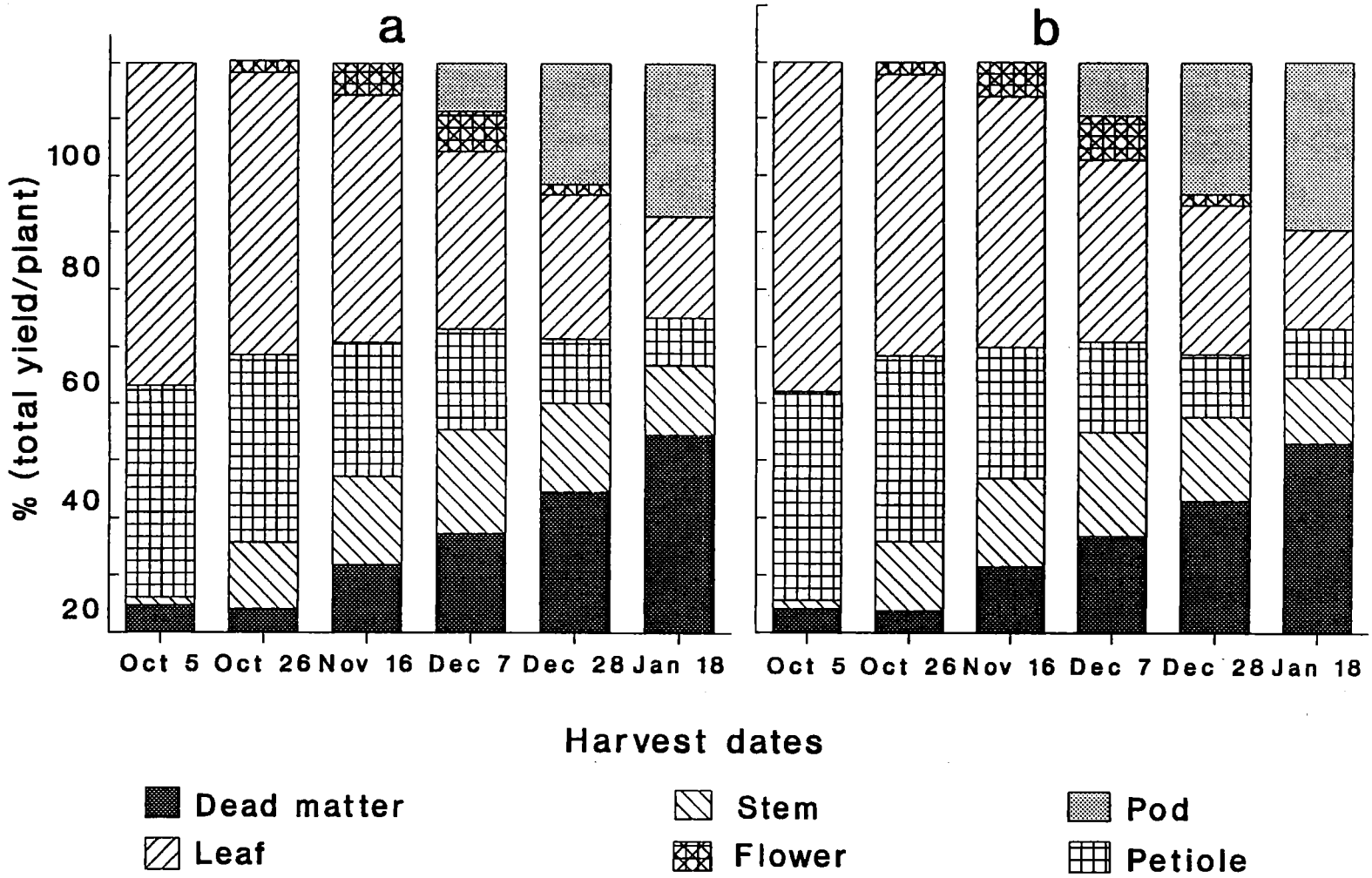

Fig. 3.17. Per cent whole plant (a) digestible DM and (b) digestible OM in different parts of Russell lupins harvested at different growth stages (1989-90).

Table 3.5. Within-harvest and between-harvest comparison of digestible dry matter yield (g/plant) of different parts of Russell lupins at various growth stages (1989-90).

HARVEST	P L A N T P A R T								
DATE	Stem	Petiole	Leaf	Flower	Pod	Dead matter	Total DDM	[1]L.S.D	[2]CV
Oct 5	0.4	11.9	18.3	-	-	1.5	32.1	0.54	3.4
Oct 26	9.2	25.8	39.1	1.6	-	3.2	78.9	1.00	3.4
Nov 16	13.6	21.1	38.7	5.1	-	10.6	89.1	2.06	6.1
Dec 7	13.9	13.6	23.8	5.4	6.7	13.3	76.7	0.75	3.2
Dec 28	11.6	8.5	18.9	1.3	16.1	18.4	74.8	1.12	4.9
Jan 18	11.3	7.5	16.2	-	24.7	31.5	91.2	3.42	10.0
[1]L.S.D.	1.13	1.52	1.06	0.09	2.35	2.72	3.00		
[2]CV	6.2	5.7	2.2	1.3	6.6	11.4	2.2		

[1]L.S.D = Least significant difference at P<0.05.
[2]CV = Coefficient of variation.

During the first three cuts the majority of DDM yield was in leaves and petioles. Stem DDM yield increased by 23-fold from 0.4 g to 9.2 g per plant within three weeks, and at its highest level (i.e. 13.9 g) composed 18 % of total DDM yield per plant (Fig. 3.17a). Both across- and within-harvest dates leaves produced more DDM per plant than stems or petioles. The DDM yield of dead matter consistently rose from 1.5 to 31.5 g per plant and constituted about 35 % of total DDM (Fig. 3.17a). The contribution of the inflorescence to the total DDM yield was very low (Fig. 3.17a). At its highest, which was at the dry pod stage, DDM yield from pods made up 27 % of the total DDM yield, a proportion only second to that of dead matter.

In summary, up to pod formation leaf DDM was the major component of whole plant DDM yield followed by petioles. After the Russell lupins developed pods, pod and dead matter DDM became the major components of whole plant DDM yield. The percentage of leaf DDM in the whole plant DDM at any harvest was significantly lower than it was at all the harvest dates that precede it (Table 3.5). The DDM yield of flowers was lower than that of all other plant parts at all harvest dates which included flowers. Over the whole sampling period the proportion of stem, petiole, leaf, flower, pod and dead matter DDM yield ranged from 1-18%, 8-37%, 18-57%, 2-7%, 9-27% and 4-34% of total DDM yield per plant (Fig. 3.17a).

3.3.8. Digestible organic matter (DOM) yield

As with their DDM yield whole plant DOM yield of Russell lupins exhibited two peaks (Fig. 3.16). The changes in the contribution of plant parts to total DOM with maturity of the Russell lupins was also as discussed above (Fig. 3.17b). The comparison of DOM yield of plant parts was similar to that of DDM yield, and is summarised in Table 3.6.

Table 3.6. Within-harvest and between-harvest comparison of digestible organic matter yield (g/plant) of different parts of Russell lupins at various stages of growth (1989-90).

HARVEST	P L A N T P A R T								
DATE	Stem	Petiole	Leaf	Flower	Pod	Dead matter	Total DOM	[1]L.S.D	[2]CV
Oct 5	0.5	11.3	18.0	-	-	1.3	31.1	0.31	2.0
Oct 26	8.9	24.1	36.6	1.6	-	2.8	74.0	1.46	5.2
Nov 16	12.6	19.0	36.1	5.0	-	9.4	82.1	2.35	7.6
Dec 7	12.7	11.3	22.4	5.4	6.7	11.9	70.5	0.88	4.1
Dec 28	10.0	7.5	17.7	1.3	15.8	15.6	68.1	1.27	6.1
Jan 18	9.4	6.8	13.8	-	23.7	26.6	80.3	3.76	12.4
[1]L.S.D	1.23	2.31	1.10	0.09	2.45	2.96	3.98		
[2]CV	7.5	9.5	2.5	1.4	7.0	14.5	3.2		

[1]L.S.D = Least significant difference at $P<0.05$.

[2]CV = Coefficient of variation.

3.3.9. Stage of optimum yield

The maximum DM, digestible DM, and N yields were obtained when the Russell lupins were at their dry pod stage. However, a considerably high portion of the yields obtained at this stage were from dead matter. For example, 38.8% of the N yield at the dry pod stage was from dead matter. The next highest N yield, which was obtained at the full bloom stage (Nov. 16), had only 15.7% of its total N from dead matter. When N yield from dead matter was disregarded the N yield per plant showed a decline after full bloom (Fig. 3.18). Therefore, optimum N yield was obtained when the lupins were harvested at the full bloom stage. The analysis of the two peak digestible DM yields also indicated the same situation (see below).

Although the two peaks of DDM yield appear to be similar (Fig. 3.16), the digestible DM composing each yield peak came from plant parts of different nutritional characteristics. For instance, digestible DM from dead matter was 11.9 and 34.5% of the total DDM yield of the respective two peaks (Fig. 3.19a). Moreover, the first peak DDM yield occurred at a stage where the total DM yield was highly digestible (Fig. 3.19b). Further, 49% of the DDM yield at the first peak came from plant parts with greater than 80% digestibility as compared with only 20% at the second peak (Fig. 3.19c). The first peak DDM yield had virtually no components with less than 60% DM digestibility while the latter made up more than 50% of the second peak DDM yield (Fig. 3.19c).

All the above features were also true for the two peak digestible OM yields. Therefore, DM yields of high nutritional quality were obtained when lupins were cut at the full bloom stage. When harvested at this stage the total DM yield had a high N content, was highly digestible, and there was considerably less loss of plant growth due to death than at later growth stages.

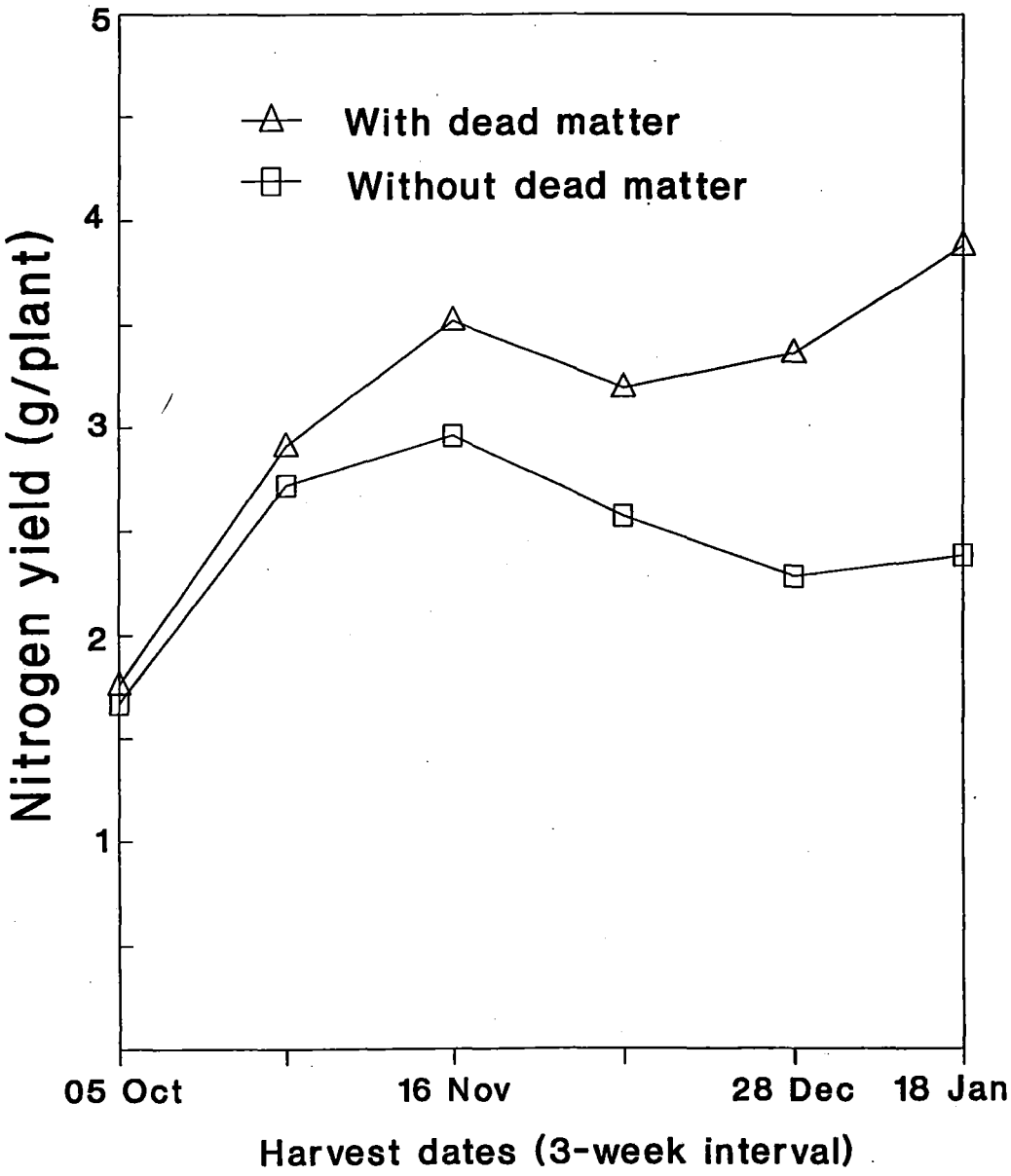

Fig. 3.18. The N yield of Russell lupins harvested at different growth stages with and without N from dead matter.

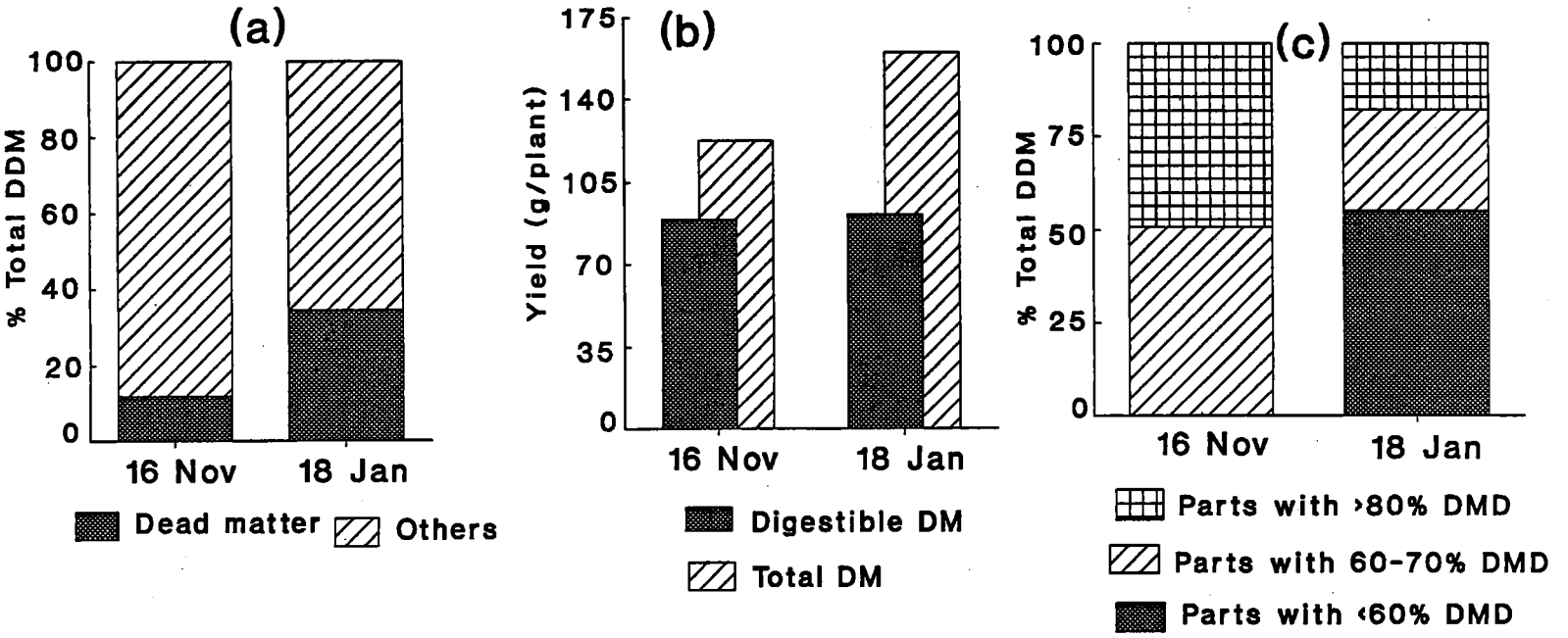

Fig. 3.19. Features of the two peak digestible DM yields:
(a) per cent total DDM from dead matter,
(b) amount of total DDM in relation to total DM, and
(c) per cent total DDM from plant parts with <60 %, 60 - 70 % and >80 % DM digestibility.

3.4. DISCUSSION

3.4.1. Dry matter yield

The DM yield (plant^{-1} and ha^{-1}) of Russell lupins compared favourably to previous reports on Russell lupins and other lupins as indicated in Table 3.7. The main points of interest are listed below.

Table 3.7. Comparison of dry matter yield of Russell lupins to that of other lupins.

Lupins	Dry matter yield		Plants	Source
	g plant^{-1}	kg ha^{-1}	(m^{-2})	
Russell lupin	110[1]	11000	10	This work
>>	50	5570	11	Gymptsho, 1987
>>	48	5270	11	Gebru, 1989
>>	250	5000	2	Tesfaye, 1989
L. angustifolius				
Uniwhite	-	4120	-	McMillan and Brown, 1973
Uniharvest	10	2540	25	McKenzie and Hill, 1984
>>	4	3510	100	>>
>>	22	8679	41	Rhodes, 1980
>>	10	9870	100	Burtt, 1981
WAU11B[2]	13	19990	156	Herbert and Hill, 1978
Lupin[3]	25	9650	38	Hassan *et al.*, 1986
Grass/clover[4]	-	8400	-	Hoglund *et al.*,1979

1 Average DM yield of the six harvests.

2 Cultivar of *L. angustifolius*.

3 Species not given, probably Uniharvest.

4 Annual yield of ryegrass/white clover pastures (without N fertiliser) from nine sites scattered throughout New Zealand.

(1). Greater yield per plant than that observed in this study was obtained only where Russell lupins were grown at a very low plant density.

(2). Generally, the Russell lupins in this study produced greater yield per plant and yield per ha than annual lupins. Only Herbert (1977) obtained a higher yield per ha from irrigated high density plots.

(3). The low per plant yield of annual lupins was largely because they were sown at a much higher density than the Russell lupins in this study.

(4). Most published values for yield of annual lupins in New Zealand were lower less than 10 t ha^{-1}, all lower than the yield of Russell lupins at any harvest, save the first harvest (Fig. 3.3).

(5). Moreover, DM yield from a spring growth of Russell lupins was comparable to the mean annual yield of ryegrass/white clover pasture in New Zealand. Only the yield of the Russell lupins at the first cut fell below this mean (Fig. 3.3).

The higher yield of Russell lupins in this study than that reported by Gebru (1989) and Gymptsho (1987) was probably related to difference in duration of growth and season of growth, respectively. Gebru (1989) measured DM accumulation only over two months. Gymptsho's DM yield result was from summer-autumn growth of Russell lupins, and Tesfaye (1989) indicated that Russell lupins produced greater DM yield in spring than in autumn.

The pattern of DM accumulation and changes in plant components of Russell lupins was different from that of annual lupins (Table 3.8). To cite the main points:

(1). The rate of DM accumulation by Russell lupins dropped markedly after flowering began while annual lupins showed continual rate of increase in DM accumulation.

(2). The percentage of maximum yield accumulated at full bloom or when maximum leaf yield was attained was greater for Russell lupins than annual lupins.

Table 3.8. Comparison of the pattern of DM accumulation in lupins as they progressed to maturity.

TOTAL DRY MATTER ACCUMULATED AT					
Vegetative¶		Full bloom		Leaf maximum	
kg/ha/d	% max.	kg/ha/d	% max.	% maximum	Lupin species
280	25	100	76	76	Russell lupin
17	0.8	58	16	-	Uniharvest[1]
90	7	188	25	-	Uniharvest[2]

PER CENT PLANT PARTS IN TOTAL DM			
Petiole + Leaf		Pod + seeds	
Vegetative	Maturity	Maturity	Lupin species
89	20	25	Russell lupin
88	5	70	Uniharvest[1]
-	-	50	Uniharvest[3]

Uniharvest[1] = from Rhodes (1980).

Uniharvest[2] = from Burtt (1981).

Uniharvest[3] = from Greenwood *et al.* (1975).

Vegetative¶ = Three weeks before the beginning of flowering.

(3). Although most of the DM, in both lupins, was initially in petioles and leaves, Russell lupins retained a greater proportion of their leaf yield at maturity. There was no complete leaf drop in Russell lupins, and at the dry pod stage DM from green leaves was still 20 g plant^{-1} (Fig. 3.4), equivalent to 2 t DM ha^{-1} at 10 plants m^{-2}.

(4). Pods, which are said to be sparingly acceptable to sheep (Tesfaye, 1989), were only 25 % of the maximum DM yield of Russell lupins while in annual lupin species they comprised more than 50 % of the total yield.

The accumulation of a large proportion of maximum yield at flowering by the Russell lupins in this study was related to their growth pattern. The lupins in this study were regrowth plants where a single plant consisted of many more or less equal stems growing together from a crown. Most of these stems flowered simultaneously and there was no substantial increase in DM yield after flowering. In annual lupins, and probably first growth perennials, which usually have a single stem, the proportion of maximum DM yield that has accumulated by the time the main stem flowers is low, and there will be a rapid increase in biomass after the beginning of flowering due to main stem elongation and the development of lateral branches (Perry, 1975; Herbert and Hill, 1978).

The difference in leafiness at maturity was probably a reflection of the difference in the rate of senescence with plant maturity. Leaf senescence in annual lupins is related to mobilisation of N from leaves as they form the major source of N for pod filling (Farrington *et al.*, 1977; Withers and Forde, 1979). In annual species as much as 50 % of the maximum DM yield attained may be lost during the later stage of pod filling (Perry, 1975). This implied that the absence of complete leaf drop in Russell lupins may be because the plant is able to meet most of its demand for N during pod filling from N fixation. It may also be due to the perenniating nature of the plant.

Compared with other lupin species, a smaller proportion of potential maximum yield would be sacrificed if Russell lupins were harvested at the stage when leaf yield was at its maximum. Considering the amount of dead matter (at 39 % of total DM in the maximum yield obtained (Fig. 3.5)) the harvesting or grazing of Russell lupins at full bloom (i.e. when

the leaf weight was at its maximum) appears to be recommendable. However, it remains to be determined if Russell lupins grown from seed (first-growth plants) will show the same pattern of DM accumulation as the regrowth plants used in this study.

3.4.2. Nitrogen concentration

The two major advantages of using forage legumes in pastoral farming are: their ability to supply their own N fertiliser and produce forage dry matter high in protein. The N concentration in Russell lupins forage varied between 4.2 % (26 % CP) and 2.4 % (15 % CP) which was only slightly different from the ranges 4.7 to 2.4 % and 4.6 and 2.0 % observed in *L. angustifolius* cv. Uniharvest by Rhodes (1980) and Burtt (1981), respectively. Over most of its growth period, the N concentration in Russell lupins was higher than reported values for N concentration in highly fertilised grass crop which rarely exceeds 2.5 % (Wilman, 1965; Reid, 1966; Sinclair *et al.*, 1977; Fairley, 1985a,b).

Nutritionally, the most important point regarding the N concentration of Russell lupins was that it was high and remained high as the lupins advanced to maturity. This was in harmony with observations on other lupins, especially *L. albus* (Davis and Offutt, 1975; Sheldrick *et al.*, 1980). The N concentration stayed high because (i) the Russell lupins retained a high proportion of leaf in their DM yield even at the latest maturity stage, and (ii) the development of pods, which were high in N, at later stages prevented rapid decline in N concentration with maturity. The rapid decline in N concentration during the first three weeks was mainly because of increased dilution (Fleming, 1973) due to rapid growth.

Regarding plant components, the N concentration of Russell lupin leaves was higher and that of their pods lower than that of Uniharvest leaves and pods (3.65%). This was because leaves in Burtt (1981) included petioles. The decrease in the N concentration of Russell lupin pods as opposed to increase in N concentration of Uniharvest pods (Burtt, 1981) was because of loss of seeds through pod shatter; in the non-shattering Uniharvest pods the N concentration increased with maturity as more nutrients were transferred to seeds.

In view of ruminant nutrition, the most important point was that at any growth stage the crude protein content of Russell was well above the minimum level of CP (9 %) recommended by ARC (1980), or the optimum level recommended for growth of lambs (12.5 to 17.5 % CP) (Andrews and Orskov,, 1970). This provides an option to use Russell lupins with low protein feeds. However, further work on duodenal supply of protein from these lupins is required to establish the actual value of their high N content.

3.4.3. Nitrogen yield

The pattern of total N accumulation of Russell lupins and its distribution among plant parts was similar to that of their DM accumulation (Fig. 3.9 vs. 3.3; 3.10 vs. 3.5). Moreover, as with DM yield Russell lupins accumulated a greater proportion of their maximum N yield by full bloom (91 %) than other lupins which accumulated 20 - 25 % of their maximum (Rhodes, 1980; Burtt, 1981).

The advantage of Russell lupins in their N yield was largely a reflection of their high DM yield as their N concentration varied over a more or less similar range with that of other lupins (see Section 3.4.2). Consequently, the maximum N yield obtained in this study was higher than that previously reported for Russell lupins or other annual lupins (Table 3.9). One striking feature of Table 3.9 was that the N yield obtained from a spring growth of Russell lupins used in this study was higher than the annual N yield of ryegrass swards, fertilised with ≥300 kg N ha^{-1} and cut four or more times a year. It was also higher than the annual N yield of ryegrass/white clover swards, the commonest pasture on New Zealand farms.

3.4.4. Neutral Detergent Fibre Concentration

The concentration of cell wall is the major factor limiting the digestibility and hence the nutritive value of herbage, as its digestibility varies with maturity based on the extent of lignification. The concentration of cell wall in Russell lupins was low; it exceeded 40 % only during the last four weeks. As with N concentration, rapid deterioration in

Table 3.9. Comparison of the nitrogen yield of Russell lupins to that of other lupin and pasture species.

Plant species	N yield	Fertiliser	Source
Russell lupin 390[1]	-	-	This work
>>	157	-	Gebru, 1989
>>	141	-	McKendry, 1987
Lupinus angustifolius			
Uniharvest	147	-	McKenzie and Hill, 1984
>>	238	-	Rhodes, 1980
>>	316	-	Burtt, 1981
Marri	157	-	Anslow *et al.*, 1983
Uniwhite	242	-	Sheldrick *et al.*, 1980
Unicrop	93	-	Harbison *et al.*, 1986
Lupinus albus	259	-	Sheldrick *et al.*, 1980
>>	345	-	Larson *et al.*, 1989
Lupins[2]	352	-	Hassan *et al.*, 1986
Ryegrass	200-280	300 kg N	See below[3]
Ryegrass	385[4]	600 kg N	Wilman and Hollington, 1985
Ryegrass/clover[5]	86[i]	350 kg P	Sinclair *et al.*, 1977
>>	160[ii]	>>	>>
>>	365[iii]	>>	>>
Ryegrass/clover[6]	269[i]	400 kg N	Wilman and Hollington, 1985
>>	375[ii]	>>	>>

1 Maximum yield at 10 plnats m^{-2}.

2 Species not given, probably Uniharvest.

3 Annual yield of ryegrass harvested four or more times a year (Cowling and Lockyer, 1967; Sollenberger *et al.*, 1984; Fairley, 1985a,b).

4 Annual N yield of ryegrass harvested seven times a year.

5 Annual N yield of ryegrass/white clover pastures (i) at low, (ii) at moderate and (iii) high fertility sites in the South Island of New Zealand.

6 Annual N yield of ryegrass/white clover pastures at (i) low and (ii) high fertility sites in Scotland.

herbage quality in terms of increased NDF concentration was minimised by the diluting effect of leaves which had very low level of NDF that remained low as the lupins matured. Buxton and Russell (1988) also suggested that dilution of stems by leaves in total herbage is the reason for low NDF concentration in legume herbage.

There is no other report on the NDF concentration of Russell lupins. However, the NDF concentration in total herbage or plant components of Russell lupins was not higher than that of other shruby legumes or pasture species. At the same research station Borens (1986) found values for NDF concentration in tagasaste (*Chamaecytisus palmensis*) leaves which increased from 29 to 42 % over six months (vs. 15 - 17 % in Russell lupin leaves). Even at full bloom the NDF concentration of Russell lupins at 33 % was comparable to the 32 % and even less than the 37 % reported for mature white clover (Ulyatt *et al.*, 1988) and low-lignin lucerne (Kephart *et al.*, 1990), respectively.

Moreover, the average increase in NDF with advancing maturity (i.e. 43 %) and the range of mean NDF (29 - 41 %) reported for lucerne, red clover and birdsfoot trefoil (Collins, 1988) were very close to that of Russell lupins.

Based on N concentration and yield, and NDF concentration Russell lupins provided herbage of moderate to high quality over most of their growth periods. This was also substantiated by their DM digestibility and yield of digestible DM.

3.4.5. Digestibility and yield of digestible DM

(i). Digestibility. Due to similarity in both the digestibility and yield of digestible DM and OM of Russell lupins only DM digestibility and DDM yield is discussed to avoid repetition. Unlike most pasture plants, in which digestibility shows a rapid linear decline with maturity, the digestibility of Russell lupins declined slowly, depicting a characteristic quadratic pattern (Fig. 3.14). This was close to the pattern observed on *L. albus* which maintained the same level of digestibility during development from vegetative to reproductive stage (Davis and Offuttt, 1975; Sheldrick *et al.*, 1980).

The pattern of decline in whole plant digestibility due to increase in proportion of less digestible components (i.e. stems and vegetative parts) was typical of all forage species. However, there were some features which distinguished Russell lupins from annual lupins, common pasture species and shruby legumes.

(1). Russell lupins had greater DMD at maturity than annual lupins because they retained a higher proportion of green leaf.

(2). They had a slower decline in DMD and higher DMD at maturity than common pastures because they developed pods, which were highly digestible, and also retained a higher proportion of green leaf. For comparison, 69 days after anthesis every plant component of annual ryegrass (*Lolium rigidum*) was dead, and whole plant digestibility was 36 % (Ballard *et al.*, 1990).

(3). They had higher DMD than other shruby legumes because they had a lower cell wall concentration which stayed lower than 50 % even at maturity.

The pattern of decline in digestibility of individual plant parts of Russell lupins was in harmony with reports on other lupin species, i.e. rapid decline in stem DMD, and little, if any, change in leaf DMD (Table 3.10). The higher digestibility value for Russell lupin leaves was again probably because leaf in this study referred to lamina alone while in that of Davis and Offutt (1975) it was lamina plus petiole.

Table 3.10. Comparison of changes in DM digestibility of plant components of different lupin species.

Stage of growth	Russell lupins	*L. albus*¶
	Stem	
Pre-bloom	86.1	72.8
Bloom	68.1	67.8
Pod	59.0	58.1
	Leaf	
Pre-bloom	84.3	75.7
Bloom	84.7	75.3
Pod	85.1	75.6

L. albus¶ from Davis and Offutt (1975)

The digestibility of Russell lupin pods (plus seeds) was lower than the 80 - 90 % DMD observed in *L. albus* pods (Davis and Offutt, 1975; Sheldrick *et al.*, 1980), probably due to greater loss of seeds because of pod shatter in the former. The quadratic change in digestibility of Russell lupins dead matter did not conform to reports on other lupins. The increase in DMD of dead matter up to pod development coincided with increased proportion of dead leaves in the fallen material collected, which probably suggested that dead Russell lupin leaves were of high digestibility.

Generally, as in many pasture species, the change in the digestibility of plant parts of Russell lupins was due to altered cell wall concentrations in those parts. That is, parts which had low level of NDF and which showed minimal increase in their NDF concentration were highly digestible and maintained high digestibility with maturity, and vice versa. On the other hand, change in whole plant digestibility was a reflection of changes in the relative proportion and digestibility of plant parts that made up the herbage. The interplay of these changes enabled Russell lupins to maintain herbage of high D-value over most of its growth period. Therefore, the digestibility of Russell lupins supports the suggestion that they are a herbage of moderate to high nutritive value over most of their growth period. Ulyatt (1973) suggested that herbage of 70 % DMD is needed for high producing livestock. The DMD of Russell lupins up to full bloom (76 - 70 %) adequately met this requirement.

The cellulase digestibility of Russell lupins was predicted well both by the proportion of dead matter in total DM and the concentration of NDF in total DM (Equations 3.3a and 3.3c, respectively). There does not appear to be any other report on lupins which has used similar parameters to predict whole plant digestibility. However, Kephart and associates (1990), who extensively examined the effect of cell wall and its components on the digestibility of lucerne, also found a very close association between *in vitro* DMD of lucerne and its cell wall concentration, which was even stronger than its association with the lignin concentration. From this and the fact that legume cell walls exhibit a slow rate of lignification (Buxton and Russell, 1988), it may be deduced that the cell wall concentration of Russell lupins provides adequate indication of their DMD. In contrast, the correlation of

cellulase DMD of Russell lupins with their N concentration ($R^2 = 0.37$) was very low as also found by Burtt (1981) on *L. angustifolius* ($R^2 = 0.39$).

(ii). Digestible dry matter yield. The yield of digestible DM is an important parameter in assessing the nutritive value of herbage, for it combines yield and quality of herbage. In fact, Belton and associates (1989) recommended the use of DDM yield in identifying the optimum harvest date for pasture herbage. Before pursuing this point further, a brief discussion will be made on the accumulation of DDM yield of Russell lupins, and on how it compares with that of other species.

The pattern of accumulation of DDM yield and its distribution among plant parts was similar to that of DM yield. This suggested that it was DM yield rather than digestibility of DM that had a major effect on the DDM yield of Russell lupins. For instance, during the first three weeks of sampling DM and DDM yield more than doubled (Fig. 3.3 & 3. 16) while DMD showed no significant change (Fig. 3.14).

Not only peak DDM yield of Russell lupins, at 89 - 91 g plant^{-1} ($\simeq$ 9 t ha^{-1}) but DDM yield after the second harvest ($\geq$ 7 t ha^{-1}) were higher than that reported for other lupins and conventional pasture species (Table 3.11). One important point shown in Table 3.11 was that DDM yield from a spring regrowth of Russell lupins was higher than the annual DDM yield of the conventional ryegrass/white clover pasture which had received commercial fertiliser and cut more than three times a year. This has a very important implication with respect to production of livestock feed of high nutritive value with little input.

3.4.6. Stage of optimum yield

Optimum harvest date is a compromise between herbage yield and quality. It may be more usefully defined as the time at which digestible DM ha^{-1} is maximised (Belton *et al.*, 1989). With Russell lupins, there was difficulty in directly applying this definition as there were two similar peak DDM yields. This required further interpretation of these peaks. One distinguishing feature was the contribution of dead matter to total N and DDM yield. It has been established that grazing animals prefer leaves to stems, green to dead tissue, and

Table 3.11. Comparison of the maximum digestible dry matter yield of Russell lupins with that of other pasture species.

Species	Yield (t/ha) DDM	Yield (t/ha) DOM	Season	Cuts/year	Source
Russell lupin	9.0	8.1	Spring-summer	1	This work
L. angustifolius	5.9	-	Spring-summer	1	Burtt, 1981
L. angustifolius	6.4	-	Spring-summer	1	Sheldrick *et al.*, 1980
L. albus	7.0	-	Spring-summer	1	>>
L. angustifolius	5.5	-	Spring-summer	1	Anslow *et al.*, 1983
Perennial ryegrass	6.396	-	Annual[1]	4	Fairley, 1985b
Perennial ryegrass	6.424	-	Annual[2]	8	>>
Ryegrass-white clover	4.0	-	Spring	1	Belton *et al.*, 1989
Ryegrass-white clover	-	6.5	Annual[3]	4-5	Frame, 1987
Ryegrass-white clover	-	7.6	Annual[4]	4-5	>>
White clover	-	4.8	Annual[5]	3	Frame, 1986
Lucerne	-	6.7	>>	3	>>
Red clover (diploid)	-	6.9	>>	3	>>
Red clover (tetraploid)	-	7.4	>>	3	>>

[1]Three-year average with annual N fertiliser at 300 kg ha^{-1}.
[2]Three-year average with annual N fertiliser at 450 kg ha^{-1}.
[3]Two-year average without N fertiliser.
[4]Two-year average with 80 kg N ha^{-1} $year^{-1}$.
[5]Two-year average with 90 kg P_2O_5 ha^{-1} $year^{-1}$.

clover to grass (Donald, 1941; Raymond and Terry, 1966; Minson, 1981; Hodgson 1982, 1990). Results on both the proportion of DDM from dead matter and the proportion of plant components with >80 % digestibility implied that DDM yield with plant components likely to be preferred by stock would be obtained if Russell lupins were harvested at full bloom. Gladstones (1970a) also recommended grazing of lupins before the end of flowering.

However, the decision on harvest date will also depend on the class of livestock to be fed. Hence, the extra DM yield obtained at the second peak DDM yield (Fig. 3.19b), when Russell lupins were at the dry pod stage, could be used to advantage if fed to animals on maintenance level of feeding, which can meet their requirements from feeds with digestibility even as low as 45 to 50 % (Ulyatt, 1973). The whole plant digestibility at the first peak DDM yield (i.e. 70 %) met the level of digestibility recommended (Ulyatt, 1973) for high producing class of livestock.

3.5. CONCLUSIONS

Russell lupins produced good quality (2.4 to 4.2 % N; 56 to 77 % DMD) DM over most of its growth period. They accumulated more than 75 % of their maximum DM (16 t ha^{-1}), N (3.9 t ha^{-1}), and DDM (9 t ha^{-1}) yield by full bloom. Up to pod development, these yields were largely from petioles and leaves. Later, stems, pods and dead matter assumed an increasingly higher proportion of total yield per plant. However, it should be noted that these lupins were regrowth plants, and that the pattern of DM accumulation may differ for first growth plants.

The change in nitrogen and cell wall concentration, and cellulase digestibility of Russell lupins was governed by changes in the proportion of plant components and changes in the composition and digestibility of these components. Changes in the proportion of plant components, their chemical composition and digestibility occurred in a way that minimised rapid decline in total herbage quality with plant maturity. That is, Russell lupin leaves which maintained their quality and, to a lesser extent quantity, over the aging process diluted the effect of rapid decline in stem quality. When the proportion of leaves later dropped decrease in quality was minimised by the late developing pods, which

were high in N and initially highly digestible. Consequently, Russell lupins produced highly digestible DM with low fibre (despite being a browse sp.) and high N content (≥15 % CP) over most of their growth period. Further work is needed to confirm the high N concentration found in the dead matter, which was probably due to lack of complete translocation of nutrients from dead tissue.

Although there were two very similar peak DDM yields observed during the spring-summer growth of Russell lupins, the first peak (89 g plant^{-1} at full bloom) contained a greater proportion of plant components that are more likely to be preferred by grazing animals. Accordingly, it was concluded that better utilisation may be achieved if Russell lupins were harvested at full bloom. However, grazing by animals on a maintenance level could provide an opportunity to use the extra DM yield obtained at the second peak DDM. Furthermore, in terms of opportunity cost, harvest at the second peak is likely to give Russell lupins an advantage as very few species produce DM yield of similar quality later in the season. Therefore, the final decision will depend on the feed plan of the farmer.

Besides digestibility and yield of digestible DM, the acceptability of these lupins may also be affected by their alkaloid content. Hence, further work is needed to define stock acceptability of Russell lupins at the stages which gave peak DDM. The optimum stage of harvest should also be weighed against the opportunity for adequate autumn regrowth.

CHAPTER FOUR

4. EXPERIMENT II: ACCEPTABILITY, HARVESTABLE YIELD, AND REGROWTH OF RUSSELL LUPINS.

4.1. INTRODUCTION

Despite reports on various agronomic merits of Russell lupins, there is no quantitative data on acceptance and harvestible yield of Russell lupins by livestock. The report by Scott (1989) describes the seasonal acceptance of different parts of Russell lupins but did not provide any quantitative comparison; neither did it compare acceptance within a season in relation to stage of growth. Gymptsho (1987) suggested that from 5,570 kg DM ha^{-1} produced by Russell lupins, 4530 kg ha^{-1} was 'browsable'. This assumption was based on an arbitrary definition that fine stem and leaf would be browsable as the study did not involve grazing by sheep.

In Experiment I it was found that Russell lupins achieved most of their potential DM yield by full bloom. It was also found that there was little, if any, increase in DM yield of high nutritional quality by harvesting Russell lupins after full bloom. When cut at full bloom they produced up to 89 g cellulase digestible DM per plant. At 10 plants m^{-2} the potential cellulase digestible DM yield was estimated to be about 9 000 kg ha^{-1}.

There is no published information on whether the optimum stage of nutrient yield determined by chemical analysis coincides with the stage when the lupins are most acceptable to grazing sheep. There is also the question of whether plant parts that composed most of the *in vitro* cellulase digestible DM yield were parts that would be readily eaten by sheep.

Therefore, an experiment was set out with the following objectives:

(1). To compare the pattern of defoliation of Russell lupins by sheep as they progressed from full bloom to late bud.

(2). To determine the preference of sheep for different plant parts of Russell lupins, and the changes in preference with plant maturity from flowering to dry pod stage.

(3). To compare regrowth of lupins grazed at different growth stages.

(4). To determine the optimum growth stage for grazing Russell lupins based on harvestible DOM yield, acceptance by sheep, and therefore to establish the amount of regrowth following grazing.

4.2. MATERIALS AND METHODS

4.2.1. Experimental site.

The trial was conducted in Canterbury in the South Island of New Zealand (43^{R}38'S.) at Henley (Block H5), Lincoln University, on a Templeton silt loam soil (Soil Bureau, 1954). The paddock was in Tama ryegrass (*Lolium mulltiflorum*) seed crop in 1989. The land was ploughed, harrowed and rolled on the 2nd of March, 1990. The soil was sprayed with Trifuralin (400 g active ingredient per ha) applied at the rate of 3 l ha^{-1} in 360 l water ha^{-1}. It was then power harrowed and rolled on the 6th of March, 1990. An area of 0.77 ha (61 x 126 m) was sown to Russell lupins, drilled with a cone seeder, on 7 March 1990.

4.2.2. Plants

The plants used in this trial were naturalised New Zealand Russell lupins (Connie lupins) (*Lupinus polyphyllus x Lupinus arboreus*). Prior to sowing seeds were scarified by soaking in concentrated sulphuric acid (36N). Seeds were placed in perforated pots and

soaked in the acid for 45 minutes (Tesfaye, 1989) using two volumes of acid to one volume of seed (Hartman and Kester, 1968).

4.2.3. Animals

Each plot was grazed by a mob of 20 two-tooth (16 months old) Coopworth ewes of average weight 40.2 kg. Prior to and between grazings the sheep were kept on maintenance feeding on ryegrass/white clover pasture. They were not fasted prior to transfer to Russell lupins. Water was supplied *ad libitum*.

4.2.4. Experimental layout

The trial was a 2 by 3 randomised complete block with two replicates and three growth stages. The three growth stages were full bloom, green pod and the dry pod stage. To distinguish whether lupin consumption at the green and/or dry pod stage was due to change in growth stage or to previous exposure of sheep to lupin consumption, accustomed (sheep which had previously consumed lupins) and unaccustomed (sheep which had not previously consumed lupins) sheep were used in the last two grazings. The accustomed sheep in both the second and third grazing were sheep that were used in the first grazing.

The total area of lupins was divided into two replicates each with three 38 by 44 m plots. Each plot was randomly assigned to grazing at any one of the three stages. Then, each plot was divided into two plots (19 x 22 m) and randomly assigned to grazing by accustomed and unaccustomed sheep. Since the first grazing did not require accustomed sheep the plots assigned to grazing by sheep accustomed to lupin feeding were left ungrazed.

4.2.5. Allowance, duration and time of grazing.

The DM requirement of ewes was calculated by using the ARC (1980) formulae, i.e.

$$I_T = M_E / 18.4q$$

where I_T = Dry matter intake required (kg day^{-1}), M_E = requirement for metabolisable energy (MJ day^{-1}), 18.4 is the gross energy content of the feed and differs for different feeds, and q = metabolisability of the feed.

Since there was no information on Russell lupins the gross energy content and metabolisability of *L. angustifolius* from MAFF (1977) was used in the calculation. Accordingly the maintenance requirement of the ewes was calculated to be 0.48 kg DM day^{-1}.

The amount of DM per plot available before the beginning of each grazing was expected to differ. Therefore, it was intended to adjust the amount of DM ewe^{-1} day^{-1} by varying the duration of grazing. It was not possible to increase the number of sheep per plot and variation of plot size was undesirable. Sheep were removed from the plots when there was insufficient material (visually estimated) for another day of grazing.

The three grazings periods were:

Full bloom stage (265 days after sowing): 27 Nov - 3 Dec 1990

Green pod stage (285 days after sowing) : 17 Dec - 24 Dec 1990

Dry pod stage (313 days after sowing) : 21 Jan - 26 Jan 1991

4.2.6. Plant sampling

The amount of DM on offer at each grazing and the rate of disappearance of DM during each grazing was estimated on 15 plants $plot^{-1}$ cut to ground level with a grass cutter. The fresh weight of each plant was recorded. Dry matter content was determined by drying a random sample of 2 plants per replicate in a forced draught oven at 70RC for a minimum of 48 hours.

The rate of disappearance of plant parts was determined by dissecting randomly selected samples. Five plants per replicate were dissected into stem, petiole, leaf, flower, pod and dead matter (see Section 3.1.3 for description of these parts). The dry matter content of each plant part was determined by drying duplicate 0.5 g of each part as above. The rest of the material from dissection was freeze-dried and stored for chemical analyses and determination of *in vitro* cellulase dry matter and organic matter digestibilities.

All samples used for determination of chemical composition and digestibility were ground through a 1 mm screen. Whole plant chemical composition and digestibility was calculated from that of plant parts.

4.2.7. Chemical analysis

(i). Nitrogen. The N concentration of samples was determined as described in Section 3.1.5.

(ii). Neutral detergent fibre. Neutral detergent fibre content of samples was determined as in Section 3.1.6.

4.2.8. *In vitro* digestibility

The *in vitro* cellulase dry matter and organic matter digestibilities of samples were determined as in Section 3.1.7.

4.2.9. Measurement of regrowth

The amount of regrowth eight weeks after sheep were removed was measured by cutting 15 plants $plot^{-1}$. The regrowth measurements were made on 3 February 1991, 24 February 1991, and 26 March, 1991 for lupin plots grazed at full bloom, green pod and dry pod stages respectively. All plots were sampled again on 29 April 1991 to measure DM yield before the beginning of winter.

4.2.10. Statistical analyses.

Data were analysed by using the statistical procedures described in Section 3.1.8.

4.3. RESULTS

4.3.1. Climate data.

Temperature and rainfall data for the site for the year 1991 is presented in Fig. 4.1 (See Figs. 3.1 and 3.2 for previous years). There was no major difference in rainfall and temperature over the three grazing periods, except 20 mm of rain one day before the third grazing was completed.

4.3.2. Pattern of defoliation and disappearance of plant parts

(i). Full bloom stage.

A general view of the trial is shown in Plate 4.1a. Based on 4 quadrat (0.5 m^2) cuts per plot weeds made up 23.5 % of total DM m^{-2}. Initially, sheep ate weeds growing between and within rows of lupins (Plates 4.1b). As a result there was a very slow initial rate of defoliation of the Russell lupins followed by a very rapid removal. This produced a highly significant ($P<0.001$) quadratic relationship between the amount of residual DM (measured at intervals) and the number of days of grazing (Equation 4.1, Fig. 4.2a).

$$y = 23.93 + 0.319x - 0.647x^2 \quad (P<0.001,\ R^2 = 0.98,\ S.E.E. = 1.61) \qquad \textbf{(4.1)}.$$

where y = g DM $plant^{-1}$, and x = Number of days from the beginning of grazing.
When grazing stopped on day 6, 88.9 % of lupin DM on offer had disappeared, and the plots were almost bare (residual ≃ 2.5 g/plant or 250 kg/ha) (Fig. 4.2a; Plate 4.1c).

The commencement of defoliation and the rate of disappearance differed among the different plant components. Leaves were the first to be consumed, and they disappeared faster and earlier than any other plant part (Fig. 4.2b). Petiole consumption

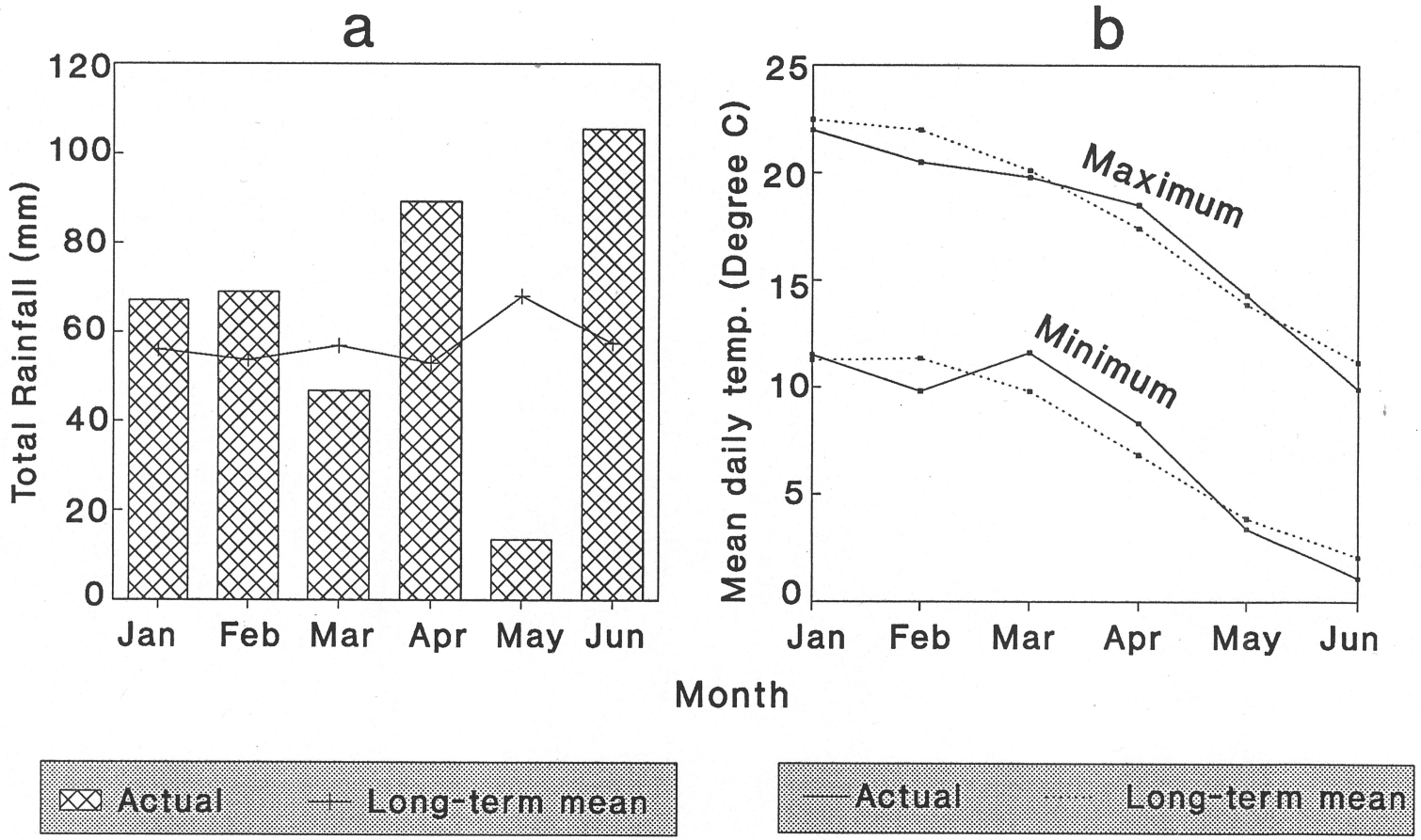

Fig. 4.1. Total rainfall (a) and mean daily maximum and minimum temperature (b) for the first six months of 1991.

a. Beginning of grazing (27 Nov. 1990)

b. After two days of grazing (29 Nov. 1990)

c. End of grazing (03 Dec 1990)

Plate 4.1. General view of plots on different days of grazing at full bloom.

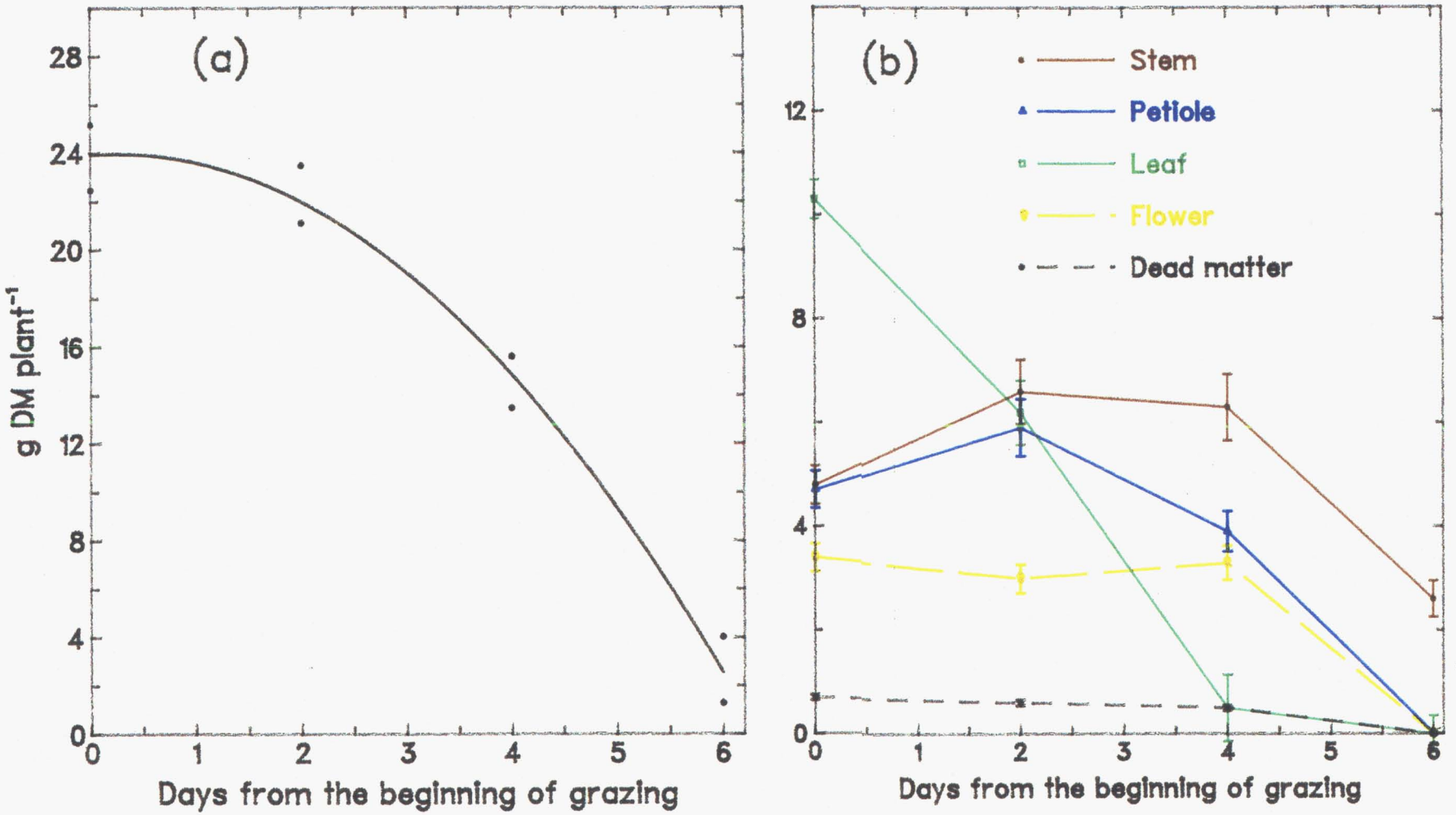

Fig. 4.2. The pattern of disappearance of (a) whole plant ($y = 23.93 + 0.319x - 0.647x^2$ $P<0.001$ $R^2 = 0.98$) and (b) plant parts over successive days of grazing at full bloom.

started day 2, while stem and flowers showed no decline until after the fourth day of grazing. By the final day all plant parts except the stem had completely disappeared from the plant (Fig. 4.2b). At final sampling of residual DM it was not possible to collect dead leaves and petioles as they were broken into fine particles and mixed with other dead weed materials due to trampling.

The proportion of plant components in the residual DM and DM disappeared during grazing clearly displayed the preference of sheep for different plant parts (Fig. 4.3). Leaves were the most preferred parts. They composed 77 and 66 % of total DM disappeared after the first two and four days of grazing, respectively which was more than twice the proportion of leaves in total DM on offer (Fig. 4.3) (N.B. Residual DM on day 0 was DM on offer for day 2 and so on). In contrast, the proportion of stem in DM disappeared was far less than it was in DM on offer (e.g. 0 vs. 20 % for day 2). The percentage of petioles and flowers, and to a lesser extent stems, in DM disappeared increased after most of the leaves had disappeared (Fig. 4.3). The proportion of petioles in DM disappeared on day 6 became higher than it was in DM on offer. The effect of such systematic disappearance of plant parts on the chemical composition and digestibility of herbage over successive days of grazing is presented in Section 4.3.4.

(ii). Green pod stage

At this stage, all plants had produced pods on their main stems although there were still some flowers present. Within the first day of grazing, sheep had removed all the weeds and started eating lupins. There was slightly less residual DM on plots grazed by accustomed sheep than on those grazed by unaccustomed sheep (Fig. 4.4). Nevertheless, none of the differences were significant ($P>0.05$). Therefore, data from plots grazed by accustomed and unaccustomed sheep were combined for statistical analysis.

At this stage, with successive grazing, there was a rapid linear decline in the amount of residual DM as opposed to the slow and quadratic decline at full bloom stage (Fig. 4.5a vs. 4.2a). Sheep removed about 5.8 g DM plant^{-1} day^{-1} (Equation 4.2), after seven days grazing DM per plant had fallen from 49 to 8 g (Fig. 4.5a). The rate of DM disappearance was faster ($P<0.01$) than at the full bloom stage.

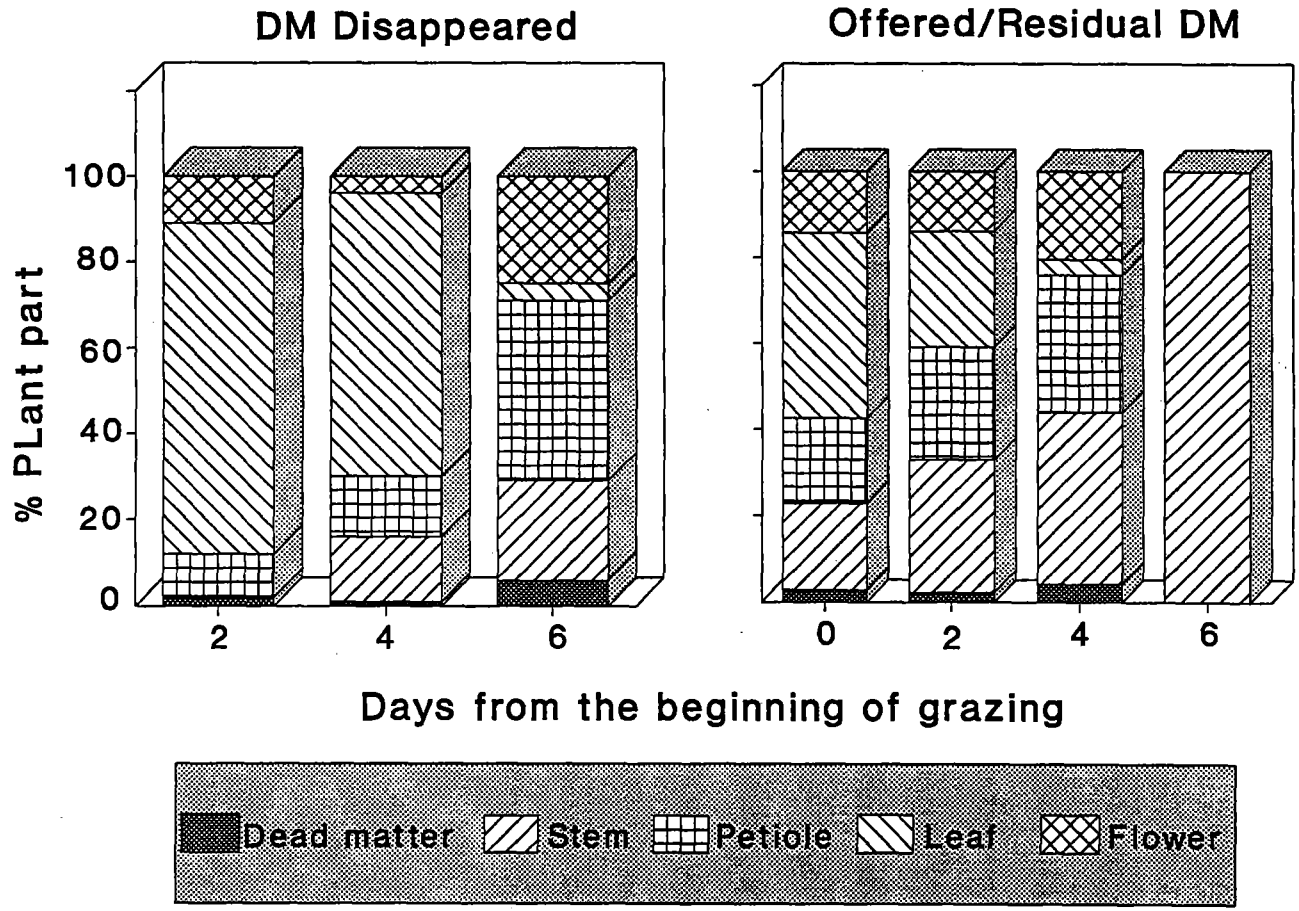

Fig. 4.3. Proportion of plant parts in DM offered, DM disappeared and residual DM when Russell lupins were grazed at full bloom.

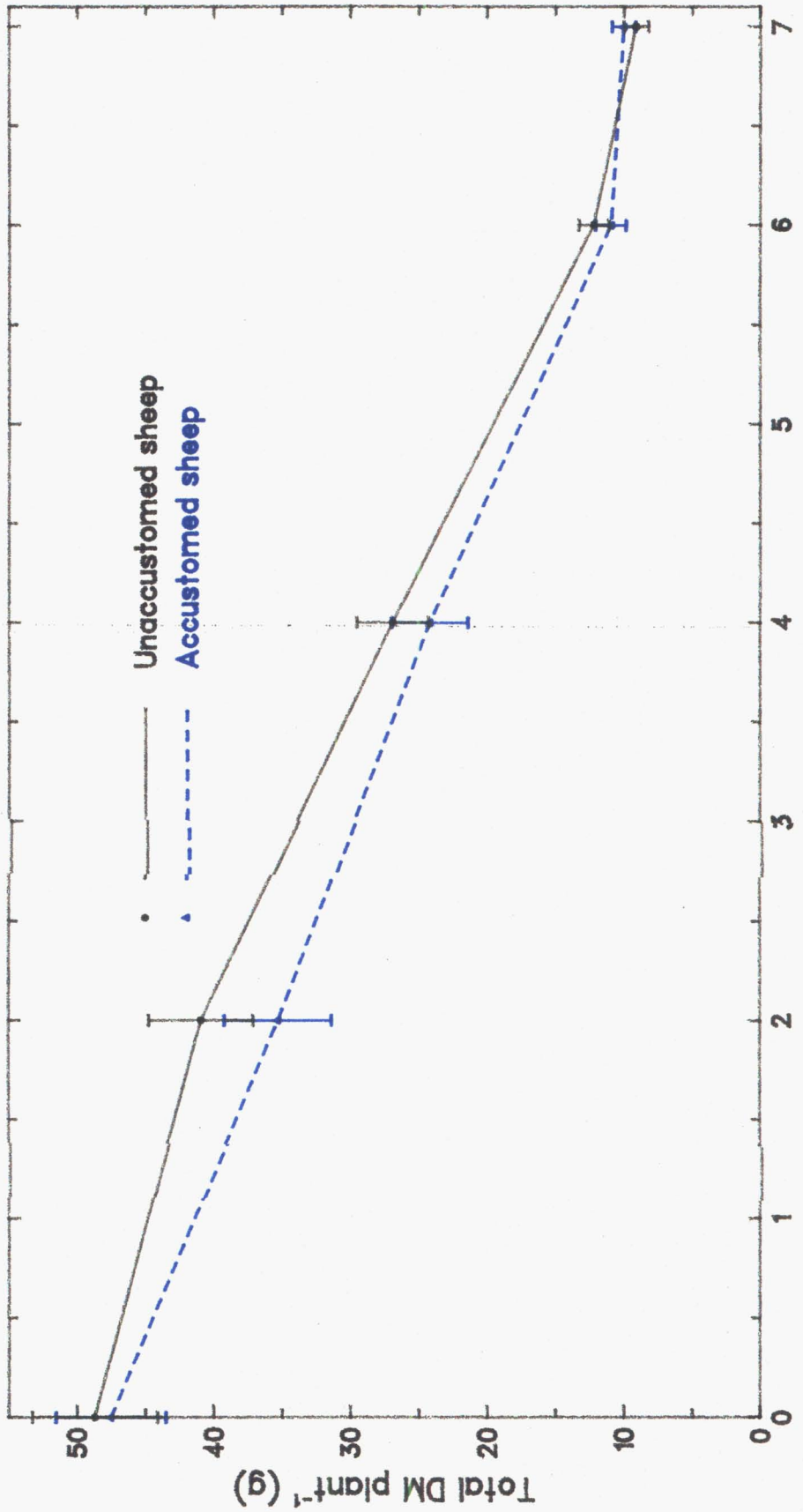

Fig. 4.4. Comparison of defoliation over successive days of Russell lupins by accustomed and unaccustomed sheep at green pod stage.

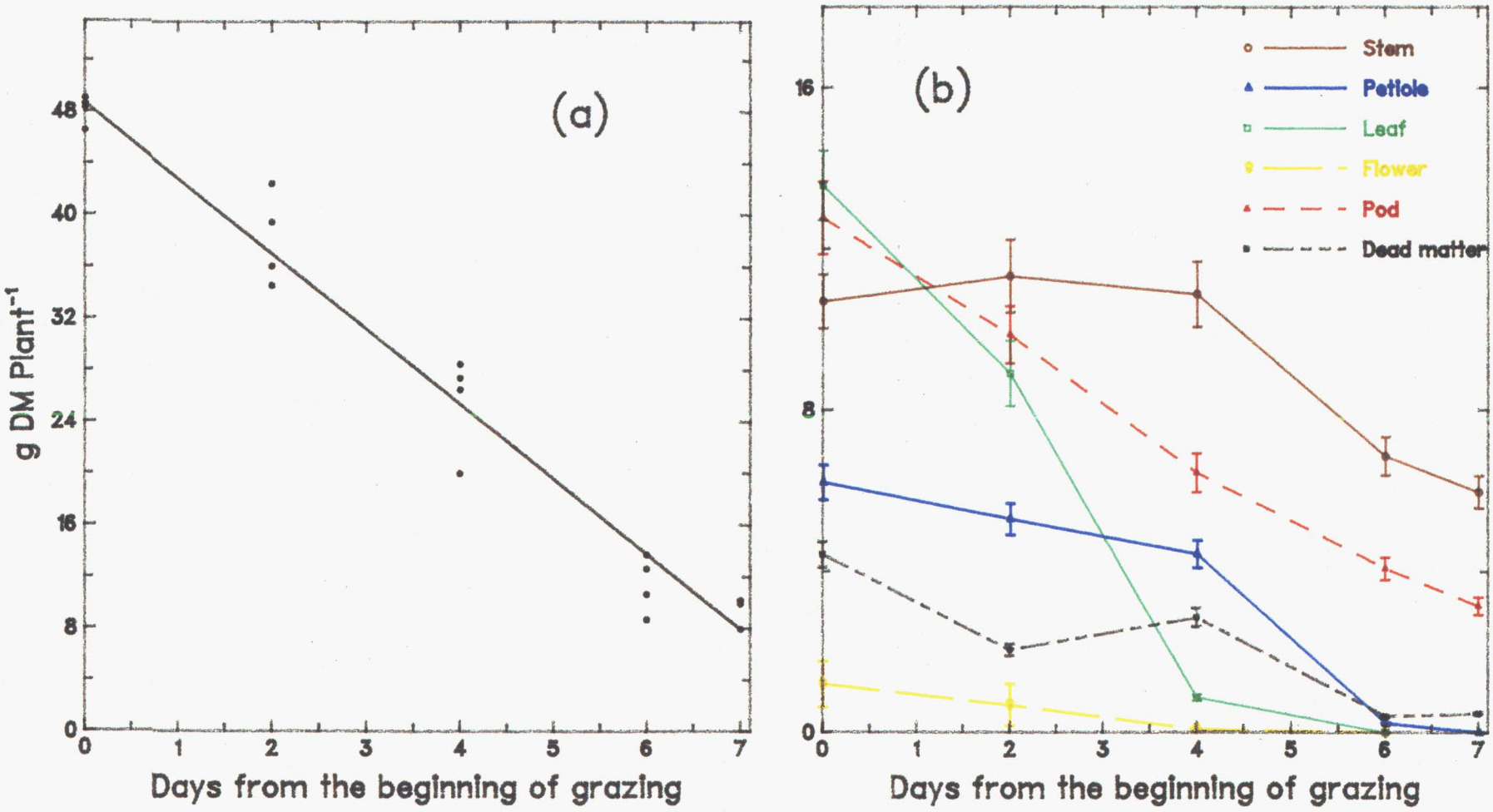

Fig. 4.5. The pattern of disappearance of (a) whole plant ($y = 48.64 - 5.81x$, $P<0.001$, $R^2 = 0.97$) and (b) plant parts over successive days of grazing at green pod.

$$y = 48.64 - 5.81x \quad (P<0.001,\ R^2 = 0.97,\ S.E.E.= 2.81). \qquad (4.2).$$

With individual plant components, leaves again were the plant part that were removed very rapidly and they disappeared before any other plant part (Fig. 4.5b; Plate 4.2). They composed the majority of disappeared DM at the early stages, and there was a greater proportion of leaves in DM disappeared than in DM on offer (Fig. 4.6). All plant parts, except stems, showed a decline in DM yield by the second day of grazing (Fig. 4.5b). The DM from stems did not show any decline until after the fourth day when almost all the leaves and flowers had gone, and other parts had been significantly reduced (Fig. 4.5b). As with the previous grazing, the proportion of stems was always greater in DM offered than in DM disappeared (Fig. 4.6). Interestingly, the contribution of pods to disappeared DM was second only to that of leaves during the first four days of grazing; later it made up to 46 % of DM disappeared (Fig. 4.6). The contribution of flowers to disappeared DM was 2 to 5 %. By the last grazing day both disappeared and residual DM were mainly composed of pods and stems (Fig. 4.6).

The amount of DM (g) removed from individual plant parts in a day's grazing was higher than it was at the full bloom stage. Results from quadrats cut (five 0.5 m^2 quadrats $plot^{-1}$) to cross-check the amount of pods left on the ground agreed with the estimates on a per plant basis. It was estimated that when grazing stopped about 80 % of the herbage on offer had disappeared.

(iii). Dry pod stage

At this stage pods were dry and some had already shattered (Plate 4.3). As at the green pod stage, accustomed and unaccustomed sheep did not remove significantly different amounts of lupins. Therefore, analyses were done on the combined data.

Like the green pod stage, there was a rapid linear decline in residual DM as described by Equation 4.3 (see also Fig. 4.7a). Over the whole period the rate of DM disappearance was about 14.5 g $plant^{-1}$ day^{-1} (Equation 4.3).

Plate 4.2. Residual herbage remaining after four days of grazing at green pod (21 Dec. 1990).

Plate 4.2. General view of lupins on day 1 of grazing at dry pod (21 Jan. 1991).

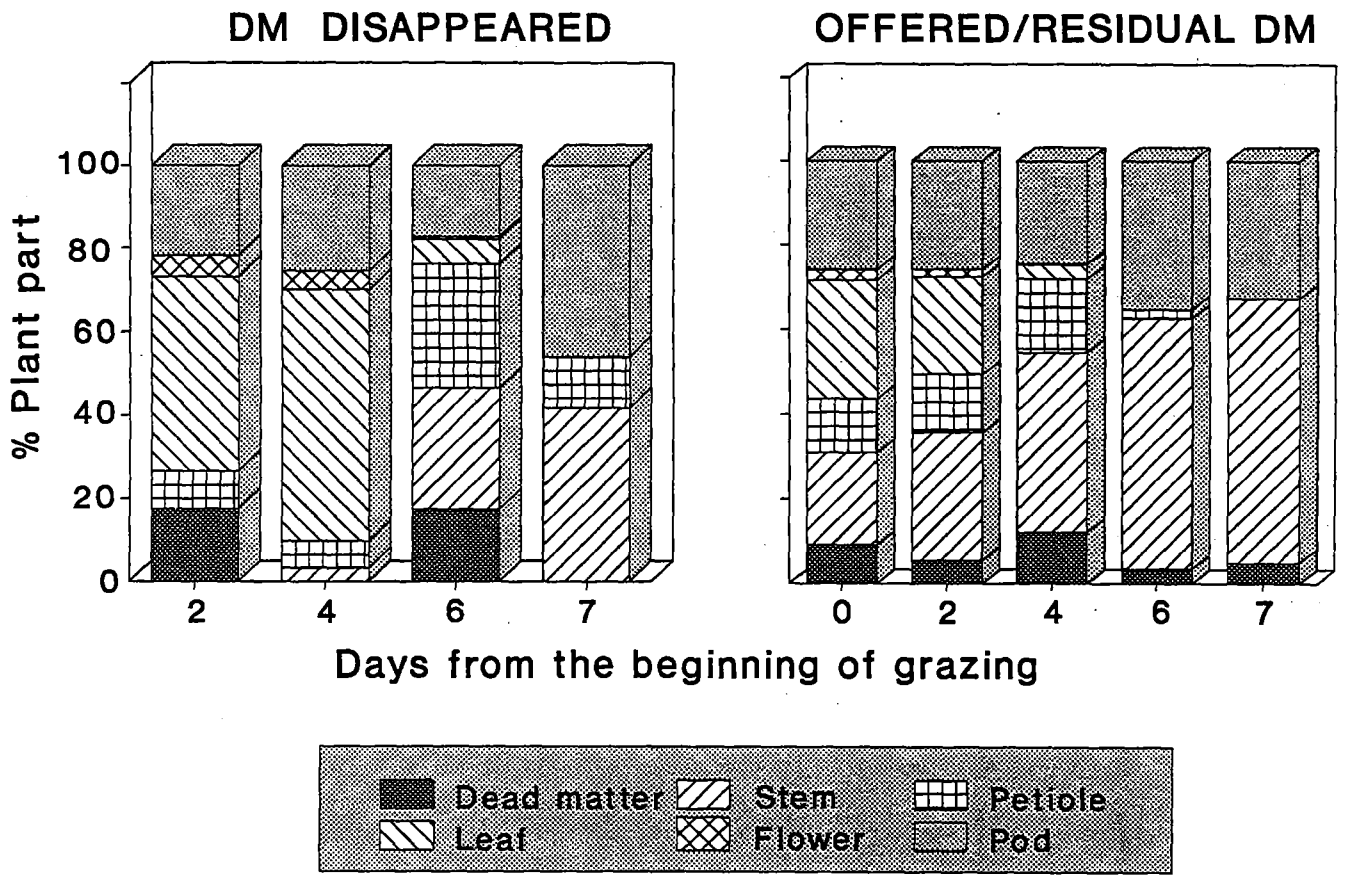

Fig. 4.6. Proportion of plant parts in DM offered, DM disappeared and residual DM during grazing at green pod stage.

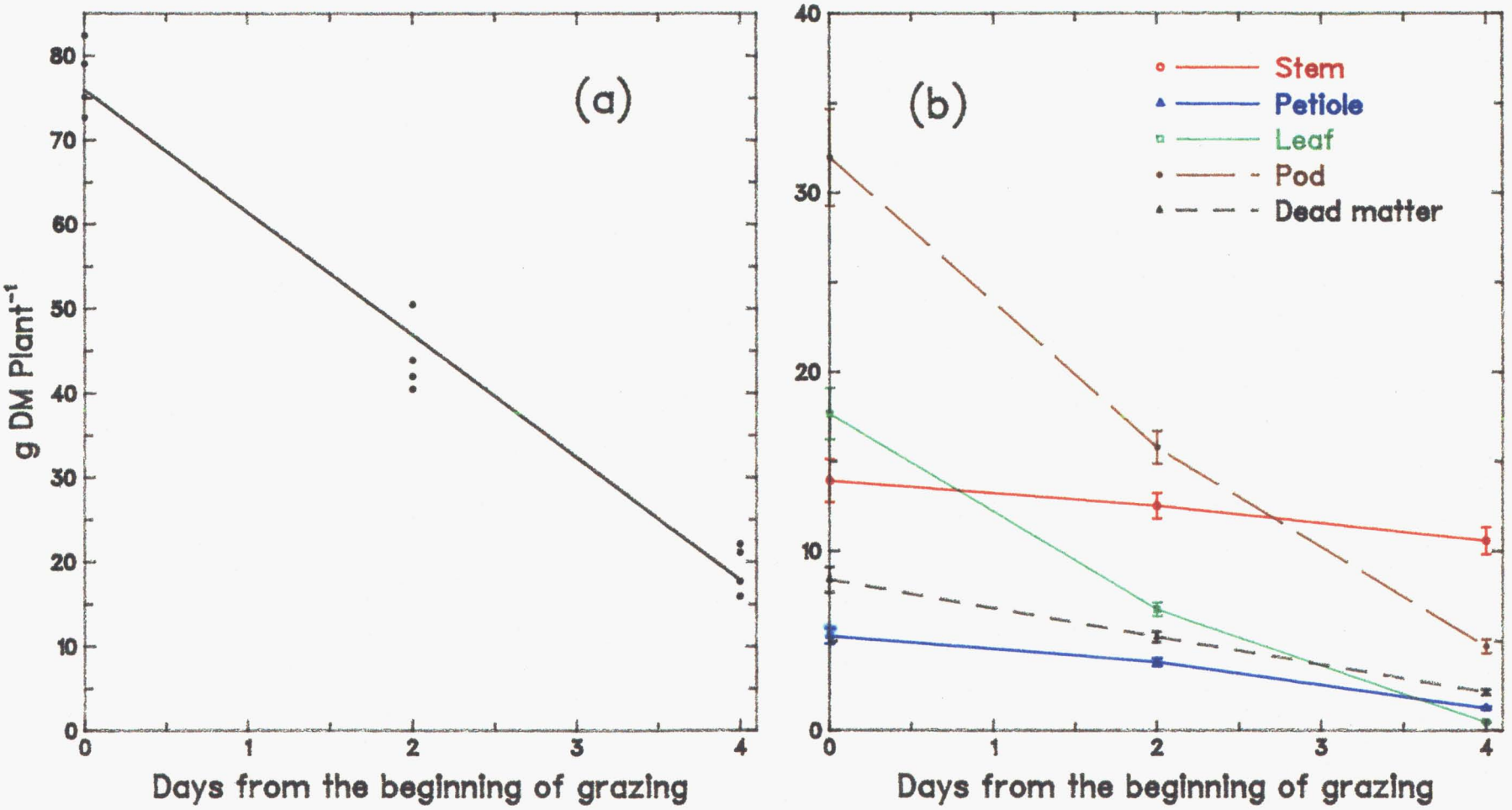

Fig. 4.7. The pattern of disappearance of (a) whole plant ($y = 75.96 - 14.53x$, $P<0.001$, $R^2 = 0.92$) and (b) plant parts over successive days of grazing at dry pod.

$$y = 75.96 - 14.53x \quad (P<0.001,\ R^2 = 0.92,\ S.E.E.= 7.85) \qquad (4.3).$$

When grazing was completed about 75 % of the DM on offer had disappeared, and DM plant^{-1} had fallen from about 76 to 18 g plant^{-1} (Fig. 4.7a).

At this stage most of the yield was in pods (Fig. 4.7b). However, there was still more g DM of leaf per plant than at the previous stages (Fig. 4.7b vs. Figs. 4.2b & 4.5b). All parts were rapidly removed except stems which dropped by only 3.6 g over the whole period (Fig. 4.7b). Like the previous stage of grazing, there was significant consumption of pods; pod DM decreased from 32 to 5 g plant-^{1} (Fig. 4.7b). A cross-check on the amount of pods left by quadrat sampling slightly increased the estimate of pods left ungrazed (Fig. 4.7b). However, the means of the two samples were not significantly different (P>0.05). Collection of seeds fallen to the ground was impracticable; it is conceded that the disappearance of pods may have been overestimated.

As opposed to the previous grazings, leaves were not the major contributors to disappeared DM (Fig. 4.8). Still, there was a greater proportion of leaves in disappeared DM (33 %) than in DM on offer (22 %). The reverse was true for stems. Pods made up about 50 % of DM disappeared, which was higher than their proportion in DM offered, during the four days of grazing (Fig. 4.8). Stems composed the largest proportion of the final residual DM followed by pods (Fig. 4.8).

4.3.3. Rate of total DM disappearance and utilisation

A comparison of rate of disappearance and apparent utilisation of DM and DDM at the three grazings is summarised in Table 4.1. The amount of DM on offer, DM daily disappeared, and DM left ungrazed increased as the lupins progressed from full bloom to dry pod stage (Table 4.1). Consequently, the percentage apparent utilisation dropped from nearly 90 % to 75 %. One main feature to emerge from this trial was that there was significant consumption of both green and dry pods. To confirm this point the rate of total

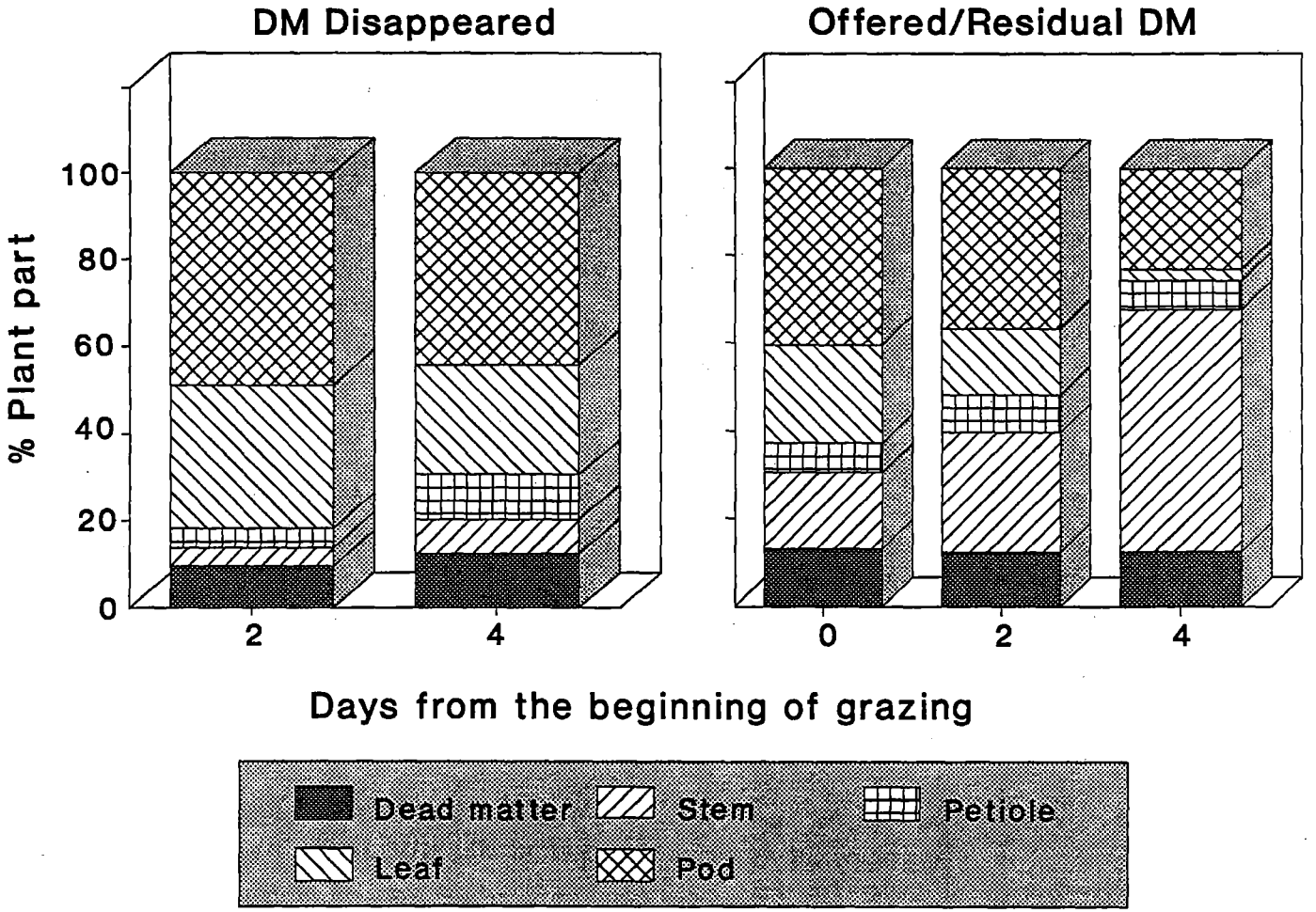

Fig. 4.8. Proportion of plant parts in DM offered, DM disappeared and residual DM when Russell lupins were grazed at dry pod stage.

Table 4.1. Comparison of dry matter disappearance and apparent utilisation when Russell lupins were grazed at three growth stages (N.B. Figures in brackets refer to digestible DM).

Stage	Total offered kg ha^{-1}	Residual kg ha^{-1}	Amount disappeared kg ha^{-1}	kg sheep^{-1}d^{-1}	App. utilisation$^{\Psi}$ (%)
1	2390(1800)	270 (170)	2120(1630)	0.74 (0.57)	88.9
2	4810(3290)	960 (550)	3850(2740)	1.15 (0.82)	80.0
3	7730(4870)	1920 (1010)	5810(3860)	3.03 (2.02)	75.1
			Excluding pod		
2	3530(2410)	640(370)	2890(2040)	0.86(0.61)	81.8
3	4530(2850)	1450(760)	3080(2090)	1.61(1.09)	68.0

$^{\Psi}$Apparent utilisation (%) refers to the difference between DM on offer and residual DM expressed as a percentage of DM on offer.

DM disappearance and the percentage of herbage on offer which disappeared during grazing was calculated with and without pods (Table 4.1). For grazing at green pod stage, the exclusion of pods had no effect on per cent utilisation. On the contrary, at the dry pod stage, when pods were excluded per cent utilisation fell from 75 to 68 %. This was because at the dry pod stage the sampling of residual herbage did not accommodate seeds that fell to the ground through trampling and pod shatter. Consequently, at the dry pod stage the amount of DM apparently eaten sheep^{-1} day^{-1}, at 3 kg (Table 4.1), was grossly exaggerated for two-tooth ewes with an average weight of 40.2 kg. The apparent utilisation of pods at the dry pod stage could be misleading because it did not take into account seeds fallen to the ground which may or may not have been picked by sheep.

4.3.4. Composition and digestibility of residual herbage and herbage disappeared during grazing

As presented above there was uneven disappearance of plant parts which produced a marked change in composition and digestibility of DM on offer, DM disappeared and residual DM with successive grazing. The pattern of these changes for each grazing is summarised in Table 4.2. At all the three grazings, with successive days of grazing, the N concentration and *in vitro* cellulase digestibility of residual herbage decreased by about 50 % while its NDF concentration increased by a similar proportion (Table 4.2). With progressive defoliation, sheep removed parts high in N and DM digestibility and low in NDF. Consequently, at all plant growth stages NDF concentration was higher and DM digestibility lower for herbage on offer than for herbage removed by the sheep (Table 4.2). Although the same was also true with respect to N concentration at the first and the last grazing, the difference was not consistent at the second grazing (Table 4.2).

Change in composition and digestibility of herbage on offer and herbage apparently removed by sheep for the pooled data is presented in Figure 4.9. Generally, the difference between the composition of herbage on offer and herbage apparently removed by sheep became less as the duration of grazing increased (Fig. 4.9). The N concentration and DMD of both herbage on offer and herbage disappeared declined, but their NDF

Table 4.2. Change in the composition and digestibility of herbage disappeared and left ungrazed over successive days of grazing at three growth stages.

	DAY	RESIDUAL DRY MATTER			DRY MATTER DISAPPEARED¶		
		N	NDF	DMD	N	NDF	DMD
				FULL BLOOM			
	0	2.7	26.8	75.2			
	2	2.4	31.3	72.7	3.4	15.5	81.2
	4	2.2	36.5	69.8	2.8	21.3	78.3
	6	2.0	45.4	63.7	2.3	34.7	71.1
L.S.D		0.57	4.19	4.23			
CV (%)		7.7	3.8	1.9			
				GREEN POD			
	0	2.67	38.9	68.3			
	2	2.87	43.1	65.4	2.6	28.2	72.5
	4	1.76	46.5	59.6	2.9	24.5	76.5
	6	1.83	49.5	58.1	1.7	44.1	60.9
	7	1.78	50.0	57.5	2.1	47.2	60.7
L.S.D.		0.33	5.11	2.59			
CV (%)		9.9	7.4	2.8			
				DRY POD			
	0	2.00	41.8	63.0			
	2	1.76	45.5	60.0	2.3	36.8	67.1
	4	1.29	53.4	52.5	2.1	39.4	65.0
L.S.D		0.1	2.67	1.19			
CV (%)		3.7	3.5	1.24			

¶ The composition and digestibility of residual DM on day 0 was the composition and digestibility of herbage on offer for day 2, and so on.

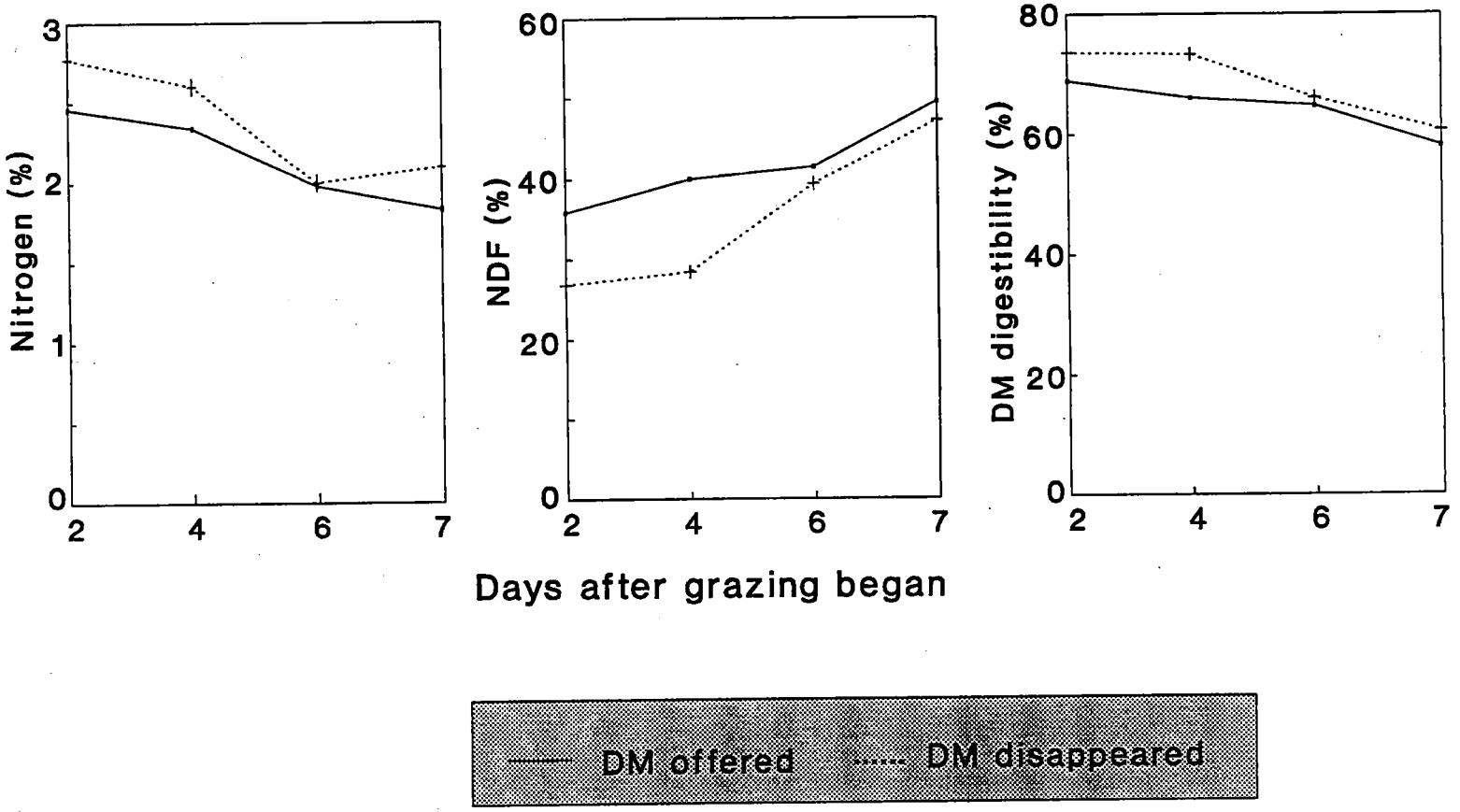

Fig. 4.9. Changes in the composition and digestibility of DM offered and DM disappeared combined from the three grazings.

concentration increased with successive grazing (Fig. 4.9). The results clearly indicated that the sheep selected DM of higher nutritional quality, especially over the first four days, than the DM on offer. However, as the amount of DM on offer and the availability of preferred parts became less with increased duration of grazing, the composition and digestibility of herbage removed (apparently by grazing) was very close to that of herbage on offer.

4.3.5. Plant regrowth.

The amount of regrowth produced, excluding residue, by the lupins before the start of winter clearly distinguished the three grazing stages. Lupins grazed at full bloom stage gave the highest amount of regrowth (Fig. 4.10). The maximum DM yield obtained from regrowth was 70 g DM per plant. Lupins grazed at full bloom completed another growth cycle, and had reached dry pod stage by 29 April, 1991. The combined DM yield from the two harvests was 9.5 t ha^{-1}.

Lupins grazed at the green pod stage produced just over half the DM yield (37.7 g DM $plant^{-1}$) of lupins grazed at full bloom. The combined DM yield for lupins grazed at green pod was 8.6 t ha^{-1}. Lupins grazed at the dry pod stage showed the least regrowth; DM yield increased by only 3.6 g $plant^{-1}$ over more than 3 months (Fig. 4.10). Although the combined DM yield, at 8.2 t ha^{-1}, was not much lower than that obtained at the second grazing, DM from regrowth was only 5 % of the combined yield. This was despite these lupins having the highest residual DM after grazing.

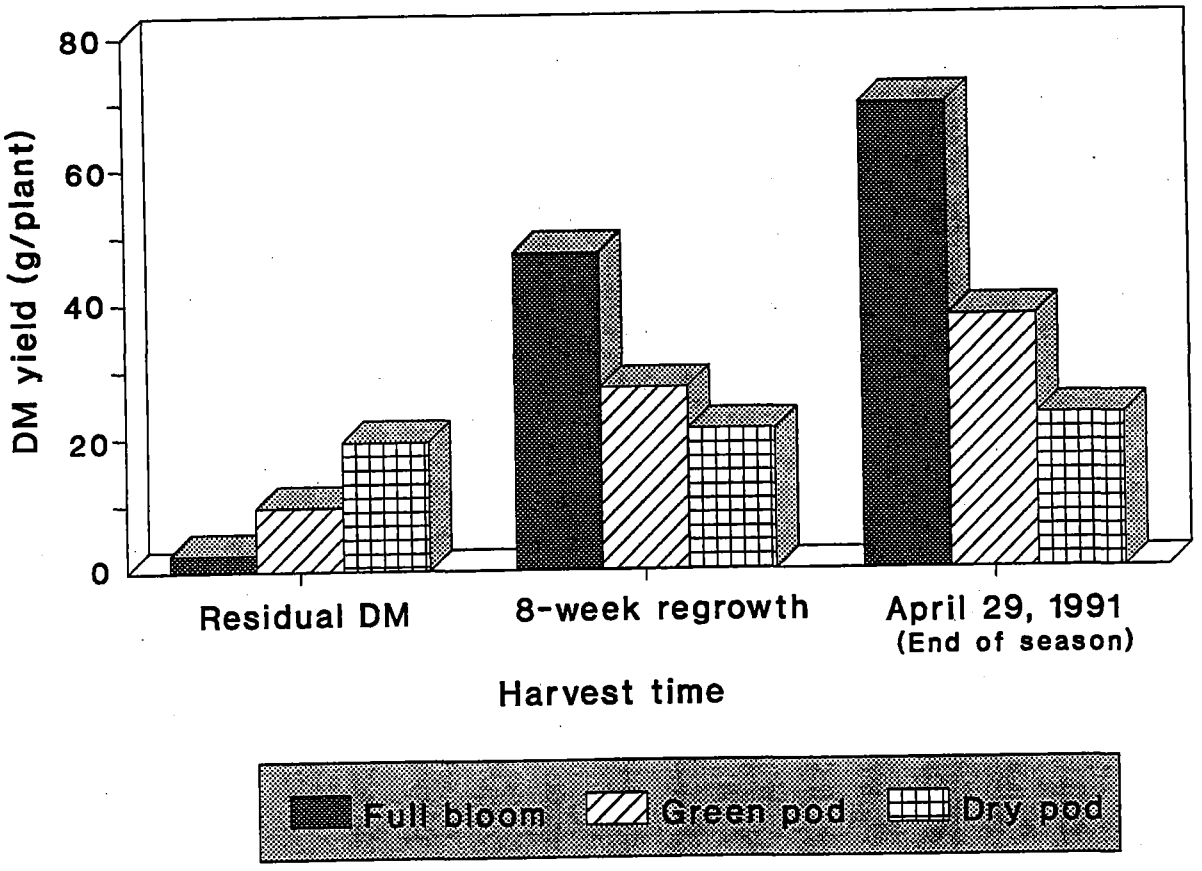

Fig. 4.10. The amount of residual DM remaining for regrowth and the amount of regrowth obtained from lupins grazed at three different growth stages.

4.4. DISCUSSION

4.4.1. Pattern of defoliation

Although sheep took a longer period to remove the harvestable yield at the full bloom stage, across growth stages the general pattern of grazing was as commonly observed on other forage species. That is:

(1). With increase in allowance, as a result of the increase in DM yield per ha across harvest dates, there was an increase in apparent intake though the increase appeared linear presumably due to excessive trampling losses at the third grazing artificially inflating apparent intake (Fig. 4.11a).

(2). There was increase in residual DM/ha as DM/ha on offer increased with increase in DM yield per ha across harvests (Table 4.3).

(3). There was a decline in per cent utilisation as both allowance and residual herbage increased and quality of herbage on offer decreased between consecutive grazings.

Across growth stages there were similarities and differences between the results of this grazing and that of Burtt and Hill (1990a), who conducted a grazing study on Uniharvest lupins at the same site. I calculated rate of disappearance, relationship between intake and allowance, relationship between pre- and post-grazing mass for Uniharvest lupins from Burtt and Hill's data, and thus any computational errors, if found, are mine.

Before pursuing these comparisons, there is a very important point that needs to be mentioned about calculation of average allowance and apparent intake. In comparing data from the two trials, average allowance was calculated as follows:

Mean daily allowance = $((H_0/N) + (H_1/N) + (H_2/N) + ... + (H_n/N))/n$.

where H_0 = Herbage mass on day 0, ..., H_n = Herbage mass on day n; N = No. of sheep; n = duration of grazing in days.

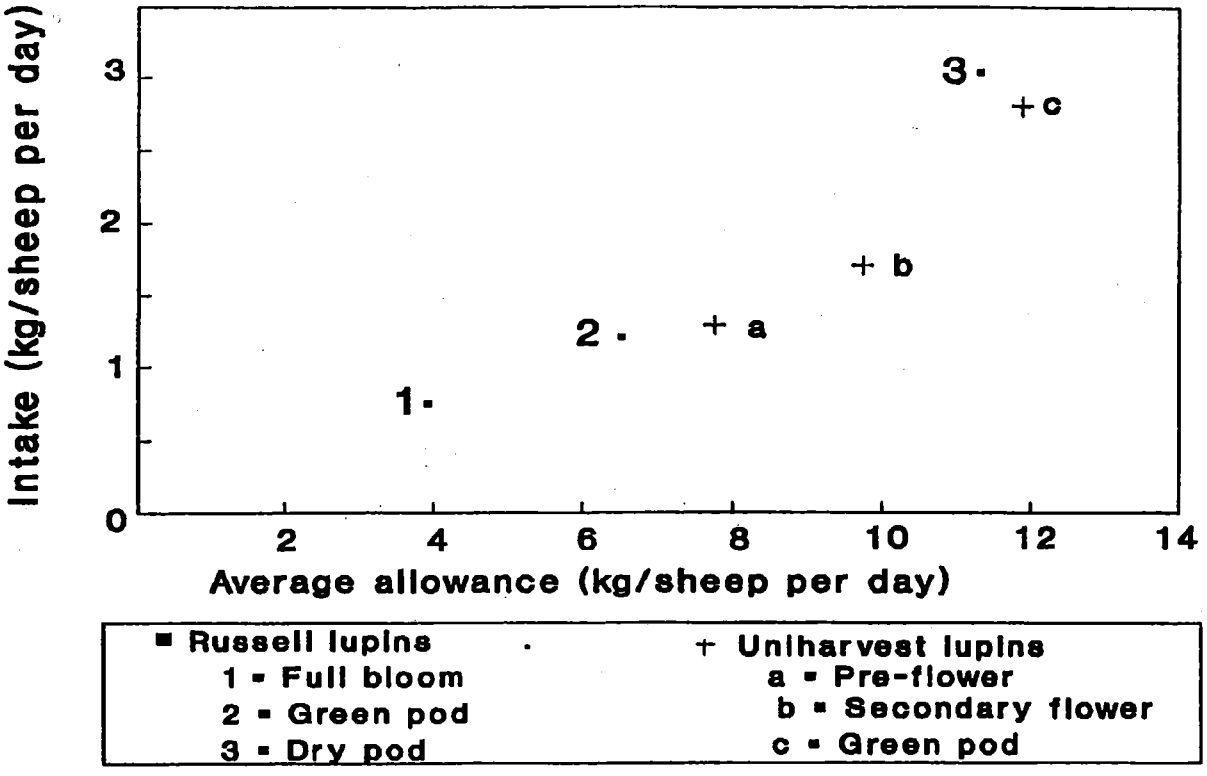

Fig. 4.11a. Relationship between average apparent intake and allowance across the three grazing stages. (Uniharvest lupins from Burtt and Hill, 1990a).

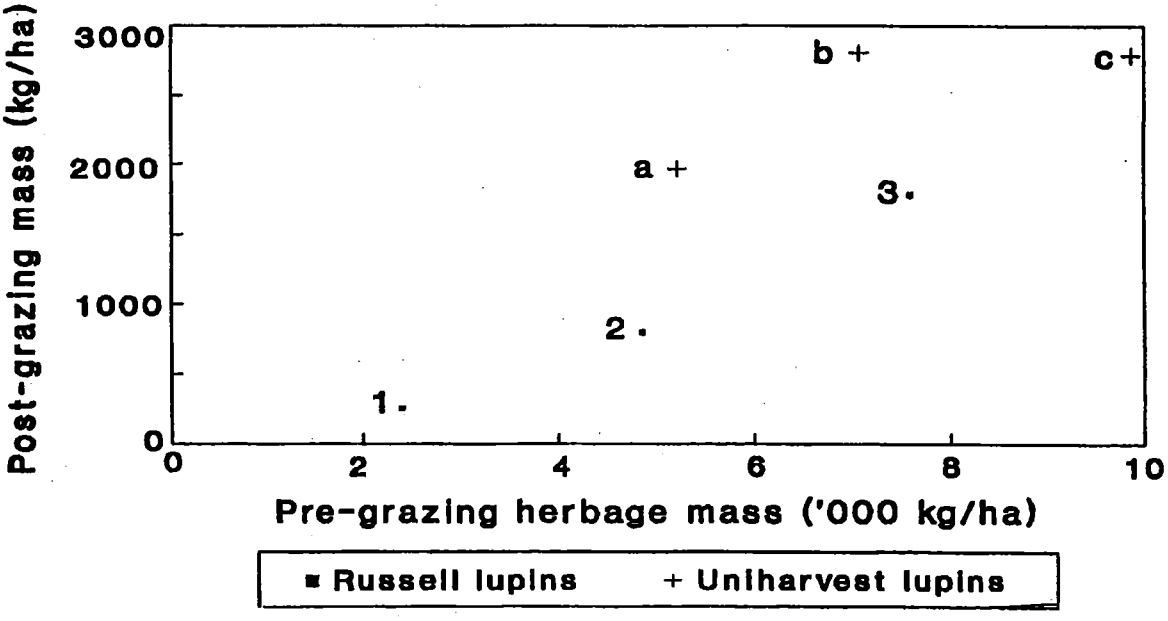

Fig. 4.11b. Post-grazing mass of Russell lupins compared to that of Uniharvest lupins at three growth stages. (a,b,c,1,2 and 3 as defined in Fig. 4.11a)

Table 4.3. Comparison of daily DM disappearance and apparent utilisation of Russell lupins to that of Uniharvest lupins.

	GROWTH STAGE			
	Pre-flower	Full bloom	Green pod	Dry pod
Russell lupins[1]				
DM allowance				
kg ha^{-1}	-	2390	4810	7730
kg $sheep^{-1}day^{-1}$(av)[2]	-	0.83	1.44	4.04
DM disappeared				
kg ha^{-1}	-	2120	3850	5810
kg $sheep^{-1}day^{-1}$(av)	-	0.74	1.15	3.03
Residual DM (kg ha^{-1})	-	270	960	1920
Utilisation (%)	-	89	80	75
Uniharvest lupins[3]				
DM allowance				
kg ha^{-1}	5100	7000	10000	-
kg $sheep^{-1}$ day^{-1}	2.02	2.77	3.96	-
DM disappeared				
kg ha^{-1}	3100	4500	7000	-
kg $sheep^{-1}day^{-1}$	1.23	1.78	2.77	-
Residual DM (kg ha^{-1})	2000	2500	3000	-
Utilisation (%)	61	64	70	-

1 Russell lupins: plot size 418 m^2, 10 plants m^{-2}, 20 sheep $plot^{-1}$.

2 (av) = average = Total DM ÷ No. of days ÷ No. of sheep.

3 Uniharvest lupin: from Burtt and Hill (1990a): plot size 99 m^2, 100 plants m^{-2}, 5 sheep $plot^{-1}$.

This procedure gives a markedly different value from average allowance calculated by dividing the total pre-grazing herbage mass by the number of sheep and days of grazing. The difference between average allowance calculated by the two methods is considerably high. For instance, using the above formula average allowance for grazing at full bloom in this study was 3.92 kg per sheep per day, while the latter method gave 0.83 kg per sheep per day. The latter assumes that if the duration of grazing is four days, herbage mass left after one day of grazing will be three-quarters of the initial mass, which is not usually the case. It is highly likely that many published reports could easily have overlooked this difference.

The main points of comparative interest include:

(1). In both experiments, apparent mean daily intake of sheep increased as average allowance increased (Fig. 4.11a).

(2). With Russell lupins, residual herbage mass increased continually with pre-grazing herbage mass, while the former remained the same when pre-grazing mass of Uniharvest lupins rose from 7076 to 9867 kg per ha (Fig. 4.11b). This was probably because the increase in DM of Uniharvest lupins between secondary flower and green pod was from components that were highly palatable to sheep. The authors also mentioned a strong preference of sheep for leaf and pods.

(3). Because of (2) above, per cent apparent utilisation improved with maturity of Uniharvest lupins, but declined with that of Russell lupins (Table 4.3).

(4). The amount of unpalatable residue left ungrazed appeared to be higher for Uniharvest than Russell lupins, even at a more or less the same pre-grazing mass (Fig. 4.11b). It's difficult to state how much of this difference was related to differences in seed losses due to trampling and pod shatter, which was not accommodated in the residue measured in either trials. (N.B. Uniharvest has non-shattering pods).

Within individual grazings, neither Russell nor Uniharvest lupins displayed the curvilinear relationship between the amount of DM disappeared per sheep per day (=apparent intake) and DM allowance established for grazing animals (Poppi *et al.*, 1987) (Fig. 4.12). The unorthodox trends found from this grazing trial were:

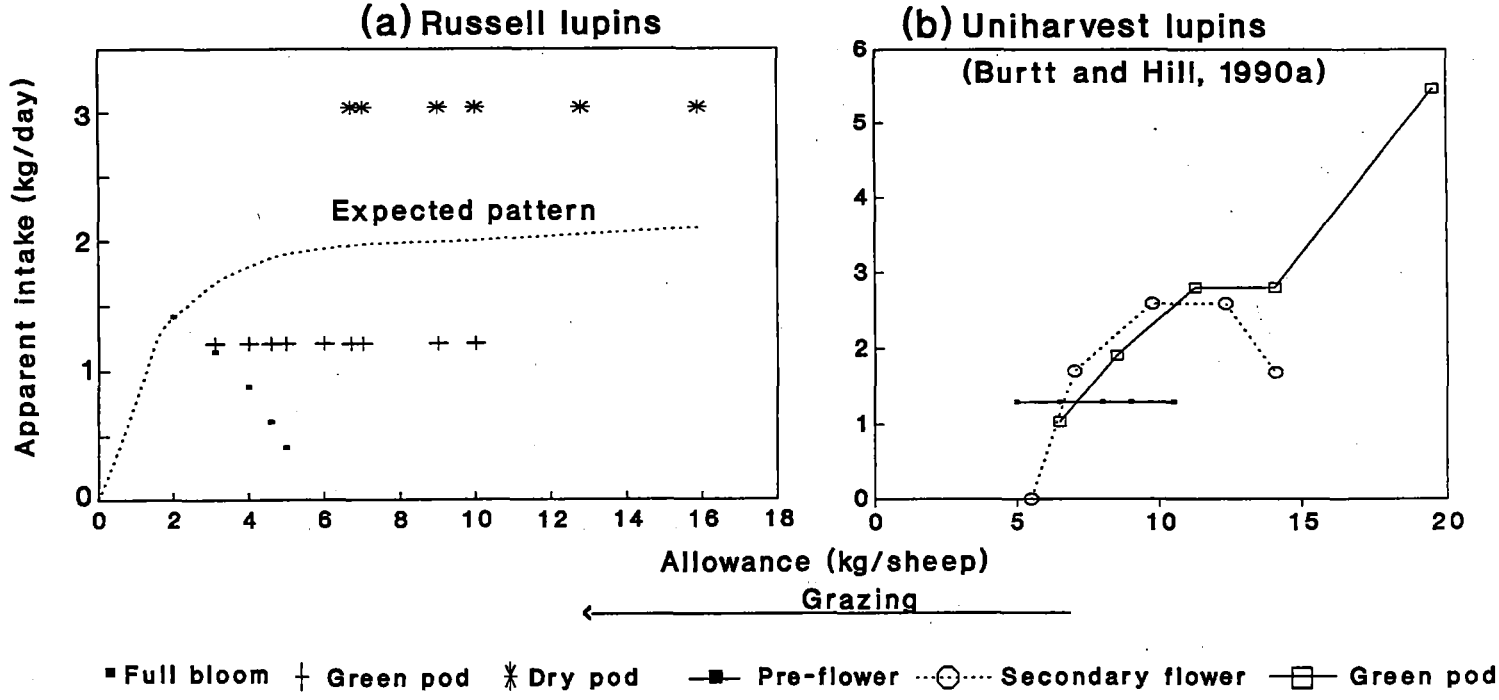

Fig. 4.12. Within-grazing realtionship between apparent intake and DM allowance of Russell lupins (a) and Uniharvest lupins (b).

(i). During the first grazing apparent intake decreased as allowance increased, largely because at the highest allowance (i.e. beginning of grazing) sheep ate weeds and were slow to start eating lupins (Fig. 4.12).

(ii). During grazing at green and dry pod stages the level of daily DM disappearance per sheep remained constant as the allowance decreased with increased duration of grazing. This was due to the apparent linear daily DM disappearance (Fig. 4.5a & 4.7a). This was also the same for Uniharvest lupins grazed at a pre-flower stage (Fig. 4.12). It might be that lupins having a more open canopy than swards of other species made it easier for sheep to distinguish the desirable components and maintain their apparent intake even at a lower allowance. Alternatively, it may be that the difference between herbage left ungrazed on consecutive days did not differ in quality to the extent of causing variation in intake of sheep.

Theoretically, at the lower allowances, one would expect apparent intake to be higher for lupins grazed at early than late growth stage. This is because at low herbage biomass the herbage at an early stage of growth will be of higher quality than that at a more advanced growth stage. This was not shown by Russell lupins in Fig. 4.12 probably due to excessive wastage through trampling which caused the calculated average DM disappearance per sheep to be high at the later stages of growth. With Uniharvest lupins, when the calculated daily allowance fell below 6.5 kg/sheep apparent intake was higher for lupins grazed at pre-flower than those grazed at the later stages (Fig. 4.12). Actually, sheep apparently stopped eating when the allowance of Uniharvest lupins at secondary flower reached 5.5 kg/sheep per day (Fig. 4.12).

From the foregoing discussions it is apparent that the evidence from this grazing trial was inconclusive as to which growth stage is the best time to graze the lupins. This was because:

(1). Based on per cent utilisation and the amount of residue , full bloom appeared to be the best stage to graze the lupins.

(2). With respect to apparent daily intake per sheep, the amount of DM apparently removed by sheep per day and total DM apparently harvested per ha was the highest at dry pod stage.

Although it can be argued that the concentration of N in the DM disappeared and the digestibility of DM disappeared were higher for grazing at full bloom, both parameters were not at too low a level for DM disappeared when Russell lupins were grazed at dry pod (Table 4.2). Therefore, the distinction of an optimum stage to graze Russell lupins required comparison of the two stages in terms of autumn regrowth, and this is presented later on. Burtt (1981) suggested pre-flower grazing as the best stage to graze Uniharvest lupins even before considering the amount of regrowth. Unfortunately, the data from that study does not substantiate the conclusion because (i) per cent utilisation and apparent intake per sheep were greater at green pod than at pre-flower (Table 4.3), and (ii) the calculated N and DDM apparently harvested by sheep respectively were about 140 and 3200 kg/ha at pre-flower and 280 and 5300 kg/ha at green pod. Even if the N concentration and MJ ME $kgDM^{-1}$ was higher at the pre-flower stage, as the author stated, the higher intake of the lambs at the green pod stage would have more than compensated for the lower concentration of these nutrients at the green pod.

4.4.2. Selection by sheep of different plant parts

The results of this study illustrated the usual grazing behaviour of sheep: at any growth stage sheep selected for leaves, but against stems. The leaf component influenced preference for other components in such a way that their proportion in the DM disappeared increased when the proportion of leaves in total DM offered declined. There are two points that emerged from this part of the study:

(1). The results conclusively indicate that plant parts which were the major contributors to the total N and *in vitro* cellulase digestible DM yield, namely leaves and petioles, were also the parts readily accepted by sheep; at all growth stages both components had around 100 % utilisation.

(2). There was no indication of change in acceptability of plant components, or their ranking in terms of sheep preference, which could be solely attributed to maturity of the Russell lupins. This appeared to contradict the assumption that

the vegetative parts of bitter lupin varieties become more acceptable at maturity when the alkaloids had moved into the seeds.

Although both plant and quadrat sampling indicated that green pods were acceptable to sheep, the acceptability of dry pods requires further study under controlled feeding or under grazing with oesophageal fistulated animals.

There is lack of previous work comparing selection for different plant components of lupins. Burtt (1981) found strong preference of sheep for leaves and green pods of Uniharvest lupins albeit there was no data on the proportion of plant components in the DM removed through sheep grazing. Therefore, it is not possible to state if, for example, selection for green leaf was stronger in Uniharvest lupins than in Russell lupins. Comparison with studies on grass species appears to show that selection for green leaves is stronger in grass swards than that observed on Russell lupins. For instance, the selection ratio (the proportion of a component in the diet divided by the proportion of the same component in the sward (Hodgson, 1979)) for green leaves in a *Setaria sphacelata* sward grazed by cattle was 650 and 2.9 at a herbage mass of 3600 and 7300 kg DM ha^{-1}, respectively (Chacon and Stobbs, 1976). The maximum selection ratio for green leaves in this study was 2.64 recorded on day 4 of the second grazing.

It is difficult, if not impossible, to present one single feature which accounts for the attractiveness of a plant part. The preference of leaf to other vegetative parts can be explained by its spatial arrangement in the canopy (Hodgson, 1982) and the ease with which it can be harvested or "tenderness" (Black and Kenny, 1984). Since flowers and pods occupy a position in the canopy which would appear to give them an equal opportunity for selection as leaves, vertical distribution may not explain why leaves were chosen in preference to flowers and pods. It was most likely related to the greater alkaloid content of the reproductive parts.

4.4.3. Composition and digestibility of diet selected

As has been generally established for sheep grazing other forage species (Arnold, 1981; Hodgson, 1982), sheep grazing Russell lupins selected a diet which had a higher nutrient concentration and digestibility, but lower fibre content than the herbage they were offered. The difference in composition and digestibility between DM offered and DM disappeared through grazing became smaller as grazing progressed, probably (i) because the decreasing level of allowance reduced the opportunity for selection, or (ii) because the sheep were less discriminating between components which remained after they had removed the plant components they preferred most. The material removed through sheep grazing at any growth stage or on any day of grazing within a growth stage contained N in excess of the minimum requirement for ruminants.

The decline in the nutrient concentration and digestibility of herbage on offer with successive days of grazing was a reflection of selective grazing by sheep which changed the proportion of plant components in the residual herbage. Within these short periods (4 - 7 days) it was unlikely that the composition and digestibility of the herbage would show as large a drop because of increased plant maturity.

4.4.4. Plant regrowth

Although the amount of residual herbage mass remaining for regrowth was the smallest for lupins grazed at full bloom, the highest autumn regrowth was obtained from these lupins (Table 4.4). Therefore, it can be stated that it was the time of grazing rather than the amount of residual herbage mass left that determined the amount of autumn regrowth obtained from Russell lupins. This probably relates to the accumulation of nutrient reserves in the root system.

As far as regrowth is concerned, full bloom was the optimum stage to graze the Russell lupins. It should be noted that the end of season total regrowth yield consisted of residue left ungrazed and DM from regrowth. With a moderate value of 70 % utilisation of regrowth for all three stages, harvestable yield will be as presented in Table 4.4. (N.B.

Table 4.4. Regrowth of Russell lupins grazed at three growth stages and calculated total harvestable yield at the three grazing stages.

Growth stage	Autumn regrowth yield			Harvestable[1] yield	
	Residual (kg/ha)	Regrowth kg/ha)	Total (kg/ha)	Regrowth (kg/ha)	Total[2] (kg/ha)
Full bloom	270	6690	6960	4872	6992
Green pod	960	2818	3774	2642	6492
Dry pod	1920	362	2282	1597	7407

1 Assuming 70 % utilisation for regrowth DM.

2 Total yield = amount harvested during grazing plus that calculated from regrowth.

Similar level of utilisation was used assuming that the greater fresh regrowth DM from the later grazings would be offset by a high proportion of ungrazed residue in their total yield).

Although annual DM yield was higher for lupins grazed at dry pod, grazing at full bloom increases the scope of incorporation of Russell lupins in the New Zealand farming system. That is to say, the regrowth of lupins grazed at full bloom provides one more grazing, a seed harvest, or a seed harvest plus stubble grazing. It also provides an option to use the lupins for autumn flushing of ewes; Marshall *et al.* (1976) found improvement in ovulation rate of ewes fed on lupins for as short as six days before the beginning of mating. In my opinion, the seasonal distribution of DM yield is as important as, or even more important than, the total annual yield.

4.5. CONCLUSIONS

In terms of acceptability to sheep, there was no apparent difference between the three growth stages considered, as apparent intake increased with increase in the amount of DM on offer. However, grazing Russell lupins when they are at full bloom gives the advantages of improved per cent utilisation and better autumn regrowth. On the other hand, grazing Russell lupins at dry pod provides a high yield of DM of moderate quality late in the season, and a higher total annual harvestable yield per ha than grazing at full bloom.

Leaves were the most preferred plant components. The proportion of green leaf in total herbage affected the selection ratio of other components. Plant components that composed most of the *in vitro* cellulase digestible DM yield of the lupins were also the parts readily eaten by sheep. There was no apparent change in the acceptability of plant components with plant maturity. Even if there was any indication of change in acceptability, it would be difficult to distinguish whether such a change was a consequence of change in the chemical composition of the component with maturity or a change in the proportion of green leaf in the total herbage that occurred with maturity.

The unorthodox pattern of change in apparent intake from Russell lupins with changing level of allowance requires further investigation under controlled feeding using weed-free stands of the plant. Moreover, if cost permits, and when enough Russell lupin seeds become available, the duodenal nutrient supply of these lupins and the maximum intake and liveweight gain achievable on their herbage warrants further study.

CHAPTER FIVE

5. GENERAL DISCUSSION AND CONCLUSIONS

Most of the features which described the pattern of DM accumulation in the regrowth lupins (Experiment I) were also manifested by the first-growth lupin in the second experiment. In both experiments: (i) petioles and leaves were the major contributors to total DM yield (i.e. up to pod development), (ii) the proportion of maximum DM yield of Russell lupins that had accumulated before the beginning of reproductive development was less than 30 %, (iii) there was more than 20 % green leaf in the total DM at maturity.

However, in the second experiment by full bloom the Russell lupins accumulated only 30 % of the maximum yield obtained at dry pod, a proportion very much lower than that accumulated by the regrowth lupins (Experiment I), but close to the proportion accumulated by annual lupins at a similar growth stage (Table 3.8). This suggested that the pattern of DM accumulation in first-growth Russell lupins was similar to that of other lupins. Nonetheless, in both experiments the proportion of pods in total DM at maturity stayed well below the level in annual lupins.

Total DM yield per plant in Experiment II was lower than it was in Experiment I, mainly due to difference in soil fertility between the two sites. The regrowth Russell lupins were in a paddock with a high level of soil P (Olsen-P = 37) and they also had an additional benefit of dung and urine return from sheep grazed on that paddock in June, 1989. This difference does not affect the harmony of results from the two experiments, because the higher DM yield in the first experiment was not associated with a lower concentration of nutrients, or with a lower DM digestibility than that in the second experiment. For instance, at full bloom the N, NDF and DMD were respectively 2.9, 28 and 73 % for the regrowth lupins, and 2.7, 27 and 75 % for the first-growth lupins.

In terms of chemical composition and digestibility, the main feature of Russell lupins, manifested by both regrowth and first-growth plants, was that their herbage quality did not deteriorate rapidly with maturity. The reasons are explained in earlier sections. Consequently, over most of their growth period Russell lupins produced herbage of moderate to high nutritional quality; in both experiments the N concentration was >2 %, the NDF <50 %, and DMD >55 %. This high concentration of N and DMD together with their high DM yield enabled Russell lupins to produce a high yield of N and digestible DM per ha. The economic implication of this must be considered in view of:

(1). the increasing cost of N and phosphate fertilisers,

(2). the alternative use of N fertiliser for crops incapable of providing their own N,

(3). the reduction in NO_3 leached into drainage water when N is biologically fixed than when it is applied from commercial fertilisers (less damage to the environment) (Laidlaw and Frame, 1988), and

(4). the decline in farm returns in New Zealand and the world.

Russell lupins also enhance the environment by increasing the range of diversity and colour in the rural landscape.

The grazing trial definitively showed that plant components which composed the majority of the initial peak DDM yield were also the parts greatly preferred by sheep, i.e. leaves and petioles. With respect to per cent utilisation and amount of unpalatable residue the results from the grazing trial were also in harmony with the interpretation of the two peak digestible DM yields from the cutting trial. That is, grazing at the second peak DDM yield (or at dry pod) gave a lower per cent utilisation and a greater amount and proportion of unpalatable residue. High dry matter losses through trampling at the last grazing, and differences in sheep adjustment to lupin feeding between the grazing stages did not allow strict comparison of the grazing stages in terms of amount of DM disappeared per sheep per day.

The balance of evidence from both the cutting and grazing trials has favoured full bloom as the optimum stage to graze Russell lupins. Besides higher per cent utilisation, grazing at full bloom gives an additional benefit of good autumn regrowth. However,

grazing at dry pod also provides high yield of good quality herbage without sacrificing total annual harvestable yield. In terms of percentage maximum yield accumulated, grazing before the onset of reproductive development is not recommendable.

The results have also clearly indicated that the plant can provide good quality herbage, at least 70 % of which is readily harvestable by sheep at any growth stage. The results of this study strongly support Scott's (1989) call for recognition of the plant by farmers and farm advisors. Besides their proved suitability to high country sites (Scott, 1989), Russell lupins may also be incorporated in other areas where fertility is low, or where, late in the season, the demand for good quality herbage cannot not be met without using irrigation and/or fertilisers. The fact that these lupins establish better by drilling than broadcasting (Tesfaye, 1989) poses problems in introduction of these lupins to hill country sites which are not cultivatable.

There are a lot of areas still open for research. Primarily, investigation of the digestion characteristics (i.e. site of digestion) of the proteins from Russell lupin herbage may indicate the true worth of its high N concentration. When enough seed becomes available comparison of the plant to other legumes in terms of intake and liveweight gain warrants consideration.

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APPENDIX 1

Table 1. Data on dry matter yield of Russell lupins (whole plant and plant parts) sampled at three-weekly intervals between 05 Oct. 1989 and 18 Jan. 1990. (Each rep is a mean of 10 plants).

Harvest	Rep	Stem	Petiole	Leaf	Flower	Pod	Dead matter	Total DM	Log(Total DM)
1	1	0.27	8.85	12.61	-	-	2.28	24.03	1.23
1	2	0.41	13.09	18.66	-	-	3.38	35.56	1.49
1	3	0.56	17.85	25.43	-	-	4.61	48.47	1.57
1	4	0.48	15.22	21.68	-	-	3.93	41.32	1.56
1	5	0.85	27.04	38.52	-	-	6.99	73.41	1.78
1	6	0.41	13.21	18.83	-	-	3.41	35.88	1.44
1	7	0.42	13.50	19.23	-	-	3.49	36.66	1.45
2	1	9.97	31.70	40.34	1.74	-	5.90	89.66	1.90
2	2	9.05	28.78	36.62	1.58	-	5.35	81.40	1.85
2	3	12.37	39.32	50.04	2.16	-	7.32	111.23	1.95
2	4	10.80	34.32	43.68	1.88	-	6.39	97.10	1.91
2	5	11.39	36.21	46.08	1.99	-	6.74	102.42	1.99
2	6	14.46	45.95	58.47	2.52	-	8.55	129.97	2.01
2	7	10.44	33.17	42.21	1.82	-	6.17	93.82	1.90
3	1	17.83	27.57	37.99	5.06	-	13.44	101.92	1.90
3	2	22.15	34.25	47.19	6.29	-	16.69	126.58	2.06
3	3	18.05	27.91	38.45	5.12	-	13.60	103.16	1.97

Table 1. Continued.

Harvest	Rep	Stem	Petiole	Leaf	Flower	Pod	Dead matter	Total DM	Log(Total DM)
3	4	24.35	37.66	51.88	6.92	-	18.35	139.18	2.07
3	5	25.15	38.90	53.59	7.14	-	18.96	143.76	2.10
3	6	14.98	23.17	31.92	4.25	-	11.29	85.63	1.91
3	7	27.52	42.56	58.65	7.82	-	20.75	157.32	2.13
4	1	28.86	24.02	30.87	7.13	8.89	27.04	126.83	2.01
4	2	20.69	17.21	22.12	5.11	6.37	19.38	90.91	1.90
4	3	29.51	24.56	31.57	7.30	9.09	27.65	129.71	2.05
4	4	25.92	21.57	27.72	6.41	7.98	24.28	113.90	1.97
4	5	25.45	21.18	27.22	6.29	7.84	23.85	111.86	2.02
4	6	31.09	25.87	33.26	7.69	9.58	29.13	136.64	2.07
4	7	21.67	18.03	23.18	5.36	6.68	20.30	95.25	1.94
5	1	22.48	13.03	21.25	1.54	22.61	37.63	118.57	2.03
5	2	17.74	10.29	16.77	1.21	17.85	29.70	93.59	1.90
5	3	32.49	18.84	30.71	2.23	32.69	54.39	171.38	2.09
5	4	30.68	17.79	29.00	2.10	30.87	51.36	161.83	2.03
5	5	20.99	12.17	19.84	1.44	21.12	35.14	110.73	1.99
5	6	19.37	11.23	18.31	1.33	19.48	32.42	102.15	1.93
5	7	20.16	11.69	19.06	1.38	20.28	33.75	106.35	1.99
6	1	36.35	19.29	28.31	-	59.59	92.65	236.21	2.29
6	2	24.72	13.12	19.25	-	40.53	63.02	160.66	2.13
6	3	22.36	11.87	17.41	-	36.66	57.01	145.33	2.10
6	4	23.04	12.23	17.94	-	37.78	58.74	149.75	2.10
6	5	14.86	7.88	11.57	-	24.36	37.88	96.57	1.91
6	6	30.33	16.10	23.62	-	49.73	77.32	197.12	2.15
6	7	20.91	11.09	16.28	-	34.28	53.29	135.87	2.09

APPENDIX 2

Table 1. Mean of transformed and non-transformed dry matter yield data (g/plant) for whole plant and plant parts of Russell lupins at six harvest dates (1989-90)

HARVEST	P L A N T			P A R T				
DATE	Stem	Petiole	Leaf	Flower	Pod	Dead matter	Leaf:stem	Total DM
Oct 05	0.5(-0.43)	15.5(1.08)	22.1(1.23)	-	-	4.0(0.49)	44.2	42(1.51)
Oct 26	11.2(0.98)	35.6(1.48)	45.4(1.59)	2.0(0.22)	-	6.6(0.75)	4.0	101(1.94)
Nov 16	21.4(1.27)	33.2(1.46)	45.7(1.59)	6.1(0.72)	-	16.2(1.14)	2.1	123(2.02)
Dec 07	26.2(1.36)	21.8(1.28)	28.0(1.39)	6.5(0.75)	8.1(0.85)	24.5(1.33)	1.0	115(2.00)
Dec 28	23.4(1.29)	13.6(1.04)	22.1(1.25)	1.6(0.12)	23.6(1.28)	39.2(1.50)	0.9	124(2.00)
Jan 18	24.7(1.30)	13.1(1.03)	19.2(1.19)	-	40.4(1.52)	62.9(1.71)	0.8	160(2.11)
L.S.D¶	4.44(0.088)	5.07(0.088)	6.95(0.088)	0.91(0.081)	6.46(0.087)	7.60(0.088)	-	26.0(0.088)
CV (%)	75(28)	69(21)	69(19)	68(54)	81(21)	89(23)	-	71(14)

Figures in parenthesis are $\log_{10}$ transformed values.

¶Least significant difference at $P<0.05$.

APPENDIX 3

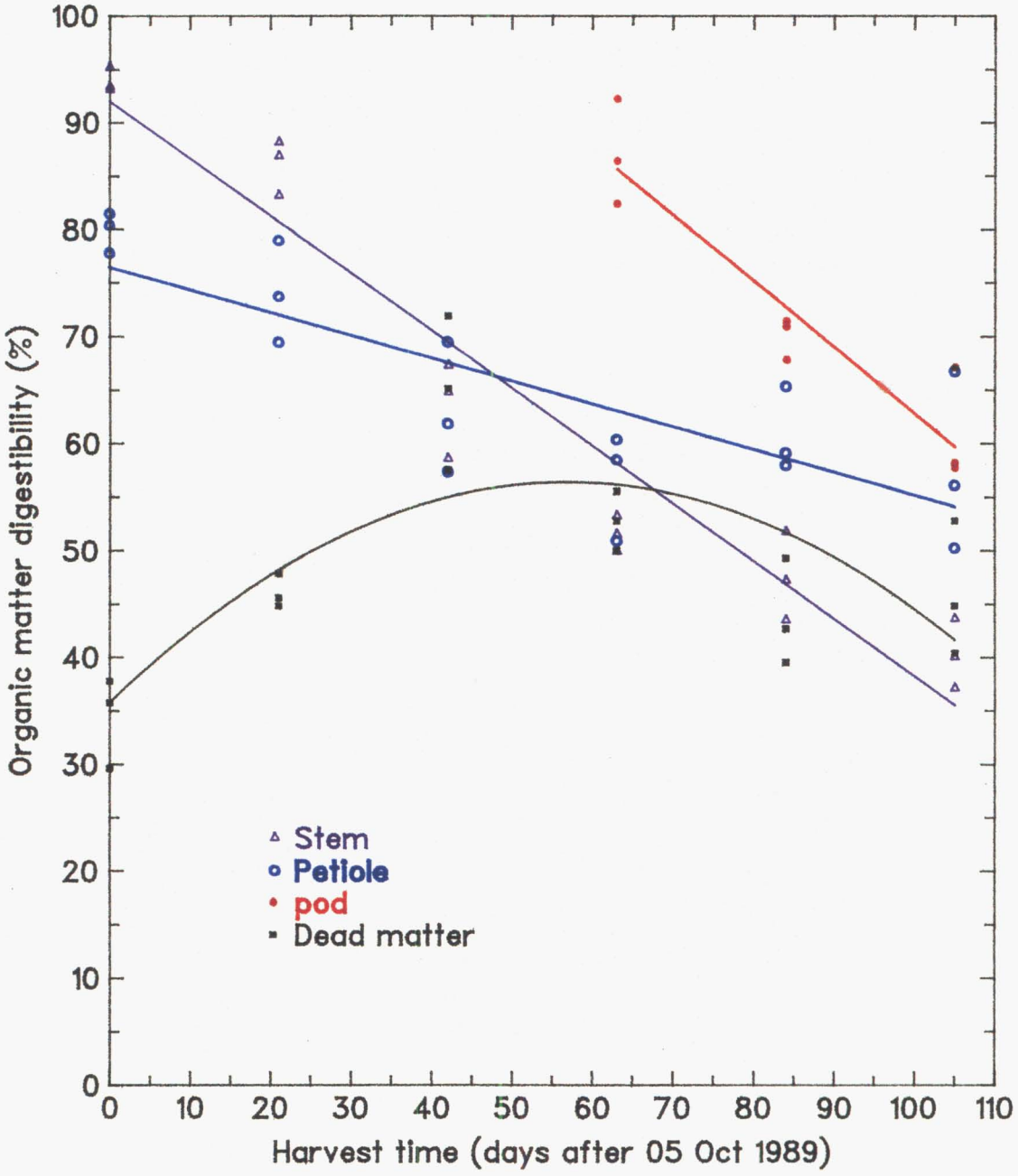

Fig. 1. Regression of organic matter digestibility of:
whole plant ($y = 81.66 - 0.13x - 0.001x^2$ $P<0.001$ $R^2 = 0.94$),
stem ($y = 91.96 - 0.54x$ $P<0.001$ $R^2 = 0.93$),
petiole ($y = 76.48 - 0.21x$, $P<0.001$ $R^2 = 0.62$)
pod ($y = 124.63 - 0.62x$, $P<0.001$ $RS^2 = 0.88$)
and dead matter ($y = 35.71 + 0.728x - 0.006x^2$ $P<0.001$ $R^2 = 0.52$)
on harvest time (x, days after the beginning of sampling).