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**SEED PRODUCTION STUDIES IN
LUCERNE (*Medicago sativa* L.)
cv. GRASSLANDS ORANGA**

A thesis presented in partial
fulfilment of the requirements for the
Degree of Doctor of Philosophy in Plant Science
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ABSTRACT

Two years of field trials with lucerne (*Medicago sativa* L.), cv. Grasslands Oranga, were used to determine plant vegetative and reproductive responses to the effects of row spacing and sowing rate, application of two plant growth regulating chemicals, and weed control.

For an autumn (March 15) sowing, seedling number per metre of row increased as sowing rate (1 to 12 kg/ha) and row spacing (15 to 60 cm) increased. However the number of seedlings was not directly proportional to the number of seeds sown, and percentage establishment six months after sowing was highest (73%) at the lowest sowing rate of 1 kg/ha. Overall mean establishment for all treatments was 57, 46, and 34% for 1, 6, and 18 months after sowing respectively. Dry matter production at 6 months after sowing was greatest at the 15 and 30 cm row spacings and 12 kg/ha sowing rate, but there were no significant differences in dry matter among treatments at later assessments. In the first year seed yield from the 15 cm row spacing was significantly lower than from the 30, 45 and 60 cm row spacings, while sowing rate had no effect on seed yield. In the second year, row spacings did not significantly affect seed yield, but the seed yield from the 1.0 kg sowing rate was significantly increased because harvestable racemes/m² and thousand seed weight were significantly increased. Seed yield over the two years of the experiment was highest at the 1 kg/ha sowing rate and for the 30 and 45 cm row spacings. The average seed yield for all treatments was 127.2 and 186.9 kg/ha for the first and second year respectively. Neither row spacing nor sowing rate had any effect on the quality of harvested seed. There were no interactions between row spacing and sowing rate for plant establishment, dry matter production, or seed production.

In the 1991/1992 season, the effect of two plant growth regulators, paclobutrazol at 1.0 kg a.i/ha (applied on 1 November or 1 December), and cycocel at 3.0 kg a.i/ha (applied on 1 December, 23 December, 1991 or 1 January 1992), on vegetative and reproductive growth was examined. Paclobutrazol applied during active vegetative growth (1 November) significantly altered vegetative shoot development by inhibiting apical dominance, thus inducing lateral branches which subsequently increased

reproductive sites, and increased seed yield by 37%. This seed yield increase was due to an increased number of racemes/m² (+36%) and pods per raceme (+72%). Paclobutrazol applied at first flower bud appearance (1 December) had no effect on seed yield or seed yield components because it did not alter shoot production or the number of racemes. Cycocel application did not retard plant height or increase racemes per unit area. However while application on 23 December (at first flowering) had no significant effect on seed yield, cycocel applied in early December (first flower bud appearance) or early January (at peak flowering) significantly decreased seed yield, because of a reduction in the number of flowers/m² and/or harvestable racemes/m².

In the following season (1992/93), paclobutrazol at 0.5 kg a.i/ha and 1.0 kg a.i/ha was applied during active vegetative growth on 25 October 1992. Both rates significantly reduced plant height by 8 weeks after application, but this effect had disappeared by final harvest. As in the previous year, paclobutrazol at 1.0 kg a.i/ha significantly increased seed yield, but the increase (+153%) was much greater than in the previous year. This increase in seed yield was associated with an increase in the number of harvestable racemes/m² (+126%), pods per raceme (+36%) and thousand seed weight (+11%). Paclobutrazol at 0.5 kg a.i/ha had no significant effect on seed yield.

In 1992/1993 the effect of hand weeding and the application of three herbicides (hexazinone 1.0 kg a.i/ha, simazine 2.25 kg a.i/ha plus paraquat 0.6 kg a.i/ha) on seed yield in a second year crop was investigated. Hand removal of weeds, predominantly white clover but also *Poa annua* L. and broad leaved species increased seed yield from 0.7 to 21.3 g/m², mainly because racemes increased from 89 to 1230/m². Increases in pods per raceme and seeds per pod were also recorded. Hexazinone applied during active vegetative growth in early spring eliminated white clover from lucerne plots and increased seed yield to 14.3 g/m². However this treatment did not control *Rumex obtusifolius* L. Simazine plus paraquat applied in winter before active spring growth controlled many annual weeds but, although initially checking white clover, did not control it. As a consequence, seed yield did not differ from that of the untreated control. Although hexazinone effectively removed white clover from a second year lucerne seed crop, it is recommended for use only on mature stands. Harvested lucerne seed viability did not differ among treatments, but hand weeding and herbicide treatments significantly reduced the percentage of hard seed.

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CHAPTER 1

1. INTRODUCTION

Lucerne has been called "the queen of forage crops" because of its remarkable ability to produce a high yield of rich, palatable, nutritious forage under a wide range of soil and climatic conditions (Hanson and Barnes, 1975). Morris et al., (1992) considered that lucerne was a legume of tremendous value as a highly digestible, high protein roughage source for ruminant animals. There are undoubtedly many factors that contribute to this plant's excellence, but recognition must be given to the microsymbiont, the nodule bacteria that fix free nitrogen from the atmosphere.

Purves and Wynn-Williams (1989) reported that 32 million hectares of lucerne are grown in the world. Assuming a five - year rotation and a seeding rate of 20 kg/ha, total world seed requirements are estimated to be nearly 128,000,000 kg/year (Marble, 1987). This area spans a wide range of temperate climates; for example in North America lucerne cultivation extends from regions where winter cold tolerance is essential to other regions where warm humid summers curtail production stand life. Small areas are also grown in subtropical and tropical countries (Leach, 1983). The USA is the largest producer of lucerne seed and forage in the world (Marble, 1987).

Doull (1967) reported that in many countries lucerne seed yields within the range of 112 - 168 kg/ha are common, but trial plot yields of up to 2422 kg/ha have been recorded. In some states of the USA average yield is about 500-600 kg/ha, but in New Zealand, seed yield tends to be low and erratic, ranging from 200-450 kg/ha (Dunbier et al., 1983). Zaleski (1963) noted that very large variations in seed yield may occur in different years.

While lucerne is a perennial forage crop, plants can be grown either for forage or seed production. In normal practice it is common for farmers to cut lucerne for herbage and then harvest for seed later in the same season.

This study is presented in 7 chapters. Chapter 1: General introduction; Chapter 2: Literature review; Chapter 3: Results of a field experiment in two successive cropping years (1991-1993) involving the effects of row spacing and sowing rate on plant establishment and seed production; Chapter 4: Studies on the effects of chemical manipulation by two plant growth regulators on plant growth and seed production; Chapter 5: Results of a field experiment to determine the effects of paclobutrazol on seed yield and its components; Chapter 6: Results of a field trial which examined the effect of herbicides on seed production of lucerne, and Chapter 7: A general discussion on the experimental results, conclusions and some recommendations for future studies on seed production.

CHAPTER 2

LITERATURE REVIEW

2: INTRODUCTION

This literature review gives a general account of the factors affecting lucerne establishment and seed production.

The first section give a general description of lucerne as a crop plant. The second section reviews specific factors that affect lucerne establishment and seed production.

2.1. GENERAL DESCRIPTION OF LUCERNE

2.1.1 HISTORY AND DISTRIBUTION

Lucerne (alfalfa) is a plant from the Near East and Central Asia. It is generally agreed that Medicago sativa L. originated in Vavilov's "Near Eastern Centre" i.e. Asia minor, Transcaucasia, Iran and the high lands of Turkmanistan(Bolton et al., 1972). The geographic centre most often mentioned as the home of lucerne is Iran.

Wilsie (1962) and Bolton et al., (1962) claimed that the history of lucerne is a story of the world's most important forage crop. Being the first forage crop to be domesticated, it was obviously recognized by man as a valued crop plant. The oldest recorded reference to date indicates that lucerne was used as a forage over 3,300 years ago in Persia and Turkey. It soon gained some importance in Greek agriculture and was acquired by the Romans from Greek civilization in the 2nd century B.C.. Roman farmer colonists

planted lucerne in southern Spain in the 1st century and from Spain it slowly spread to France, Belgium, Holland, England Germany, Austria, Sweden and Russia during the 16th to 18th centuries. However it was in the 18th century that lucerne become distributed worldwide when it was taken from Europe to the Americans by the Spanish and Portugese and to Australia and South Africa by colonists in the 19th century. Lucerne probably reached New Zealand from Europe about 1800 or earlier (Bolton, 1972). Klinkowski (1933) suggested that now lucerne is grown from 59° N to 53° S.

The USA, USSR, and Argentina contribute about 70% of worldwide production, and China, France, Italy, and Canada combine to account for an additional 17% (Michaud et al., 1988).

Hadfield (1952) reported that the name "lucerne" originates from the French "luzerne". In America however the plant is called "alfalfa" a name derived from an Arabian word meaning "the best fodder". It has also been called "purple medic" to differentiate it from "black medic" or yellow trefoil (M.lupulina).

2.1.2. BOTANY

Lucerne belongs to the family Leguminoseae and genus Medicago, of which there are several species.

The lucerne plant is a perennial, and the erect stems usually reach a height of 50-90cm (Kipps, 1983). The first stem arises between the cotyledon, and succeeding stems arise in the axils of the cotyledons or of the lower leaves. As the stems age, they become woody at the base and gradually a compact multiple stem or crown is formed (Bolton, 1962). The crown may be at the surface of the ground or slightly beneath and is made up of a series of short branches (Kipps, 1983). There may be 5-25 or more stems per plant, arising from the woody crown from which new stems grow when the older ones mature or are cut (Kipps, 1983). In cultivars with creeping-roots the stem buds

arise from submerged crowns or horizontal roots (Bolton, 1962). The first leaf is unifoliate. The leaves, arranged alternately on the stem, are pinnately trifoliate. The leaflets vary greatly in size and in shape from almost linear to almost orbicular. The top part of the leaflets is toothed along the margin.

The flowers of lucerne are borne in groups called racemes which arise in the axils of leaves. According to Barnes et al., (1972), development of the lucerne flower begins at the shoot apex with the transition from vegetative to reproductive growth. This transition takes place between the 6th and 14th node (Dobrenz et al., 1965). Each flower primordium is determinate and produces a calyx, a corolla, 10 stamen, and a pistil. The calyx tube consists of five undiverged sepals terminated by five lobes or teeth that exceed the length of the tube. Nelson (1968) reported that the papilionaceous corolla is highly evolved and consists of five petals (a large standard, two lateral wing petals and two fused petals that form the keel). The colour of the lucerne flower is usually some shade of purple. The seeds are borne in spirally twisted pods, which have 1 to 3 coils. Each coil contains up to 8 seeds (Kipps, 1983). The seed is yellow, sometimes with a buff or brown tinge (Percival, 1949), and consists essentially of two cotyledons surrounding the embryo and enclosed in a seed coat. Hard seeds are often common.

The root of lucerne is very long and penetrates to a great depth as compared with other field crops. The root system has a distinct taproot, which under favourable condition may penetrate 7-9m or more into the soil (Hanson and Barnes, 1975).

2.1.2.1. LUCERNE SPECIES

According to Iversen and Meijer (1967) there are two main species of lucerne, Medicago sativa L., which is a native of temperate climates and the Siberian Medicago falcata L.. Medicago falcata L. appears to have extended further north into Siberia. This is a plant of upland areas, of colder more humid climates, of leached acid soils where it has been subjected to much more competition and diseases are more common. Under these conditions it is found as a prostrate plant of low productivity, late in spring growth, slow in recovery, with many branched roots and a deep crown, giving it excellent resistance to cold. Disease resistant forms have also been evolved. The flowers are yellow, the pods do not form a complete spiral, the leaves are small and dark in colour and the stems are fine and branched.

Medicago sativa L., is purple-flowered, narrow-crowned, and erect. Strains of this species vary greatly in winter hardiness, but as a group they are less hardy than Medicago falcata, generally referred to as "common" lucerne.

An intermediate group (Medicago media), which is the result of natural and artificial hybridization between Medicago sativa L. and M. falcata L. is complicated by the difference in the chromosome number (32 and 16) and appears to have been relatively infrequent (Iversen and Meijer, 1967).

In the western world M. sativa L. is the only species to be cultivated, but in Siberia and China strains of M. falcata L. are in use.

Iversen and Meijer (1967) noted that lucerne has tremendous plasticity due to the more or less hybrid nature of all the cultivated forms, to the fact that it is cross-pollinated and to the heavy mortality in all sowings.

Various classifications of lucerne varieties have been made by different workers. Criteria used include time of flowering, growth form, type of tillering, winter hardiness, disease resistance, water stress, spring earliness and type of parental stock (Bordafkov, 1934; Graber, 1950; Zaleski, 1954).

2.1.3. MORPHOLOGY, GROWTH AND DEVELOPMENT OF THE LUCERNE PLANT

2.1.3.1. VEGETATIVE GROWTH

Grove and Carlson (1972), stated that "the primary axis of lucerne is well defined in the mature embryo and consists of an elongated hypocotyl, root and stem tip. Divergences include two cotyledons and several foliage leaves. Early differentiation of provascular strands is evident".

The primary root emerges near the hilum and penetrates the soil as an unbranched tap root. It is derived from the apical meristem of the radicle. The tap-root may penetrate deeply (Bolton, 1962). As the hypocotyledonary area straightens and becomes elongated, the cotyledonary leaves emerge above ground. The first foliar leaf (unifoliolate leaf) is simple, with a slender petiole. Subsequent leaves produced on the primary stem are trifoliolate (Teuber and Brick, 1988).

The seedling axis continues to elongate and develop alternately arranged leaves. Vegetative buds develop in the axil of the cotyledonary leaves and subsequent foliar leaves. The primary crown develops from the axils of the unifoliolate leaf and the cotyledons (Teuber and Brick, 1988).

The stems of lucerne vary from erect to prostrate, but are usually erect to partially decumbent; the first stem arises between the cotyledons (Bolton, 1962).

2.1.3.2. REPRODUCTIVE DEVELOPMENT

Dobrenz et al., (1965) reported that the transition from vegetative to reproductive growth take place about the 10th to 14th node from the crown during spring growth and at about the 6th to 10th node during summer

growth. The transition is first recognized by the protuberance of meristematic tissue in the axil of the leaf primordium nearest the shoot apex (Dobrenz et al., 1965). Each primordium gives rise to a simple raceme. The shoot is normally indeterminate, and the shoot apex continues to differentiate both vegetative and floral organs until the stem senesces or is removed.

Barnes et al., (1972) showed that the lucerne flower has a special floral morphology and tripping mechanism. The tripping process involves the release of the ten staminal column from the restraining processes on the wings and keel (Bolton, 1962). This is necessary for pollination and seed set in lucerne (Rincker et al., 1988). The act of tripping is not reversible. When the flower is tripped, the slapping of the stigma into the standard petal ruptures the stigmatic cuticle and transforms the stigma into a concave shape.

When pollen grains reach the stigma they germinate in the stigmatic secretion, which appears to be primarily a source of moisture (Viands et al., 1988). On the tripped stigma, pollen tubes penetrate the core of the transmitting tissue at the base of the stigma. Fertilization take place within 24 to 32h, depending on pollen tube growth, the position of the ovule and temperature (Sayers and Murphy, 1966).

2.1.4. IMPORTANCE AND USE

Lucerne can be grown for green forage, pasture, hay, silage, dehydrated meal, or seed (Arnon, 1972). Beginning with its Asian origin as a range plant, lucerne is a superior pasture legume for many classes of livestock because of its high yield, forage quality, and wide climatic and soil adaptation (Van Keuren and Matches, 1988).

Lucerne is one of the most important forage plants in the world and particularly in USA. It has the highest feeding value of all the commonly grown hay crops (Barnes and Gordon, 1972). Lucerne produces more protein

per ha. than any other crop for livestock. In some situations the most efficient use of lucerne is in combination with corn silage, where the protein of the lucerne complements the energy from the corn. Lucerne is high in mineral content and contains at least 10 different vitamins It has long been considered an important source of vitamin A. These characteristics make lucerne (used as hay, pellets, or low-moisture silage) a desirable ration component for most farm animals. Lucerne is excellent pasture for swine, and despite the bloat hazard it also is being used more widely as a pasture for cattle and sheep. In general, mixtures with a grass such as smooth brome grass , timothy or cocksfoot are recommended when it is used primarily for pasture or homegrown hay. Bloat is less likely to occur when lucerne is sown with grass. Supplemental feeding of grain to dairy cows, sheep, and fattening cattle balances the high protein level of lucerne pasture with energy and extends the usefulness of pasture (Van Keuren and Marten, 1972). Lucerne will persist when rotationally grazed. Stands weaken rapidly if grazed continuously (Meyer et al., 1956). Creeping-rooted lucernes are also well adapted for dryland conditions (Heinrichs, 1963).

Despite these many advantages of lucerne, it would be unwise to extol them without drawing attention to certain weaknesses. Apart from problems of establishment and management (see section 2.3), there are some animal health questions, such as bloat and the possibility of oestrogen effects (McLean, 1967). Furthermore, for dehydrated meal production lucerne is not sufficiently drought-resistant to give sustained levels of growth on shallow soils in the absence of irrigation. Nevertheless, a plant which is capable of producing up to 25,000 kg/ha of nutritious dry matter a year must be considered a most valuable asset and worthy of increasing use.

2.1.5. LUCERNE IN IRAN

Lucerne is grown throughout most of Iran, with major producing areas in the central province and in the provinces to the west and northwest. Little lucerne is grown along the Caspian Sea and Persian Gulf. An estimated 284,000 hectares were planted to lucerne in 1990 with an average forage yield of about 4.8 t/ha (Baghestani, 1976). Yield is highest in the warmer regions of the southwest and lowest in the northwest (Baghestani, 1976).

Lucerne is fed green on small farms and oases to all types of farm animals. Local Iranian cultivars, such as Hamadani, Yazdi and Nikshahri are used, together with cultivars such as Simerchanscaia, Ranger, Krisari, and Kodi imported from other countries (such as Italy, Turkey, and Russia, USA). Major pest problems are: lucerne stem nematodes, Sitona spp., Egyptian lucerne weevil (Hepera brunneipennis), blue lucerne aphid (Acyrtosiphon kondoi), pea aphid (Acyrtosiphon craccivora Koch), lucerne mosaic virus (AMV), Phytophthora root rot (Phytophthora megasperma Drech), Rhizoctonia root rot (Rhizoctonia solani Kuhn), Fusarium root rot (Fusarium spp.), and dodder (Cuscuta approximata Bab). Lucerne research is carried out in different areas of Iran and involves utilization by animals, biology, ecology, morphology and/or control of lucerne pests (Baghestani, 1976).

2.1.6. LUCERNE IN NEW ZEALAND

Bolton et al., (1972) noted that the history of lucerne in New Zealand is relatively obscure. Lucerne is thought to have been introduced around 1800 from Europe, although Argentina was also suggested as a place of origin by Hadfield and Calder (1936).

Lucerne for grazing and conservation has been actively promoted in New Zealand for nearly 100 years (Hill, 1925; Langer, 1967; Wynn-Williams, 1982a). During the early 1970s, the area in lucerne rose steadily, being

recommended by advisers as one answer to maintaining good stock performance in dry years and in areas where pasture were adversely affected by grass grub (*Costelytra zealandica*). The area of lucerne in New Zealand peaked at 220,000 ha in 1976 but since then has declined to approximately 84000 ha in 1988. (Purves and Wynn-Williams, 1989). The increasing lucerne area prior to 1975 was due to an extension "push" for lucerne, including an establishment subsidy in some areas, as a result of a series of dry summers during the 1970s (Dunbier et al., 1983). During this time lucerne's advantage over pasture was greatest. Adult lucerne was resistant to insect pests, especially grass grub, a major problem at that time. The subsequent decrease in lucerne area was due to a number of indirect and direct factors (Purves and Wynn-Williams, 1989). Indirect factors which reduced the need to grow lucerne included changes in management, especially "all grass" wintering, increased use of irrigation and the closure of lucerne dehydration plants. Direct factors included those that affect production persistence and the economics of lucerne. According to Dunbier et al., (1982) the introduction or recognition of a number of pests and disease exacerbated by a series of seasons with above average rainfall were major factors causing loss of farmers' confidence in lucerne. Poor grazing management and high establishment costs have also been contributing factors. Palmer (1982) noted that this reduction may be temporary because the reduced plantings seem to be associated with a series of solvable or changeable problems such as diseases, insects and a period of high rainfall, but time has not supported this viewpoint.

Hoglund et al., (1974) reported that the pattern of lucerne growth is closely related to temperature and radiation where water is non-limiting. Growth rates are high in summer and low in winter and although winter kill is rare in New Zealand, growth may be negligible for 100-120 days in colder regions. Over 90% of the lucerne in New Zealand occurs in four regions with 16% in the North Island and the rest in the South Island (Marlborough, Canterbury, North Otago, Central Otago). About 64% of the

lucerne planted in New Zealand is grazed for periods of the year, and is used for production of either hay or silage. The other 36% of the planted area is used solely for grazing (Dunbier et al., 1982).

Lucerne seed production in New Zealand is considered inconsistent with an average yield of 200-450 kg/ha (Dunbier et al., 1983). The primary limiting factor is considered to be the lack of suitable pollinators (Wynn-Williams and Palmer, 1974).

2.1.7. "GRASSLANDS ORANGA " LUCERNE (*Medicago sativa* L.)

Until the early 1970s, Wairau or Hunter River were the main lucerne cultivars recommended and grown in New Zealand (Dunbier and Easton, 1982). Local seed growers produced enough seed to supply demand in most years. In 1971, bacterial wilt (*Corynebacterium insidiosum* (McCull) H.L.Jens) was recognized as a serious disease of lucerne in New Zealand (Close and Mulcock, 1972), and since then stem nematode (*Ditylenchus dipsaci* (Kuhn) Filipjev), blue-green lucerne aphid (*Acyrtosiphon kondoi* Shinji) pea aphid (*A. pisum* Harris) and phytophthora root rot (*Phytophthora megasperma* Drechs) have been recognized as serious pests or diseases.

Cultivars resistant to some of these pests and diseases have been introduced from the U.S.A. and recommended for use (Palmer and Donovan, 1980). Saranac, resistant to bacterial wilt, was the first in 1974, followed by Washoe in 1976 and Iroquois, Pioneer 521, AS13 and AS13R, WL311, Rere and WL318 in 1978, and Pioneer 524 in 1979.

Grasslands Oranga is a 23-parent synthetic. It was selected for resistance to bluegreen lucerne aphid from within a successful American cultivar, WL311, (Beard and Kwaguchi, 1978). It has good resistance to bacterial wilt and spotted alfalfa aphid and has yielded well at several trial sites. Grasslands Oranga is leafy and dark green, with a broad crown and moderate to good cool season growth; flower colour is variable. It is suitable for growing throughout

New Zealand except where phytophthora root rot or stem nematode is a problem (Easton and Cornege 1984).

Grasslands Oranga lucerne grows and persists well under cutting and grazing. It is less susceptible than some other cultivars to foliage pathogens. It can be used as a general purpose cultivar in all growing areas of New Zealand. Grasslands Oranga grows vigorously from early spring to late autumn and in mild areas. Some growth continues through the winter. It has the high herbage quality typical of lucerne and a good seed crop can be harvested after early spring sowing (DSIR). In later years seed can be taken after an early hay crop or late spring grazing.

2.2. ENVIRONMENTAL CONDITIONS FOR SEED PRODUCTION

In the field, environment is constantly changing, and the lucerne crop shows a corresponding genetically programmed response to environmental signals. Seed germination, elongation of basal buds, flowering, and cold hardening are specific examples of plant responses modified by the environment (Fick et al., 1988).

Hampton (1990) noted that seed yield in herbage legumes can change widely within and between seasons, yet in many species potential seed yield is high. Environment and management have significant effects on actual yield, which is often less than 20% of the potential.

It is well known that the environment in which seeds are produced has an effect on seed characteristics such as size, hard seeds and germination (Bass et al., 1988). A study by Walter and Jensen (1970) showed that, under controlled environmental conditions, air temperature and soil moisture not only affected seed yield, size, and germination, but also vigour of the subsequent seedlings of lucerne cultivars Ranger and Moapa.

2.2.1. TEMPERATURE

Temperature conditions may affect vegetative growth of the lucerne crop, floral induction, growth and differentiation of the inflorescence, flowering, pollen, germination, seed setting and seed maturation (Hampton, 1990).

2.2.1.1 EFFECT ON GERMINATION AND SEEDING EMERGENCE

Herbage legumes germinated more rapidly than herbage grasses at all temperatures, and temperature within the range 5-20°C did not affect the germination of white and red clover or lucerne (Hampton et al., 1987).

Bula and Massengale (1972) showed that temperature regulate speed of germination, primarily by regulating the metabolic processes involved. The acceleration of metabolic activity is reflected in the rate of growth and these reactions generally increase 2-3 fold for every 10° rise in temperature over the range 5-35°C. (Field et al., 1976).

Williams (1963) and Larsen (1967) quoted 4 -5°C as the minimum, 25°C as the optimum and 38°C as the maximum temperature for lucerne germination and emergence, with only small differences in the 15 - 30°C range and with appreciable varietal differences. Heinrichs (1967) studied the rate of germination of twenty lucerne cultivars at 5, 10, 15, and 20°C and found significant differences in rate of germination between cultivars at each temperature although for each cultivar the rate of germination increased with increasing temperature.

As temperature deviated more from the optimum, germination rates for all species declined, and the time to the commencement of germination increased (Hampton et al., 1987).

Van Keuren (1988) reported that frost heave is a serious problem with winter wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) as well as lucerne.

Townsend and McGinnies (1972) showed that the rate of lucerne seed germination depended on temperature, but the final germination percentage after 7 days was relatively insensitive over the 5 to 35°C range. Generally, lucerne germinated between 2 and 40°C with an optimum of about 19 to 25°C (Stone et al., 1979). McElgunn (1973) found that a 13/2°C alternating temperature treatment (12 h/12 h) reduced the final germination percentage compared with constant temperatures of 7, 10, 13, and 21°C, and alternating temperatures of 15/4, 18/7, and 27/16°C.

Stout (1992) found that freezing to -10°C was ineffective but freezing to -80°C was highly effective in decreasing hard-seedness. The -80°C freeze-thaw treatment increased rate of germination based on total seed population, total germination, rate of seedling development and number of seedlings established.

Temperature is also a primary factor affecting seedling emergence. Most rapid and vigorous seedling emergence occurs when daily mean air and soil temperature are near 25°C. (Pearson and Hunt, 1972b). Seedling emergence and growth is minimal at soil and air temperatures below 10°C or above 35°C.

Garza et al., (1965) claimed that growth of seedlings up to 4 weeks of age was better at 30°C than 15°C. Growth of 8-week-old seedlings however, was better under alternating temperatures of 30°C during the day and 15°C at night. Musgrave (1977) noted that with lucerne sown at widely differing sites, maximum establishment occurred when the mean 10 cm seed bed temperature was in the range 3-7°C, and that when soil temperatures were above or below this range, establishment was substantially reduced. He suggested that the poor establishment at low temperatures was due to slow germination of seed, since

the germination rate of lucerne is very temperature dependent over the range 0-5°C.

2.2.1.2. EFFECT ON VEGETATIVE GROWTH AND PLANT SURVIVAL

Temperature does not appear to be the main factor limiting the distribution of lucerne, since in the USA this species has survived for 19 weeks at temperatures below freezing and sometimes as low as -17.7°C (Bula & Smith, 1954). Rachie and Schmid (1955) also reported that 19-day-old lucerne seedlings showed 91.3% survival when subjected to -10°C for 12 hours. Jensen et al., (1967) showed that cv. Moapa lucerne plants grown in a warm regime (33°C day/17°C night) grew faster and reached 10 % bloom in about half the time of plants grown in a cool regime (24°C/4°C), and growth of seedlings is most rapid at 20 to 30°C. For example fresh weight of lucerne sprouts after 6 days was greater at 21 and 27°C than at 16°C (Hesterman et al., 1981). Growth rates were greatly reduced outside the temperature range of 10 to 37°C (Harding and Sheehy, 1980).

2.2.1.3. EFFECT ON REPRODUCTIVE GROWTH

Temperature and photoperiod appear to be the main factors involved in phenological development in lucerne, and development rate is accelerated by increasing temperature and increasing photoperiod (Fick et al., 1988). A general shortening of the prereproductive period as temperature increases has been noted by some workers (Greendfield and Smith, 1973; Harada, 1975), and Faix (1974) showed that flowering began about 3 weeks earlier at 35° than at 17°C.

2.2.1.4. EFFECT ON POLLINATION AND SEED SET

Hacquet (1990) reported that temperature between 25°C and 30°C have several other favourable effects: mainly, they promote pollinator activity and increase pod set.

The environment also affects fertilization of the ovules in pollinated flowers. Fertilization of lucerne flowers has been studied by many workers, and Doull (1967) reported a distinct tendency for fertilization to occur at the style end of the ovary, suggesting that pollen tube growth was not vigorous enough to ensure fertilization of ovules at the basal end of the ovary. Pollen tubes penetrated the ovary seven to nine hours after pollination, but fertilization did not occur until 24 to 27 hours after tripping. This means that pollen germination and the fertilization of ovules is a process which continues both day and night during flowering. Pollen does not grow well at high humidities and germinated best at 38°C.

Low relative humidity and high temperature were reported to decrease the lucerne floret's resistance to tripping, thereby increasing the incidence of automatic tripping (tripping without insect assistance) (Hely and Zorin, 1977). Knowles (1943) found temperature to be the most important of the weather factors influencing the frequency of tripping. Blondon et al., (1979) examined temperature and light effects on seed yield in phytotron studies, and found that pollen fertility and hence the number of fertilized ovules per ovary increased as temperature increased from 17° to 27°C.

High temperature (25-30° C) also promotes pollinator activity and seed set (Delaude, 1972), and seed yield usually increases as temperature at anthesis increases (Delaude, 1976).

2.2.1.5. EFFECT ON SEED PRODUCTION

The effect of temperature on seed production has not received much attention in recent years. Walter and Jensen (1970) found that air temperature and soil moisture during the period of seed production not only influenced seed weight and percentage germination but also influenced the growth of seedlings grown from seed.

Guy et al., (1971) showed that the effect of temperature on flower number is complex. Over the 17° to 27°C range, increasing temperatures generally increase the number of racemes per shoot but decrease the number of flowers per raceme, and they pointed out that high temperature during seed formation increases the initial amount of hard seed and may decrease seedling vigour (Dotzenko et al., 1967). Temperatures above 20°C are known to favour seed production (Doull, 1967), an effect which might be due to increased bee activity. However, the optimum temperature will vary between cultivars (Hampton, 1990).

2.2.2. RAINFALL

According to different authors, the main climatic factors affecting lucerne seed production are moisture deficiency, moisture excess, and rains during the harvest period. (Marble, 1981; Rincker, 1979).

Rincker et al., (1988) reported that the climate of the best lucerne production areas is distinguished by a low summer rainfall, adequate sunlight and rather high temperature as is verified in France (Hacquet, 1989), in USA (Rumbugh et al., 1971), and Iran (Hampton.pers. comm.).

Excessive water supply causes excessive vegetative growth (Fick, 1988). When that excess occurs, producers observe lodging and then vegetative branching which competes with seed set. But lucerne requires the

equivalent of 150 - 180 mm of water for maximum vegetative growth (Bolton, 1962).

Rainfall during the reproductive phase can have negative affects on pollination, increase disease problem and cause plant lodging (Hampton, 1990). Low seed yields in higher rainfall areas are undoubtedly due to insufficient moisture stress at the critical time (Langer, 1967).

According to Fick et al., (1988) temperature, light and water supply are known to interact in their effects on lucerne physiology. These authors reported that:

- The number of stems and the number of racemes per stem are reduced with increasing moisture stress due to reduced amounts of plant growth.
- The number of seeds per pod and 1000-seed weight are reduced with severe moisture stress while the hard seed percentage increases.

Relative humidity (above 50%) also appears to reduce pod set, especially at high temperature.

2.2.3. SOIL MOISTURE

The first step in germination is the uptake of moisture by the seed, termed imbibition (Lovato, 1981), with consequent swelling of the entire seed. In the absence of hard seed, imbibition of water in legume seed is much quicker than that of grasses and most of the water required for germination is imbibed during the first 4-8 hours (McWilliam et al., 1970). Inadequate moisture in the seed bed is probably the main reason for failure of seeds to germinate (Lovato, 1981). Campbell and Swain (1973b) also found that water stress was the major cause of seedling loss during establishment and in oversowing situations.

Both the respiration and photosynthetic processes in legumes are influenced more by water shortages than in many other species. For example, in lucerne, photosynthesis starts to decrease when soil moisture is reduced to 35% of the soil's maximum water-holding capacity (Walton, 1983).

Cowett and Sprague (1962) considered soil moisture to be one of the factors affecting the occurrence of basal shoots on the crown of the lucerne plant. Gist and Mott (1957) also found that growth of both shoot and roots of lucerne seedlings was reduced by increasing moisture stress. Under moisture stress the growth rate of the tops is usually reduced more than that of the roots (Peters and Runkles, 1967; Kramer, 1969).

Jackson (1960) showed that lucerne extracted soil moisture initially from the upper soil layers but gradually from the lower soil layers as the soil moisture content of the upper layers approached wilting point.

Vough and Marten (1971) observed a reduction in lucerne dry matter yield by high soil moisture stress due to reduced amounts of plant growth. Moisture stress greatly reduced the number of stems per plant, the number of internodes per stem, and internode length of all lucerne cultivars examined by Perry and Larson (1971).

Bula and Massengale (1972) showed that a sufficient soil moisture supply was important for seedling growth but that excess moisture was detrimental, due to reduced soil aeration. Excess water may thus cause the development of shallow root systems and plants with small crowns. In addition excess moisture may cause loss of seedlings by damping-off pathogens (Halse and Francis, 1974).

Goldman and Dovrat (1980) showed that when the overall frequency of tripping was low, plants in plots with low soil moisture had a higher frequency of tripping than plants in plots with high soil moisture.

Moisture stress has a significant effect on seed production in lucerne, although not in the same way as it affects forage yield. According to Pedersen

et al., (1972), the highest seed yields are produced when there is enough soil water available to prevent severe moisture stress, while moisture conditions causing excessive vegetative growth reduce seed yield. Highest seed yield, however is obtained when moisture stress develops at early flowering, and from this point on soil moisture in the root zone should be sufficient only to maintain plants in a healthy condition, and to fill the seed (Taylor et al., 1959).

2.2.4. LIGHT

The factors of light that influence growth can be separated into three parts: intensity, quality, and duration, all of which are determined by the latitude, time of year, atmospheric conditions and evaluation (Bula and Massengale, 1972).

Pritchett et al., (1951) showed that as lucerne seedlings were placed under decreasing light intensities ranging from 2833 f.c. to 157 f.c. the number of nodules and the dry weight of the plants decreased, and the growth response to nitrogen fertilizer decreased. Response stopped entirely below 422 f.c.

Matches et al., (1962) reported that lucerne seedlings were not tolerant of low light intensities a reacted to such conditions by reducing total plant dry weight, and the weight of aerial parts. These results further confirmed that root production is affected more than shoot production.

Gist and Mott (1957, 1958) grew legume seedlings in light intensities ranging from 204 to 1593 f.c. for 12 hours per day and reported a curvilinear growth response. Growth responses to different intensities of light varied with stage of seedling development.

Light quality refers to the wavelength of the light rays. Plant development is better under the full spectrum of sunlight than under any portion of it. Plants grown only under long wavelengths of infrared light usually grow continuously, as in darkness, while plants grown only under short wavelengths of ultraviolet light may be retarded in growth or even injured or

killed (Dale Smith, 1975).

Blackman and Black (1959) calculated that for maximum relative growth rate, lucerne seedlings required 2.51 times the amount of summer light energy in comparison with factors of 0.85 to 1.85 in other legumes.

As is the case with many others pasture and forage legumes, lucerne can be classified as a long day plant with regard to inflorescence initiation (Thomas, 1967). Medicago sativa grown at 17° to 18°C does not flower in short days (natural days up to 9½ to 10 hours long) but flowers in long days (the same natural days supplemented by light at 30 to 80 ft.c. from just before sunset to midnight) (Thomas, 1967).

2.2.5. SOIL CONDITIONS

Crop adaptation, yield, and fertility responses can vary considerably among contiguous soils on a landscape. Soil morphology, fertility status, and wetness characteristics are among the variables that contribute to differences in crop performance (Rennie and Clayton 1960).

Lucerne cultivation is generally restricted to deep, well-drained soils, because of severe stand depletion and yield losses on wet soil (Russell et al., 1978, Benoit et al., 1967). Soils with the desirable characteristics may not be present or available to only a limited extent on some farms. Appropriate management factors that improve the success of lucerne on less well-suited soils would provide the potential lucerne grower with more production options.

Erwin (1965) and Kuan and Erwin (1980) reported that phytophthora root rot (Phytophthora megasperma f.sp. medicaginis; PRR) is often considered to be a major cause of lucerne failure in wet soils. Nevertheless, serious growth suppression and yield loss has also been reported when plants were grown under conditions of excess soil water but in the absence of PRR (Barta, 1984). Plant nutrient application and plant disease resistance are management factors that may contribute to successful production on soils that are not inherently

well suited to growing lucerne (Alva, et al., 1986).

Assadian and Miyamoto (1987) showed that lucerne is susceptible to salt damage during establishment. Increasing concentration of single salt solution, in particular NaCl, decrease the rate and total percentage of lucerne germination (Redman, 1974; Uhvist, 1946), the germination percentage decreasing by at least 8% at an EC of 23 dSm⁻¹ (Electrical Conductivity, d. Siemons/m²) and by over 80% at an EC of 32 dSm⁻¹ (Assadian and Miyamoto, 1987). Additionally, a further study indicated that poor seedling emergence of some furrow irrigated crops in saline areas may be caused by hypocotyl salt injury after germination (Miyamoto et al., 1985).

Deinum (1990) noted that lucerne has been considered a good forage crop for clay soils. It has also now been shown to be good for acid sandy soils, provided good growth of Rhizobium bacteria is taken care of by inoculation and/or by lime pelleting the seed. Regrowth of lucerne and plant survival may be reduced on all soils when harvesting is done with heavy machinery under wet soil conditions.

2.2.5.1. pH

Historically the majority of acid soils in the world have been associated with humid regions receiving high amounts of precipitation. However the applications of high levels of ammonium - based N fertilizer have contributed to soil acidification.

Legumes have variable tolerance to soil acidity (Andrew, 1976) and the availability of nutrients and other chemicals in acidic soil may reduce the herbage yield of some legumes. In particular, N may be limited by poor nodulation arising from acidity (Conventry et al., 1987). However, when acidity reduces the number of nodules established, the nodules formed may increase in weight (Munns et al., 1977; Coventry et al., 1987). Evans et al.,

(1990) found that average nodule weight usually increased at lower pH. It is possible that this response may assist the production of dry matter, although maximum N content may not be achieved (Coventry et al., 1987). Most forage and pulse legume crops grown in northern Idaho show yield reduction when soil pH values are below 5.6 (Mahler and Mcdole, 1985; Mahler, 1986).

Rechigle et al., (1987) showed that soil acidity is a major growth-limiting factor responsible for stunting roots, reducing forage yield, and limiting nitrogen fixation in lucerne. Root stunting reduces moisture and nutrient uptake. There is a general consensus that the problem of acidity can be alleviated through liming and increasing pH (Adams, 1984).

Black and Cameron (1984) reported that lucerne is very sensitive to pH extremes in solution culture media, especially when the plants depend on nitrogen from rhizobial fixation (Andrew 1978). Munns (1968) showed that acidity inhibits nodulation of lucerne in the early stages but has no effect on nodulation after nodule infection. The acidity prevents root-hair infection. Although the optimum soil pH range for lucerne is slightly alkaline (6.2-7.8), the total range is 5.5-8.8 (Spurway, 1941). In soil of pH 5.3, Fox and Lipps (1955) found that root penetration was only 90 cm in the first year, nodulation was poor and the incidence of winter-kill high, whereas in soils of pH 6.3, lucerne established well and its roots penetrated to a depth of 150 cm.

Another reason for lucerne stand loss is sensitivity to soil acidity. At a soil pH lower than 5.5, Al or Mn may be toxic to plants or Ca and Mg may be deficient in the soil (Morris et al., 1992).

However, the optimum pH depends on the soil properties and no single pH value is optimal for all soil conditions (de Mooy et al., 1973).

2.3. EFFECT OF CROP MANAGEMENT ON SEED PRODUCTION AND QUALITY

Lucerne seed production is an integrated system composed of several parts.

Different environmental conditions (soil texture, soil depth, rainfall and seasonal temperature variation) may require differing production systems for specific locations. The challenge in producing high yields of lucerne seed at reasonable cost involves the managing of all principles associated with seed production, and applying these principles to the different situation.

The important principles in successful lucerne seed production are:

- 1- Good cultural practices (fertilizer, preparation of the seed bed, row spacing, rate of sowing, sowing date, inoculation, etc.).
- 2- Adequate amounts of properly timed irrigation water.
- 3- Adequate supplies of honeybees or other pollinating agents.
- 4- Control of weeds, diseases and insects.
- 5- Selection of the best time for harvesting and a rain-free period during seed maturation and harvest.
- 6- Choice of the best cultivar for seed production.

Lucerne seed production is affected by many factors: Climate, soil type, pollinator activity, genetic variability, insect pests, diverse cultural technique, management, and interactions between these different factors (Hacquet, 1989).

2.3.1. CHOOSING THE CORRECT SITE FOR SEED PRODUCTION

Lucerne is productive as a pasture plant in many climatic regions of the world. There are ecotypes that are adapted to cold, hot, and dry climates and grown on soils that vary from heavy clay to sand. Lucerne has survived

temperatures as low as -64°C and as high as 49°C, and may be found growing in areas with an annual precipitation of 250 mm or less (Aamodt, 1941). However lucerne seed is mostly produced in geographical locations other than where it will be planted for forage production (Jensen, 1991) because the climatic requirements for seed production are quite specific. Climate affects all phases of growth, development and seed production, and determines the distribution of successful commercial seed production. Current weather is the main factor limiting seed yield in any year.

Doull (1967) summarized climatic conditions favouring seed production as follows.

- 1- Mean temperature above 24°C during the day and above 18°C at night during the flowering period.
- 2- Growing period of more than three months.
- 3- Relatively dry air (<50 percentage R.H) both day and night during flowering.
- 4- Bright sunny days during flowering with a minimum of cool cloudy periods.
- 5- Rainfall distribution which provides adequate soil moisture for early vegetative growth, but induces a gradually increasing moisture stress from the beginning of flowering.

These climatic conditions promote good flowering of lucerne and provide an environment conducive to the pollinating activity of bees, two factors essential for seed production (Rincker et al., 1988).

2.3.2. SEEDBED PREPARATION FOR SEED PRODUCTION

The final objective is to produce a well drained, weed free, fine, firm, moist and level seedbed and root bed (White, 1973a). The seedbed must provide physical conditions optimum for germination of the seed and development of the seedling. The root bed must provide a zone having physical

properties favourable for root growth and must also sustain a healthy and vigorous root system through the intended life of the plant. An ideal seedbed for small seeded legumes should have the following characteristics:

- 1- There should be ample moisture in the surface layer and in the sub soil.
- 2- The surface soil in which the seeds are to be sown should be reasonably fine and granular but not excessively fine and pulverised.
- 3- The soil should be firm beneath the depth at which the seeds are to be sown.
- 4- The ploughed layer of soil should be in direct contact with the layer below in order to allow an uninterrupted upward, movement of soil moisture and nutrients (Ahlgren et al., 1945).

2.3.3. SOWING DATE

Lucerne sowing throughout the world is timed to coincide with reliable rainfall and moderate soil temperature, and to avoid aggressive weeds, high or low soil temperature, damaging insects and high or low intensity rainfall.

Wynn-Williams (1982) reported that in New Zealand lucerne is generally sown in the spring or early summer when soil temperatures are high enough to give rapid germination and the plants will be well established before the first winter. Hampton et al., (1987) noted that lucerne is less temperature dependent than some other species and can be sown in early spring. However, providing soil moisture is adequate, better establishment will result from sowing in early autumn (March/April) and mid spring (October).

Peters and Peters (1972) consider that weeds are often more of a problem in spring planted lucerne than in lucerne planted at other times.

In the USA the time of sowing depends on several factors and it therefore varies in different locations of the country, but spring sowings are more successful than summer or autumn sowings. In light textured soils

September sowing should be aimed for (Janson 1972; White 1975).

Kunelivs and Campbell (1987) showed in Canada direct-drilling lucerne between late April and mid-June resulted in the best establishment and yield. In Iran lucerne is generally sown in early spring or late summer.

2.3.4. EFFECT OF SPACING AND SOWING RATE ON SEED PRODUCTION

Row spacings and sowing rates are two management factors that have an effect on seed production of lucerne (Pankiw et al., 1977). Many workers have discussed the relationship between seed production and plant density. Density of stand required for high seed yields varies depending on the area and climate (Tesar and Marble, 1988). In the USA row spacings of 1.2-1.5 m on the sandy soils, 0.9-1.2 m on medium-textured soils, 0.6-0.9 m on clay or shallow hardpan soils, and spacings as low as 23 cm on heavy clay soils are suggested for lucerne (Pedersen et al., 1972). Also very low sowing rates are often used. For example, in California, optimum sowing rates vary from 0.3 to 2.0 kg/ha and in Mexico, sowing rates of 0.5 to 1.0 kg/ha were superior to more densely planted stands (Rincker et al., 1988).

Traditionally in New Zealand (for seed production) lucerne was sown at 5 to 10 kg/ha (Palmer and Donovan, 1980). In Canterbury and Marlborough there have been no consistent differences in seed yield between sowing rates which vary from 0.5 to 8 kg/ha and with row spacings of 19, 38, and 75 cm (Wynn-Williams and Palmer, 1974). Sowing 1 kg seed/ha gives 30-40 seeds/m² and with an average establishment rate of only half the seed sown producing plants, this gives enough plants for maximum yields (Palmer and Donovan, 1980).

Abu-Shakra et al., (1969) suggested that a square planting of 50 X 50 cm. gave a higher seed yield than 50 x 25 cm. Sufficient space for vigorous growth is the apparent reason for the superior performance of the plants spaced 50 cm

apart.

Prochazka and Kopriva (1988) noted that seed yields in rows 25 cm apart were better than in rows 12.5 cm apart. Beran (1966) showed that greater seed yields of lucerne were obtained when plants were grown in double rows (12.5 cm between rows) 45 cm apart compared to plants grown at closer spacing in single rows 12.5 cm apart. Lovato (1987) pointed out that in Italy high seed yields were achieved with row spacings from 20 to 50 cm and sowing rates of 4 to 8 kg of seed per hectare. Mozhaevand Luzko (1975) reported that a four year average lucerne seed yield in the USSR was 620 kg/ha when plants were grown in rows 60 cm apart, compared with only 420 kg/ha when plants were grown in rows 15 cm apart.

Some workers have reported that seed yield reductions occurred when lucerne plants were grown at wide spacings; for example, Antoniani (1972) grew lucerne for seed with 30, 45, 60, and 100 cm between rows, and densities of 10, 6.2, and 4.8 plants per square meter. Seed yield was increased with increased distance between the rows (from 30-60 cm) but decreased with both increases in plant density and when the distance between rows was greater than 60 cm.

Moga et al., (1985) suggested that higher seed yields were obtained at inter-plant spacings of 25 or 50 cm rather than 75 cm. Robinson et al., (1964) showed that the disadvantages of a very high population density are the cost of extra seeds required and an increase in lodging percentage.

Hoff and Mederski (1960) reported that equidistant planting may reduce competition between the roots of adjacent plants for water and nutrients and therefore should increase seed yield.

Sevecka (1985) showed that when lucerne cv. Palava was sown at different rates (0.75, 1.25, 2, 2.5, 3, 4, 5, 8 million germinable seeds/ha) and different spacings (12.5, 25, 50 cm), crop density was highest at the highest sowing rates but percentage emergence was highest at the lowest sowing

rates. Seed yields were not significantly affected by treatment. This indicated that the lowest sowing rates were adequate.

Al-Dulaimi et al., (1987) reported that when lucerne was sown at rates of 12, 24, or 36 kg seed/ha by broadcasting, or in rows 15, 30, 60, 90, or 120 cm apart, increasing row widths increased the numbers of stems/plant, racemes/stem, pods/raceme and seeds/pods. Increasing sowing rate decreased seed yield from 49.9 to 25.9 kg/ha in the first year and from 487 to 359 kg/ha in the second year.

Beran (1966) showed that at the widest spacing of 45 cm between rows, lucerne plants produced more branches and had a greater number of pods and seeds per branch than plants grown at a close spacing. This suggests that plants compensate for low density by increased development. Khrbeet and Al-Shamma (1987) reported that different sowing rates (1, 4, and 7 kg/ha) and number of cuts had a significant effect on the number of branches/plant, raceme/branch and pods/raceme whereas seeds/pod and 1000-seed wt were not affected. A sowing rate of 4 kg/ha gave the highest seed yield.

Abdel-Halim (1989) showed that shoot weight, root weight, and root diameter decreased with increasing sowing rate whereas the number of established roots increased.

Takasaki et al., (1970) reported that when growing lucerne at spacings ranging from 2 cm to 16.7 cm between plants, in the first year higher densities gave significantly higher yield than lower densities but in the second and third years there were no differences in dry matter.

2.3.5. DEPTH OF SOWING

Depth of sowing is a critical factor in the establishment of the relatively small lucerne seed. The optimal depth of sowing appears to be dependent on time of sowing, soil texture, soil moisture and degree of compaction. Highest field emergence is generally recorded at a sowing depth of 1.5 cm regardless of depth of soil loosening (Kubinec, 1987), a lowest field emergence (34.7%) being recorded at a sowing and loosening depth of 6 cm (Kubinec, 1987). Sund et al., (1966) found that the best depth of sowing was 1.3-2.5 cm in loam and 1.3 cm or less in clay soil. The optimal sowing depth for sandy loam or silt loam was found to be 1.25 cm. by Triplett and Tesar (1960). Bolton (1962) recommended that lucerne seed should be sown to a depth of 0.5 to 2.5 cm, or only deep enough to cover the seed adequately. Also he suggested lucerne seedlings may emerge from depths of 3.75-5 cm in sandy soils, but these depths cannot be recommended on heavier soil types. Many other workers have shown that optimal seeding depth is 1.25 cm. (Nel and Burgers, 1968). Townsend (1992) found that seedling emergence decreased with increased depth of planting, and that a decreasing seed size and an increasing depth of planting reduced seedling establishment.

2.3.6. SEED QUALITY

Seed quality in legume crops encompasses several important components or attributes. These include: genetic purity (Baskin, 1974; Delouche, 1974), physical purity (Baskin, 1974), germination/viability (Wilcox et al., 1974; Green et al., 1966), vigour (Chin, 1976), physical characteristics (West and Harris, 1963), size (Vaughan, and Delouche, 1968), insect and disease infestations (Miranda, 1977), mechanical damage (Baskin and Delouche, 1971), aeration and drying (Matthes and Rushing, 1972), moisture control (Matthes and Rushing, 1972), chemical and physical characteristics (Harrington, 1973),

and storage potential (Abdul-Baki and Baker, 1974).

These components must be recognized by agriculturalists (including seed producers) and should be taken into consideration throughout the production cycle if high quality seeds are to be produced.

Viability and vigour of seed are two important qualities in determining a high level of emergence and subsequent establishment with all plants (Hill, 1974). The speed of seed germination or seed vigour is an important factor in establishment under field conditions.

Perry (1981) noted that several factors cause variation in seed vigour such as environment and nutrition of the mother plant, stage of maturity at harvest, genetic constitution, seed size, mechanical integrity, deterioration and aging, and pathogens.

McWilliam et al., (1970) reported that germination rate of lucerne is as high or higher than of other species commonly oversown, and in arid environments, rapid elongation of the seedling root is consider a pre-requisite for successful establishment (Tadmor and Cohen, 1968).

Beveridge and Wilsie (1959) found no consistent relationship between seed size and emergence but found that the growth rate of resulting seedlings increased as seed size increased. This was attributed to greater cotyledonary food storage in the larger seeds, giving greater nourishment to the young plants.

Dalianis (1980) reported that there is generally a positive correlation for legumes, including lucerne, between seed size and rate of germination and seedling vigour. Large seeds tend to produce more vigorous seedlings than small and medium-sized seeds (Townsend, 1992). Carleton and Cooper (1972) found a significant positive relationship between seed weight and seedling vigour with birdsfoot trefoil, but not with lucerne and sainfoin. In general, in

lucerne, the heavier seed weight had the highest seedling emergence over all depths of plantings (Townsend, 1992).

Hampton (1990) claimed that not always but often large seed from within a seed lot produced high germination and high seedling vigour.

2.3.7. SOIL FERTILITY

2.3.7.1 Effect on plant establishment and growth

Bolton (1962) reported that the mineral elements necessary for growth of lucerne are: phosphorus, calcium, potassium, magnesium, sulphur, boron, iron, manganese, zinc, molybdenum, copper, and chlorine. Phosphorus, calcium, and potassium are the most important elements for establishment and phosphorus is particularly important because of its role in root development (Tesar and Jackobs 1972; Lathwell 1966).

Cowett and Sprague (1962) suggested that nutrient balance was more important than nutrient levels alone for the growth and basal shoot development of lucerne seedlings.

Valesh (1980) reported that high rates of N (240 kg/ha) markedly reduced emergence of lucerne, as did high PK rates (800 kg P₂O₅ and 1200 kg K₂O/ha). The effects of fertilizer on emergence in individual years were affected by weather conditions, particularly precipitation.

Langer (1968, 1973) showed that in New Zealand phosphorus, potassium, sulphur, molybdenum, copper, and boron are the elements to which lucerne has given the most positive responses. Adequate soil P at planting is essential to establishing productive stands of legumes. The amount and methods of placement of supplemental P depend on native soil fertility and P fixing capacity of the soil (Griffith, 1974). Sanderson and Jones (1993)

reported that P incorporated before planting increased lucerne dry matter more efficiently than did application by broadcasting. Markus and Battle (1965) noted that increasing rate of P (0-190 kg/ha) reduced lucerne stands in New Jersey.

Andrew and Norris (1961) pointed out more calcium is needed for nodulation than for plant growth, and even greater amounts are required for nitrogen fixation (Loneragan 1959).

Rehcigl et al., (1987) reported that soil acidity is a major growth-limiting factor responsible for stunting roots, reducing forage yield and limiting N fixation in lucerne.

The effects of lime in alleviating poor root development of lucerne have been variously attributed to lowering toxic levels of hydrogen ions (White 1965a), manganese (Schmehl et al., 1950) or aluminium (McLeod and Jackson, 1965) in soil.

Collins et al., (1986) reported that potassium fertilization increased shoot weight per plant, nodule number per core, and N fixation rate on a silt loam soil and a loamy sand soil more than the other nutrients studied (P,S). Phosphorus fertilization also increased shoot weight at both sites but had less effect than K fertilization. Addition of P and S increased nodule numbers on the sandy soil but not on the silt loam.

Sulphur fertilization had no effect on shoot weight but increased nodule numbers in lucerne grown on sandy soil Collins and Duk (1981) showed one of the important responses to K fertilization is increased photosynthesis.

Nitrogen fertilization for lucerne establishment is apparently associated with the concept that inoculated legumes benefit from nitrogen during the "prefixation" stage. There is little evidence in the literature that justifies nitrogen fertilization for establishing lucerne. Properly inoculated lucerne will fix large quantities of atmospheric N by symbiotic N₂ fixation. Small

amounts of N may be recommended at sowing time to aid seedling establishment prior to the development of effective nodulation (Hojjati et al., 1978). This provides N for rapid growth of the lucerne until nodules form on the roots and the rhizobia are able to fix N. In Ohio 90 kg/ha of nitrogen banded with P aided establishment, while 150 kg/ha. proved detrimental (Haynes and Thatcher, 1953).

Kim and Jensen (1989) noted that N application increased root, shoot and total seedling length, seedling volume and weight and nodule number per plant on lucerne.

Giddens (1959) reported that 50 kg nitrogen/ha at seeding time slightly increased lucerne forage yield.

Nuttal (1985) reported that N,P, and S are important nutrient elements in the production and quality of legume crops and that lucerne dry matter was increased with N fertilizer. Similar result have been observed by others (Feigenbaum and Hadas, 1980; Mathers et al., 1975).

In contrast, Markus and Battle, 1965, Gerwing and Ahlgren (1958), Murphy and Smith (1967) and many others have determined that N fertilization of lucerne tends to reduce stand density and yield, decrease longevity, and encourage the invasion of weeds and grasses.

Yun (1992) and Khar'kov and Tukan (1990) noted that for lucerne grown on acid soil, N application did not produce significantly more dry matter.

Curcita et al., (1991) reported that N application had no significant effect on yield of lucerne.

Nuttal (1978) showed that cool temperatures result in less microbial activity, and low soil moisture stress can reduce N concentration in lucerne herbage.

2.3.7.2 Effect on seed production

Craiu et al., (1984) reported increasing seed yield of lucerne with increased P application up to 140 kg/ha. The role of sulphur in seed production is not well known, but in Canterbury, New Zealand, an area known to be S deficient, growers report better responses from ammonium sulphate than other nitrogenous fertilisers (Rolston et al., 1985).

Sherrel (1983) reported a requirement for boron for seed production in Trifolium repens, Trifolium hybridum, T. pratense, and Medicago sativa. Boron application increased pollination in white clover and promoted flowering in lucerne. Lucerne seed yields have been increased in some areas by the application of B (Fisher and Berger, 1951).

2.3.8. IRRIGATION

Irrigation of lucerne, as for any crop, depends largely on the purpose for which the crop is grown (Steiner et al., 1992). Irrigation requirements for lucerne seed production are dependent on soil texture and depth, natural precipitation, evaporation, temperature, length of growing season, and cropping practices (Rincker et al., 1988).

The management practices for lucerne seed production are different from those for hay production (Beukes and Barnard, 1985). Lucerne is an inefficient user of water, since it has a low stomatal resistance to water transpiration (Kerr et al., (1973). This may well explain why the values for growth curve parameters and final lucerne yields under irrigation can be simply predicted from evapotranspiration and radiation. These findings are in agreement with studies by McFarlane et al., (1974).

Irrigation during the establishment season of lucerne substantially increases herbage production during the first season and total root weight and

root penetration at the end of the first season. Generally, the number of stems and the number of racemes per stem are reduced with increasing moisture stress (Goldman and Dovrat, 1980). Goldman and Dovrat (1980) showed that flowering increased with increased amounts of applied water, but the percentage of tripped (insect pollinated) flowers and seed yield decreased.

Irrigation in dry areas with high radiation levels can increase seed production of most seed crops. Highest seed production is achieved when irrigation practices prevent severe plant stress and promote slow, continuous growth through the entire production period without excessive stimulation of vegetative growth (Rincker et al., 1988).

Lucerne seed yields increased as the frequency of irrigation and the total amount of water applied increased during bloom and seed set. The highest yield was produced when the crop was irrigated at an accumulated E_{pan} of 75 mm between irrigations (Taylor and Marble, 1986).

Abu-Shakra et al., (1969) found irrigation applied once every two weeks, providing a seasonal total of 257 mm of water, produced the greatest seed yield. However, pod set, or the number of pods per raceme, was reduced with either high or low amounts of irrigation (Fick et al., 1988). The number of seeds per pod and 1000-seed weight were reduced with severe moisture stress, while the hard seed percentage increased (Abu-Shakra et al., 1969). Continued slow plant growth promotes floral development and results in maximum seed yields (Taylor and Marble, 1986). Few details as to the degree of stress and amount of water required to maximize lucerne seed production are available. Lucerne seed production in California has been reported to require as much as 1100 to > 1200 mm of water per season (Henderson et al., 1975). Taylor et al., (1959) in Utah reported highest relative seed yields when the soil was kept moist from initial regrowth in the spring until the initiation of bloom at which time irrigation water was withheld to increase stress and usage of stored water in the soil.

Water management during the vegetative season may also affect seed

yield. High seeds yield have been reported when 1000 mm of water (half of the crop season water requirement) was supplied during the nonreproductive period, with the remainder applied during reproduction (Yamada et al., 1973). Reduction in seed yields after the first or second production years have been attributed to a lack of sufficient subsoil water during each growing season (Kolar and Kohl, 1976).

Excessive water encourages vegetative growth (Fick et al., 1988), leading to lodging, competition with reproductive growth, and physiological and pathological injury (Alva et al., 1985).

2.3.9. WEEDS AND THEIR CONTROL

Weeds are the main problem in first-year seed production crops (Palmer and Donovan, 1980). Lucerne seedlings do not compete well with weeds, and the operation will fail without adequate weed control from the time of sowing. Weeds 10 mm high are already competing with seedling lucerne, and become increasingly difficult to kill as they grow. Trifluralin applied before sowing controls many annual weeds from the time of lucerne seedling emergence.

Douglas (1986) showed poor land selection and preparation, inadequate fertilizer, frequent cutting, prolonged grazing, pests and diseases may all weaken lucerne and lead to increased weed growth. Correcting cultural deficiencies and overcoming pest and disease effects by the use of therapeutants or resistant cultivars may overcome the weed problem. Palmer (1982) found that killing weeds often, but not always, increases the spring production of lucerne, but may not have any longer term effects.

Martin (1984) reported that fathen (Chenopodium album L.) is an important weed in lucerne stands in Canterbury. The main reason for the persistence of this problem weed is the large number of seeds produced, most

of which are dormant and can remain viable in the soil for many years and its greater competitive ability, especially during the establishment phase. Recommended herbicides for New Zealand conditions have been listed by Meeklah (1984).

Deinum (1990) showed that weed competition and water supply may be a greater problem on sandy soil than on clay soil.

Weeds reduce stands and yields, slow seed harvest, increase cleaning costs, and may contaminate other crops in the rotation (Dawson and Rincker, 1982). The most difficult weed seeds to remove from lucerne seed include: johnsongrass [*Sorghum halepense* (L.) Pers.]; mustard (*Brassica* spp.); dodder (*Cuscuta* spp.); sandbur (*Cenchrus* spp.); pigweed (*Amaranthus* spp.); alkali mallow (*Sida hederacea* Torr.); field bindweed (*Convolvulus arvensis* L.); curly dock (*Rumex crispus* L.); and both sweetclover (*Melilotus* L.) and sourclover (*Melilotus indica* All.). In many countries dodder is the most troublesome weed in many lucerne seed fields, where it not only reduces yield but contaminates the lucerne seed. The profitable production of lucerne seed is impossible in the absence of dodder control (Rinker et al., 1988). Lee and Timmons (1956) showed that when heavy infestations of dodder were controlled, seed yields were increased 500%.

Weed control in lucerne seed fields is important from stand establishment to seed cleaning. Cultural and chemical methods of control are available for both seeding and mature stands (Rinker et al., 1988).

In the USA, weeds are controlled by physical and chemical methods. In general, physical methods are the safest while chemical methods are the least expensive (Kuhns and Haramaki, 1985). Hand weeding is a high cost method. It is not only expensive in terms of labour, but if weeds are allowed to grow out of control for a short period of time, the crop may be damaged.

Mikhalev (1992) found that applying herbicides for weed control gave higher lucerne seed yield than sowing without weed control.

Herbicides commonly used in lucerne include (chemical name), 24-DB, simazine, terbacil, propyzamide, hexazinone, EPTC, metribzin, carbetamide, dinoseb, fluazifop, sethoxydim, benefine, profluralin, and haloxyfop.

2.3.10. INSECT PESTS AND INSECT CONTROL

Numerous insects can be present in lucerne. Some cause little or no damage to the seed crop, but others have been found to affect seed yield considerably. Macfarlane and Pottinger (1976) recorded 15 insect species which reduced lucerne production by damaging flower buds, seeds and pods. Pottinger and Macfarlane (1967) suggested that the two major lucerne insect pest in New Zealand were the larva of the grass grub (Costelytra zealandica Whits) and lucerne stem nematode (Ditylenchus dipsaci Kuhn). Other insects reported to affect lucerne establishment include white fringed weevil (Grapognathous leucoloma Boh.), red legged earth mite (Halotydeus destructor Tuck.), lucerne flea (Sminthurus viridis L.), Sand dune weevil (Cecyropa discors Broun) and slugs. Slugs have been reported to be the most important pests of red clover (*Trifolium pratense* L.) and lucerne during establishment in Pennsylvania (Byers et al., 1985), lucerne in New York (Dowling and Linscott, 1983), and white clover in England (Williams, 1984). No-till systems may actually enhance slug damage by providing a moist, dark drill slot which serves as a refuge for slugs (Ferguson and Barratt, 1983). In a comparison of pesticide treatments to control insects, plant diseases and slugs, Williams (1984) concluded that slugs were the most important problem, because slug control produced the best establishment, greatest harvest and biggest stolons of white clover. Grant et al., (1982) arrived at a similar conclusion with lucerne in Kentucky.

Slugs, Deroceras reticulatum (Muller), D. laeve (Muller) and Arion fasciatus (Nilsson) preferred lucerne and red clover to birdsfoot trefoil (Lotus corniculatus L.) in laboratory tests (Byers and Bierlein, 1982). The age and

growth stage of legume seedlings are important in determining their acceptability to slugs. Byers and Bierlein (1982) showed that slugs preferred the youngest seedlings of newly emerged to 7-day-old plants in the laboratory.

White fringed weevil is a major problem of seedling and established lucerne in the North Island of New Zealand, particularly on the lighter and sandy soil of the Manawatu, Wanganu district (Morton and Roberts, 1978). The root-feeding larva of white fringed weevil kill seedling lucerne, and in area with summer droughts, reduce the production and persistence of young (Morton and Roberts, 1978) and mature crops (East and Parr, 1977b).

Since 1967 blue green aphid (BGA) (Acyrtosiphon kondoi Shinji), pea aphid (PA), (A. pisum Harris) and Sitona weevil (Sitona sp.) have become established in New Zealand. After the establishment of BGA and PA, it soon became evident that the local cultivar Wairau, the most commonly-grown lucerne at that time, was highly susceptible to both pests (Kain and Trought, 1982).

Although any insect that attacks a plant may reduce seed production, blister beetles, pea aphid, grasshopper and mites are especially likely to influence the numbers and size of the seed (Walton, 1983). Some of the more specific injurious pests of lucerne grown for seed production are:

Lygus bugs: Two species, Lygus elisus and L. hesperus cause severe damage to lucerne seed in western USA. A third species, L. prantensis oblineatus, is also injurious in eastern USA. These bugs thrive on a wide range of cultivated and wild plants. Lucerne is the preferred host of Lygus bugs (Bolton, 1962) and the adults fly freely from one host to another and from farm to farm. The flower-buds are usually damaged seriously and a large proportion are shed; the pods are also attacked and either shrivel and drop off or produce under-developed, poor-quality seeds (Armon, 1972). A number of

insecticides such as taufluvalinate, demeton-S-methyl, maldison, diazinon, parathion, malathion, and demeton are available for the control of these pests in lucerne.

Lucerne weevils: These weevils (Hypera spp.) are very common pests of lucerne. The adult female weevils burrow into the stem to lay their eggs, whilst the larvae feed on the growing tips, leaves, and buds of lucerne and may prevent the profitable production of seed. The pest can be controlled by spraying with an appropriate insecticide, such as Dieldrin (Bolton, 1962).

Pea aphid (Macrosiphum pisi) : Heavy populations of the pea aphid on lucerne reduce the yield of seed.

Manglitz and Ratcliffe (1988) suggested four methods for insect control:

- I. Cultural control.
- II. Biological control.
- III. Use of a resistant cultivar.
- IV. The use of chemical control.

Each of these methods has a part in any reduction of insect damage to lucerne forage or seed and should not be considered alternatives. The choice depends on which method or methods will produce the best result, be economically practicable and have little or no adverse effect on the crop, beneficial insects, or environment. However, control of harmful insects is different for hay and seed crops because: (i) the forage from the seed crop is usually not fed to livestock; (ii) there is a need to protect bees in the seed crop; and (iii) the time required to produce a seed crop is longer than that required for hay (Pedersen et al., 1972).

2.3.11. DISEASE

Diseases have been estimated to cause annual losses of 24% of the forage and 9% of the seed yield in lucerne (Graham et al., 1972). Lucerne diseases are many and varied. Close (1967) reported 12 diseases on lucerne in New Zealand. Diseases can affect lucerne at all stages in its development and so influence establishment, herbage yields, seed quality, and lucerne stand life through decreased efficiency of water and nutrient utilization. Diseases that affect lucerne establishment in New Zealand are fungus diseases associated with Pythium species, Fusarium species and common leaf spot (Pseudopeziza medicaginis Sacc).

Hawthorne (1988) reported that germinating lucerne seeds, and seedlings less than 21 days old, are particularly susceptible to infection by Pythium spp. The consequent rotting of seed, and pre-or post-emergence losses of seedlings, reduces the initial establishment of lucerne crops in New Zealand and elsewhere (Close et al., 1982).

Stem nematode (Ditylenchus dipsaci) a widespread problem of lucerne in the South Island, has been increasing in incidence.

The seed-borne lucerne viruses, alfalfa mosaic virus, (AMV), Australian lucerne latent virus (ALLV) and lucerne transient streak virus (LTSV) are present in New Zealand lucerne crops (Ashby et al., 1979). ALLV is the most prevalent virus in New Zealand lucerne crops and at times its incidence has reached a level of 75-100% (Ashby et al., 1979). The vector for this virus has not been identified and its effect on yield is unknown.

Environmental conditions, such as high soil moisture and low temperature, which are unfavourable for rapid growth, are particularly conducive to disease development (Hawthorne, 1988). Graham et al., (1979) stated that the best way to reduce disease losses in lucerne is to grow locally adapted disease-resistant cultivars. Also good cultural and management practices help reduce disease losses.

2.3.12. GRAZING AND CUTTING

Defoliation by grazing or by cutting appears to have different effects on persistence of lucerne (Counce et al., 1984). Lucerne can be successfully managed under grazing by mimicking cutting management Iversen (1967). Lucerne grazed in short rotations, or almost continuously, gave considerably less production and reduced plant survival (O'Connor, 1970). In New Zealand the recommended resting times between grazing of 36 days (Iversen, 1967) and 42 days (O'Connor, 1970) are in agreement with numerous cutting trials (Smith, 1972) and Leach (1983). Where growth is severely restricted, such as in prolonged drought conditions, these resting times may be inadequate to maintain stand persistence (Brownlee, 1973).

Lucerne cultivars tolerant to grazing usually have poor seed yields (Smith and Bouton, 1989). Grazing or cutting seed crops before floral initiation or flower appearance generally does not decrease seed yield in forage crops (Hare, 1985). Later defoliation, however, which removes flowering parts is usually harmful. Defoliation can delay flowering time.

Hadfield (1957) indicated that in the establishment year, lucerne plants should not be cut if a subsequent seed crop is contemplated in the same year. Kowithayakorn and Hill (1982) suggested that time and severity of cutting were both responsible for seed yield reduction, the time of cutting tending to have the greatest effect on seed yield. Cutting plants prior to seeding resulted in a weakening of the plants, severely depressed reproductive potential, delayed flowering time and subsequently affected flower and seed production. They also found that plants cut at 7.5 cm resumed growth faster than those cut at 1 cm. Leaving a high stubble seems to be an advantage in connection with the amount of residual of leaf or leaf area index. This enables plants to resume growth faster than when all leaves are removed by cutting as reported by Cowett and Sprague (1962). Another advantage of leaving a high stubble is

that it provides more available sites for the initiation of flower buds and hence a larger number of flowers per plant. Kowithyakorn (1978) suggested lucerne plants should therefore not be cut at all in the year of plant establishment if high seed yields are expected.

Abu-Shakra et al., (1977) noted the effect of harvesting lucerne for forage purposes on subsequent seed yield. Their results showed that seed yield was greatly reduced when 3 or 4 forage harvests were taken before the crop was allowed to seed, compared to the situation when plants were allowed to run to seed following only 1 or 2 forage harvests. Seed crops taken following 1 or 2 forage harvests resulted in 4 times more seed per unit area than the yield from a crop taken following 3 or 4 forage harvests. They also reported that effects of forage harvesting on 1000 seed weight during the first and second seed crop were not significant and forage harvesting had no effect on the production of hard seed.

Melton (1973) showed that the highest seed yield of lucerne obtained from a plot in which only one harvest for fodder was taken before harvesting for seed.

Montanari and Lovato (1990) reported that one forage cut gave higher average seed yield and the greatest number of pods/m² and seeds/pod than two normal forage cuts before cutting for seed. Ciricifolo and Peccetti (1990) showed that in dry years a hay cut at the early bud stage gave higher seed yield than cutting at the early flowering or full flowering stage.

Pacucci et al., (1977) reported that cutting at the flower bud stage gave an average of 1070 kg seed/ha, cutting at the beginning of flowering 1210 kg, and cutting at full flowering 1160 kg seed/ha.

2.3.13. POLLINATION

When the pollen of a flower reaches the stigma of the same flower or of a flower of the same species, pollination takes place. In the former case we have self-pollination, and in the latter cross-pollination.

Lucerne has diadelphous flowers with nectar, and is cross-pollinated by insects. Self-pollination is prevented by a membrane which covers the stigma and which must be ruptured before the stigma becomes receptive. The tripping mechanism is explosive and can not be reset (Armstrong and White, 1935). Tripping of a lucerne floret occurs when the keel petals are disturbed, and it involves the sudden and forceful emergence of the staminal column, consisting of the fused filaments surrounding the ovary, from behind the keel petals (Viands et al., 1988). Tripping is the release of the sexual column from the keel of the flower and can be caused by many insects (Pedersen et al., 1972). Tripping is a requirement for cross pollination and seed production in lucerne (Rincker et al., 1988), lack of tripping being a major factor limiting lucerne seed yields (Knapp and Teuber, 1990).

Ambrus (1980) found lucerne seed yield was positively correlated with the presence of pollinators. Olmstead and Wooten (1987) reported that significant increases in lucerne seed yields and subsequent regional specialization in producing this crop were made possible by intensive use of honey bees and solitary bees in California, Washington, Oregon, and Idaho. Between 1950 and 1960, lucerne seed yields in these four western states increased to more than 1600 kg/ha, while the average yield in all other states remained about 400 kg/ha.

In New Zealand studies, honey bees and wild bumble bees (Bombus spp.) were shown to pollinate only 10% of lucerne flowers and even where waves of fresh hives were introduced, seed set was increased to only 16% (Palmer- Jones and Forster, 1972, Forster, 1974). Honey bees are most efficient pollen collectors where temperatures are above 32°C (Doull 1967) and areas

of the world where honey bees are efficient pollinators of lucerne have mean summer temperatures 8°C higher than anywhere in New Zealand (Palmer, 1966).

Honey bees are often very numerous in flowering lucerne, but flowers are seldom tripped because honeybees soon learn to dislike "taking it on the chin" and learn to avoid the tripping mechanism by working the flowers for nectar from the side (Hill, 1975) so that nectar is taken without triggering the tripping mechanism. Rincker et al., (1988) stated that in the northern USA and Canada, only 0 to 1% of the field force of honey bees are pollen gatherers, and that the nectar gatherers trip only 0.2 to 0.3% of florets visited. However, if there are pollen shortages caused by lack of other flowers, honeybees sometimes trip lucerne flowers to obtain pollen. Honey bees should be placed in lucerne seed fields when flowering has reached about 20-30% of maximum (Pedersen et al., 1972). Eight to nine colonies per hectare are required for effective pollination; half should be placed in the field initially, and the rest 10-14 days after.

Of the four species of bumble bees in New Zealand, the short-tongued bumble bee, *Bombus terrestris* L. is an excellent lucerne pollinator (Gurr, 1955; 1966; Macfarlane, 1976). The successful development of bumble bee hives, (Donovan and Wier, 1978) has provided the means to use bumble bees as pollinators of lucerne. A population of 1000-2000 bees/ha is recommended in New Zealand (Dunbier et al., 1983).

Solitary bees, including the alkali bee (*Nomia melanderi*) and the alfalfa leafcutting bee (*Megachile rotundata*), are better pollinators of lucerne seed than honey bees in Washington, Oregon, and Idaho (Olmstead and Wooten, 1987). The alkali bee is a soil-nesting bee native to western North America. Entomologists first documented the value of managing alkali bees for pollinating lucerne seed in the 1940s (Menke, 1952).

Donovan and Macfarlane (1984) reported that the alkali bee and the leaf

cutting bee were introduced to New Zealand in 1971 as efficient pollinators of lucerne, to increase seed yields and make them more reliable (Wynn-Williams and Palmer, 1974). These bees had already proved successful lucerne pollinators in the U.S.A. (Pederson et al., 1972). Donovan and Read (1984) showed in areas where 30-50,000 leafcutting bees/ha were introduced, seed yields of 500-700 kg/ha have been obtained.

Alfalfa leafcutting bees, which nest above ground and can therefore be maintained in transportable artificial shelters, were found to be valuable as a pollinator of lucerne seed in the 1950s (Bohart, 1972). These bees were particularly suited to conditions in Idaho, where yields increased significantly during the 1950s and 1960s (Olmstead and Wooten, 1987).

Marble (1990) reported that pollinating with leafcutting and/or alkali bees is a specialized industry. They are more effective than honey bees at latitudes greater than 35°.

The lucerne leafcutter bee is the most important pollinator of lucerne in North America and is increasing in importance throughout the world (Richards, 1991). The leafcutter bee is easily managed and is readily moved to its main target crop, lucerne, at the appropriate time for maximum benefit.

Palmer and Jones (1968) showed that one of the major problems of lucerne pollination in New Zealand was the competing pollen sources available during the flowering period.

2.3.14 SEED YIELD COMPONENTS

Adams (1975) explained a general yield component structure for legume involving pods/plant, seeds/pod, and seed weight/seed. Seeds are produced in pods and the yield components include pods per raceme, racemes per stem, stems per plant, and plants per unit area. Stems per unit area, racemes per

stem, and racemes per unit area were not affected significantly by cultivars (Pedersen and Nye, 1962). Many authors have reported correlations between seed yield and yield components (Hacquet, 1989), and seed number per pod is usually highly significant. The number of racemes and pods per raceme are also important characters. Seed yield depends on the number of seeds per unit area and individual seed weight. Seed yield in a legume consists of a series of yield components which in turn are determined by a combination of plant and environmental factors.

Rincker et al., (1988) observed that seed weight and seeds per floret (pod) within cultivars were influenced by environmental conditions over a period of four years.

Seed yield and seed weight are often negatively correlated, e.g. Pedersen (1962) found that seed weight is generally highest in low yielding cultivars.

2.3.15. SEED HARVESTING.

Coolbear (1993) stated that there is a good relationship between stage of seed development and seed moisture content. Generally, high moisture content (70-85%) is a characteristic of young seed in the early stages of seed development. This decreases as seeds go into a ripening stage of development. When using moisture content as a guide for maturity or harvesting Hill (1990) agreed that there are two aspects which farmers should be aware of - the relationship between moisture content and the percentage of seed viability may vary with growing season and also precipitation may alter the values obtained. Harvesting should commence when approximately 60% of the pods are brown (Kipps, 1983), but whichever process is employed, the crop must be cut at about 14% seed moisture (Hill, 1975).

Technology advances in harvesting practices have greatly reduced seed losses (Hanson and Barnes, 1972). All the lucerne seed does not mature at the

same time. When the seed is mature, it is an olive green colour. The seed shatters rather easily, so the crop should be handled carefully.

Various methods are used to collect the crop and separate the seeds. Under primitive conditions lucerne may be cut with a scythe, threshed with a flail, and the seeds windrowed in the wind. A more modern approach for small plots is to cut and bind with a grain binder, dry in stooks, and thresh with a threshing machine. In large fields where modern mechanization is possible, it is customary either to combine the crop directly, or to swath or windrow it and leave it until it is dry, before threshing with a pick-up attachment on a combine harvester (Bolton, 1962; Rincker et al., 1988).

2.3.16. SEED CLEANING

The cleaning of lucerne seed, particularly the separation of weed seeds, is highly specialized, and is probably best left to commercial operators who have the equipment and skill to do satisfactory work (Bolton, 1962). For cleaning of lucerne seed, conventional seed cleaning equipment can be used, such as, air screen cleaner, specific gravity separator, velvet roller separator, magnetic separator and indented cylinder. For good work, particular attention should be given to regulating the air blast, and to selecting the right type and size of screens.

2.3.17. SEED STORAGE

Several factors may determine the longevity of seeds stored in natural or controlled environments. These factors are moisture, temperature, gaseous exchange, seed coat characteristics, maturity, microflora, and insect infestation (Gunn, 1972). But there are some factors that affect storage life such as preharvest factors, harvest and conditioning methods, and postharvest factors

such as processing conditions, temperature of storage, seed moisture content (Bass et al., 1988).

While lucerne seeds may be long-lived under natural conditions, the maintenance of highest viability and vigour for several years dictates care in storing, whether they are commercial lots to be stored for one or two years, or genetic lots to be stored for longer periods. Maximum longevity of lucerne is obtained by:

- i. Using mature seeds with high initial viability and hard-seed count, handled so that mechanical injury is minimized (Bolton, 1962).
- ii. Storing in an environment with less than 10% seed moisture, preferably about 5%, with a temperature near to, 0°C. Low moisture is more important than low temperature, because a reduction of 1% in moisture doubles the life of seed in storage (Bewley and Black, 1982).
- iii. Replacing ambient air with carbon dioxide or nitrogen and sealing in containers.

A long-term (5-20 years) storage facility run at 0°C/30% relative humidity (RH) reduces the need for frequent multiplication (Rolston and Gomez, 1986). Less expensive long-term storage using sub-zero temperature (-15°C) with minimal RH% control (Rincker, 1981) is being tried on a limited basis. For short-term storage it is possible to use a low temperature (5°C) and 60% RH room or open ambient storage, provided germination is tested every 6 months and seed lots discarded once the germination has fallen 10% from their pre storage level.

2.4. PLANT GROWTH REGULATORS

Plant growth regulators are substances that, when added in small amounts, modify the growth of plants, usually stimulating or inhibiting part of the natural growth regulatory system (Halmann, 1990). They include hormones and synthetic chemicals.

Application of exogenous plant growth regulators have increased seed yields in several forage and grain legumes (White et al., 1987). Some plant growth regulator (PGR) substances are effective in maintaining various cool-season forage species in the vegetative state thereby enhancing the forage quality (Buck et al., 1988 and Wimer et al., 1986). Most of this work involved perennial grasses, the body of literature regarding the use of plant growth regulators on legume forage being comparatively small. The use of plant growth regulators such as paclobutrazol and chlormequat in herbage legumes is discussed separately in Chapter 4.

2.5 MAIN OBSTACLES FOR SEED PRODUCTION AND SEED YIELD

There are two major obstacles that limit lucerne seed production; firstly, while lucerne is a cross-pollinating plant, there is perhaps no agricultural crop in which the seed yield is as uncertain as it is in lucerne (Black, 1952). Success or failure depends largely on pollination. For this reason the type and number amount of pollinators and environmental conditions for activity of pollinators are important for high seed yield (Hampton, 1991). Secondly, its indeterminate flowering habit results in plants flowering over an extended period, during which raceme buds, blooming racemes, young pods and mature pods ready to dehisce can be present simultaneously on an individual plant (Kelly, 1988, Marshal et al., 1989; Hampton, 1991). This range in flowering period makes it extremely difficult to ascertain the correct time to harvest the crop for maximum seed yield. Early harvesting can result in unripe racemes being gathered but a late harvest may result in yield loss through shattering of seed (Hill, 1975).



Plate: 3.1 The Frewen's block, Pasture and Crop Research, Massey University, Palmerston North, New Zealand.

CHAPTER 3

EFFECT OF ROW SPACING AND SOWING RATE ON ESTABLISHMENT AND SEED PRODUCTION IN LUCERNE.

3.1 INTRODUCTION

Plant density plays a major role in maximizing yield, because competition between and within plants affects a plant's ability to produce vegetative and reproductive material. Too low a density will give high yield per plant but will give low yield per unit area, while on the other hand densities which are too high will tend to decrease yield because of interplant competition for light, water and nutrients.

In New Zealand, lucerne is considered an expensive crop to establish. Seed costs, especially of imported cultivars, have been high when compared with ryegrass/white clover seed (Purves and Wynn-Williams, 1989). Costs of establishing lucerne can be reduced if lower seeding rates are used (Purves and Wynn-Williams, 1989). The density of stand required for high lucerne seed production varies depending upon the area and climate (Tesar and Marble, 1988). Plant density is a primary factor to be considered in studies on seed production. The number of plants per unit area can have a major effect in altering the environment (i.e. light, water, nutrients etc.) and result in changes in both vegetative and reproductive crop yields.

Increased dry matter production with increasing plant density has been

reported in lucerne (Kowithayakorn, 1978). However the relationship between seed yield and plant population is very complex because of the plasticity of yield components and the interaction between the environment and genotype. These relationships were extensively reviewed by Chapman (1981). In general, relationships conform to one of two curves i) parabolic: where the yield of a crop reaches a maximum at a given population density and then declines, or ii) asymptotic: where yield approaches a maximum and is then relatively constant at high density. Holliday (1960) reported that the vegetative yield of a crop conforms to an asymptotic relationship and that reproductive forms of yield (i.e. fruit, grain, and seeds) conform to a parabolic relationship. Usually maximum seed yield is obtained at moderate plant densities and reduces thereafter. Yield components are determined by a combination of plant and environmental factors (Adams, 1975). Average number of flowers per plant decreases with increasing plant density because at very low density, plants have space to produce more branches and finally flowers in response to the extra light and nutrients (Hill, 1987). In legumes the number of pods per unit area is usually the first component to be influenced, as reported for *Vicia faba* (Ingram, 1976) and *Glycine max* (Chanprasert, 1988). i.e. pod numbers per unit area increases in spite of a reduction in the number of pods per plant as plant density is increased. In contrast, both seed weight and number of seeds per pod tend to be less affected by changes in plant density and are capable of considerable compensation depending on the number of pods per plant (Bennett et al., 1977).

In New Zealand lucerne seed has commonly been produced in rows 9 or 18 cm apart at seeding rates of 6-12 kg/ha (Wynn-Williams and Palmer, 1974). Dunbier et al., (1983) recommended a sowing rate of 1.0 kg/ha and row spacing of 75 cm. Kowithayakorn and Hill (1982) reported that to obtain

highest seed yield, plants should be grown at a density of 11-25 plants/m². Experiments conducted overseas, especially in the USA have shown that highest seed yields were obtained from lucerne sown at rates ranging from 0.5 to 2.0 kg/ha and in rows from 60 - 150 cm apart (Bolton, 1956, Abu-Shakra et al., 1969, Goplen, 1972).

However the literature differs with respect to whether wide spacings favour high seed yield per unit area in lucerne. Al-Dulaimi (1987) reported that when lucerne was sown at rates of 12, 24, and 36 kg/ha in rows 15, 30, 60, 90, or 120 cm apart, increasing row widths increased the number of stems/plant, racemes/stem, pods/raceme, seeds/pod, and therefore increased seed yield. However increasing sowing rates decreased seed yield from 49.9 to 25.9 kg/ha in the first year and from 487 to 356 kg/ha in the second year due to competition between plants for nutrients, water and light. In addition Mozhaev and Luzko (1975) found that a four year average lucerne seed yield was higher when plants were grown in 60 cm rows than when plants were grown in 15 cm rows. In contrast, Moga et al., (1985) suggested that higher seed yields were obtained at inter row spacings of 25 or 50 cm rather than 75 cm. Antoniani (1971) found that with 30, 45, 60, 80 and 100 cm spacings between rows and at densities of 10, 6.2 or 4.85 plants/m², seed yield increased as distance between the rows increased from 30 to 60 cm, but decreased with both increases in plant density and when the distance between rows was greater than 60 cm. Also Abu-shakra et al., (1969) suggested that a square planting of 50 X 50 cm gave a higher seed yield than spacings of 50 X 25 and 50 X 75 cm.

Pedersen et al., (1972) suggested that row spacings should vary with soil type and the size to which plants are expected to grow. Pedersen and McAllister (1955) showed that widely spaced plants produced flowers with more nectar than closely spaced plants, and were visited more frequently by

bees. Among wider spaced plants humidity is lower and insecticides and herbicides penetrate more thoroughly, and consequently there is less damage from weeds and pests (Pedersen et al., 1972). Widely spaced plants also use less water, and seeds mature more uniformly (Melton, 1962). On the other hand sowing to produce a very low plant population in wide rows may reduce hay yields, which in some cases may be an important component of the economics of seed production, and necessitate cultivation or the use of herbicides to prevent weed infestation.

Establishment is the most critical stage of a crop's life (Culleton and McCarthy, 1983), since the result largely determines subsequent performance (Sears, 1961). Establishment of lucerne when measured as a percentage of viable seed sown is generally poor (Hawthorne, 1987), even under favourable agronomic conditions. Tesar and Jacobs (1972) noted that some part of this low survival was due to competition between plants causing self-thinning, but even at a low sowing rate (2.5 kg/ha) in New Zealand, the best survival was only 50% (Wynn-William, 1982). There are also occasional crop failures brought about by pathogens such as *Pythium* spp. (Falloon and Skipp 1982). This study reports how factors such as sowing rate and row spacing affected the establishment and seed production of lucerne in Palmerston North, New Zealand.

3.2 Definition of terms used

Cultivar: a group of cultivated plants, distinguishable from other groups of plants belonging to the same species by distinctive, inherited characteristics, and which when reproduced retain these distinctive characteristics. Thus, Grasslands Oranga is a lucerne cultivar.

Indeterminate: said mainly of an inflorescence whose axis is not limited by terminal flowers.

Seedling: very small plant which has just sprouted from a seed.

Reproductive shoot (RS): Shoots bearing at least one floral bud and/or flower.

Vegetative shoot (VS): Non-flowering shoot.

Main shoot (MS): shoot emanating from the crown.

Primary lateral shoot (PLS): shoot emanating from a node on the main shoot.

Secondary lateral shoot (SLS): lateral branch emanating from a primary lateral shoot.

Tertiary lateral shoot (TLS): lateral branch growing from a node on a secondary lateral shoot.

Floret: same as a flower in function, but only a part of a group of flowers forming an inflorescence.

Raceme: Inflorescence, particularly of lucerne.

Flower bud initiation: the morphological changes in the development of a reproductive meristem from a vegetative meristem.

Flower bud (FB): inflorescence with floret not yet open.

Open flower (OF): raceme with at least one open floret.

Flowering: stage where at least one floret of a raceme is open and ready for pollination.

Pod: A carpel which has grown into a fruit after fertilization.

Harvestable raceme : raceme with developing and/or developed pods.

3.3 MATERIALS AND METHODS

3.3.1. Experimental site and seed source

The 1400 m² trial site was located at the Massey University 'Frewen's Block experimental area', Palmerston North, New Zealand (Latitude 40° S, Longitude 175° E) (Plate 3.1). The soil, a Manawatu fine sandy loam (Cowie, 1974) is described in Appendix 3.1 and soil analysis results are shown in Appendix 3.2. The site had previously been in ryegrass/white clover pasture. The land was ploughed in March 1990 and then fallowed. Glyphosate (Roundup) at 0.75 kg a.i./ha was applied in February 1991 to control weeds. The site was then rotary hoed once before sowing in March 1991.

The certified basic seed of lucerne (*Medicago sativa*, L.), cv. Grasslands Oranga used in this study was supplied by the Grasslands Division of DSIR (now Ag Research, Grasslands). Uninoculated lucerne seed was sown using a cone seeder (Elite-Drill-Machine, Seedmatic 6, 'System Weihenstephan', F. Walter and H. Wintersteiger K.G., Austria). No irrigation was applied.

3.3.2. Treatments and experimental design

The experiment was set up using a split plot design with four replicates, having four row spacings as main plots and four sowing rates as sub-plots. The row spacings were 15, 30, 45, and 60 cm, and the sowing rates were 1, 3, 6, and 12 kg/ha (which produced 15, 45, 91, and 182 seeds/metre of row). Seeds were sown at a depth of 1.5 cm on 15th March 1991, using 13 rows/plot for the 15 cm spacing, six rows/plot for the 30 cm spacing, four

rows/plot for the 45 cm spacing, and three rows/plot for the 60 cm spacing. The area of each main plot was 50 m² and each sub-plot was 5 x 2 m² (10 m²), with a 0.5 m gap between each sub-plot and 3 m gap between replicates.

3.3.3. Experimental management

1991/1992: Plants were sprayed with fungicide (Benlate at 0.25 kg a.i./ha) on 10 April when the first symptoms of fungal (damping-off group) infection were observed, and again on 10 December for controlling lucerne leaf spot (*Pseudopeziza medicaginis* (Lib.) sacc. Mavrik aquaflo insecticide (Fluvalinate) 0.1 kg a.i./ha was applied at 30 ml/100 litres of water on 30 April and 10 December 1991, to control white-fringed weevil (Plate 3.2), aphids and leaf and flower-eating insects. The insects and fungi were identified by staff of the Plant Health Group, Department of Plant Science, Massey University. Mesurol snail and slug pellets (Methiocarb, 20 g/kg bait) were broadcast at about 8 kg/ha on 1 April and 7 May 1991. Because seeds were not inoculated, N fertiliser was applied (as urea) at 50 kg N/ha on 20 November.

1992/1993: Plants were grazed by sheep on 30 July, and fluvalinate (0.1 kg a.i./ha) was applied on 20 November and 15 December 1992 for controlling harmful insects. Plants were sprayed with Benlate at 0.25 kg a.i./ha on 15 December 1992. N fertiliser was applied (as urea) at 25 kg N/ha on 15 November 1992. Details of agronomic management for both years are provided in Table 3.1.

A



B



C



Plate 3.2 White fringed weevil A. Adult B. larvae, C. Lucerne seedlings damaged by larvae.

3.3.4. Environment during emergence

Daily mean, maximum, and minimum soil and air temperature were obtained with the use of a LI-COR data logger LI-1000 sited in the field. Two temperature probes were used. One probe was used to measure air temperature, at a height of 25 cm above ground level. Another probe measured soil temperature, at a depth of 5 cm during seedling emergence (first two weeks after sowing). Maximum and minimum temperature, rainfall, sunshine, and wind run for 1991-1993 and 60 year average data (obtained from AgResearch Grasslands) were recorded at a station 2 km from the trial area.

3.3.5. Weeds and their control

Weeds present at the experimental site and identified by Dr K.C. Harrington, Department of Plant Science, Massey University were broad leaved dock (*Rumex obtusifolius*), white clover (*Trifolium repens*), annual mouse-ear chickweed (*Cerastium glomeratum*), mouse-ear chickweed (*Cerastium fontanum*), dandelion (*Taraxacum officinale*), annual poa (*Poa annua*), twin cress (*Coronopus didymus*), willow weed (*Polygonum persicaria*), prickly sow thistle (*Soncus asper*) (see Chapter 6), toad rush (*Juncus bufonius*), and soldiers button (*Cotula australis*). There were two methods of weed control employed, hand hoeing and herbicide application. The herbicide 2,4-DB was applied post emergence at a rate of 2.4 kg a.i/ha on 25 May 1991 for broad leaf weed control and propyzamide (Kerb) at a rate of 0.75 kg a.i/ha on 21 July 1991 for grass weed control. However, white clover was a major problem and had to be removed

by hand hoeing in October 1991 with a follow up in late November 1991. On the first of October 1992, hexazinone (Velpar L) at 1 kg a.i/ha was applied to remove white clover, Poa annua and broad leaf weeds. Weeds not controlled by the herbicide were removed by hand-pulling or hoeing in early November.

3.3.6. Pollination

Pollination in both years was provided by honey bees. Two honey bee colonies were placed adjacent to the trial after flowering started on 10 January 1992, and 24 December, 1992. During the period of the experiment bumble bees (Bombus spp.) were also present but the population was low.

As mentioned before in the literature review, leaf cutter bees are known to be better pollinators for lucerne than honey bees. However, the windy weather during the flowering period in Palmerston North is not suitable for leaf cutter bee activity (E. Roberts, pers. comm.).

3.3.7. Establishment

Plant establishment was recorded on 11 April and again on 13 May 1991, by counting all plants within two randomly selected 0.5 m lengths of row per sub-plot. The recorded sections of row length were marked and plants recounted on 28 September 1991, to assess winter survival. The recorded number of plants were compared with the number of seeds originally sown per metre row and the percentage plant establishment determined at all times. On 30 September 1992 a final plant population count was made using the same method as above but with a different randomly selected site in each plot.

3.3.8 Plant morphology

Plants from a 0.25 m² quadrat in each plot were cut at ground level for growth analysis to evaluate plant morphology at 10 days after peak flowering (10DAPF) on 7 February, 1992. From each sample the length of 25 stems, the number of vegetative and reproductive shoots divided into main shoots (MS), primary lateral shoots (PLS), secondary lateral shoots (SLS), tertiary lateral shoots (TLS) (Plate 3.3) and the number of harvestable racemes, open flowers and flower buds were counted. All plant material was then placed in an oven at 65° C for 96 hours, and weighed to determine dry matter content.

In the second year to enable the identification of primary lateral shoots as well as main shoots, five plants were sampled at random from each plot for growth analysis ten days after peak flowering (10DAPF) on 29 January 1993. Plants were dug from the soil, and plant height, main stem length, number of nodes on the main stem, number of lateral shoots, and dry matter per plant were determined as described for the previous year.

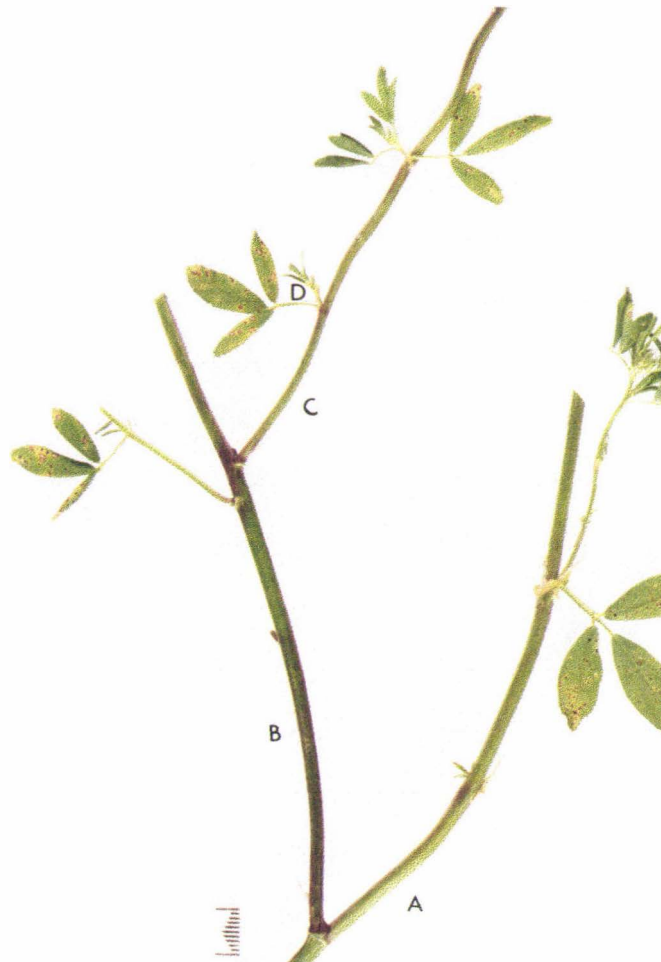


Plate: 3.3 Stem branching A. Main stem, B. Primary lateral shoot, C. Secondary lateral shoot, D. Tertiary lateral shoot.

Table 3.1 Agronomic management and experimental detail, 1991/1992, and 1992/1993.

	1991/1992	1992/1993
Site	Massey University	As per 91/92
Seed source	AgResearch Grasslands, NZ.	-
Sowing date	15 March 1991	-
Sowing rate	1, 3, 6, 12 kg/ha	-
Row spacing	15, 30, 45, 60 cm	-
Irrigation	None	-
Soil type	Manawatu fine sandy loam	-
Site soil analysis	pH-5.2 Olsen P-15, So4-10, Exch K-0.27, Exch Ca-5.56, Exch Mg-1.5, Exch Na-0.07, CEC-15	-
Grazing	None	30 July
Slug control	Mesurool 8 kg/ha 1 April, 7 May	None
Insect control	Fluvalinate 0.1 kg ai/ha 30 April, 10 Dec.,	as per 91/92, applied 20 Nov., 15 Dec.
Herbicide	2,4-DB 2.4 kg ai/ha 21 May, Propyzamide 0.75 kg ai/ha 21 July	Hexazinone 1.0 kg ai/ha 1 Oct.
Disease control	Benlate 0.25 kg ai/ha 10 April, 10 Dec.	as per 91/92 applied 15 Dec.
Hand weeding	Oct. and late Nov.	1 Nov.
Plant stand recorded	11 April, 13 May, 28 Sep.	28 Sep.
Dry matter recorded	12 June, 8 Oct. 15 Jan.	17 March
Defoliation	8 Nov.	None
N fertiliser	50 kg N/ha 20 Nov.	25 kg N/ha 15 Nov.
First flowering	31 Dec.	8 Dec.
End of flowering	20 March	17 March
Pollinators introduced	10 Jan.	24 Dec.
Seed harvest	20 March	17 March

3.3.9. Dry matter production

Dry matter was obtained by removing all the plants from within a randomly sited 0.5 m² quadrat in each sub-plot on 12 June, and 25 September 1991, and 10 days after peak flowering on 7 February 1992. At the 12 June sampling plants were dug up, the number of leaves per plant were counted and the dry matter of roots and vegetative growth determined after drying in an oven at 65° C for 96 hours. For the second and third sampling dates only vegetative dry matter was recorded because the plants were cut at ground level. The lucerne and weed components were then separated. The green material from each sub-plot was placed at 65° C for 96 hours and dry weight determined.

3.3.10. Flowering pattern

Flowering pattern was recorded from a randomly allocated 50 x 50 cm permanent quadrat in each plot in both years. Only flowers with at least one open floret and no withered florets were counted. First flowering began on 31st December 1991 in the first year and on 8 December 1992 in the second year. Flowers were counted every seven days during the flowering period. To prevent double counting or missing the counting of flowers, open flowers were tagged with different coloured wires until 14 days after peak flowering, and then this tagging process was stopped. The number of floret buds per flower and florets per raceme were recorded from 50 randomly selected inflorescences 10 days before flowering and full bloom respectively in the first year, and at peak flowering in the second year.

3.3.11. Seed yield and yield components

All plant material from within two randomly placed 0.5 m² areas per sub-plot was harvested 59 and 62 days after peak flowering in the first and second year respectively, when the majority of pods had turned brown. Sampling was done by using a motorized hand piece to cut plants at ground level and all plant material was collected and bagged. Samples were then left to air dry for four weeks in the first year, after which the racemes from each sample were separated by hand. In the second year racemes were separated from the plants immediately after harvest and dried at ambient temperature for three weeks. Seeds from each sample were threshed by hand rubbing and cleaned using 1.0 to 1.7 mm sieves and then a Burrows portable blower set at 41.4 km/h air speed for three minutes. Pure seed weight was recorded, and seed moisture content determined. Yield per unit area was obtained from the weight of seeds from each sub-plot in each treatment. Actual seed yields were corrected to 8% moisture content. Potential harvestable seed yield/unit area (PHSY) was determined from the seed yield components recorded at harvest by using the formula (Hill, 1993):

Potential harvestable seed yield = $P \times E \times N \times S$

Where P = Total number of flowers/unit area

E = the number of pods/raceme

N = the number of seeds/pod

S = seed weight or TSW/1000.

The percentage of actual seed yield compared to PHSY was determined by dividing actual seed yield by PHSY x 100. All stems and threshed pods were



Plate 3.3a Lucerne is an indeterminate legume. The plant can have flower buds, fully-opened flowers, young and mature pods all on the same stem (photo taken 30 days after peak flowering).

oven dried at 80°C for two days for harvest index assessment. Harvest index was determined by using the formula: actual seed yield (at 0%MC)/total plant dry weight x 100.

The number of pods per raceme were determined from 50 brown black racemes taken randomly from each sub-plot just after harvesting. Seeds per pod were determined by hand threshing of racemes.

After harvest in the first season remaining plants were cut to 7 cm and the cut material removed from the field. On 30 July the field was grazed to 7-8 cm above the ground (Table, 1) before being closed for seed production on 2 August 1992.

3.3.12. Germination

Seeds from each sub-plot were germination tested in early May 1992, and late April 1993 using the test prescriptions in the ISTA Rules (ISTA, 1985), with four replicates of 50 seeds.

3.3.13. Thousand seed weight and seed moisture content

Thousand seed weight (TSW) for each treatment was obtained (ISTA, 1985). For each treatment eight replicates of 100 seeds were counted and weighed and the mean TSW calculated from the average. TSW was then adjusted to 8% seed moisture content.

The seed moisture content for each treatment was determined using the recommended method of oven drying at 130°C for one hour (ISTA, 1985).

3.3.14. Statistical analysis

Statistical analysis was done using the SAS system (SAS 1991). Least significant differences at the 5 per cent probability level ($P < 0.05$) were used to differentiate treatment means where analyses of variance (ANOVA) or general linear model (GLM) were significant at the 0.05 or 0.01 level of confidence. The figures in this study were drawn using the Microsoft chart programme.

3.4. RESULTS

The results of this experiment are presented in three sections: section 3.3.1 presents the meteorological data for the 1991-1993 cropping seasons and the 60 year averages; section 3.3.2 presents the effects of row spacing, and section 3.3.3 presents the effect of sowing rate on plant establishment and seed production. These latter two sections have been presented this way because with one exception (seeds per pod in the second year) there were no significant interactions between row spacing and sowing rate for any of the data recorded.

3.4.1 METEOROLOGICAL DATA

The mean, maximum, and minimum daily air (25 cm above ground) and soil (5 cm depth of soil) temperatures during the first two weeks after sowing (15-28 March) are presented in Appendix 3.3. Air temperature ranged from a minimum of 7.3 to a maximum of 29.9°C, while 5 cm soil temperature ranged from a minimum of 12.4 to a maximum of 23.9°C. Mean air and soil temperatures were 17.6 and 17.1°C respectively (Appendix 3.3).

Climate data for the cropping seasons 1991/1992, and 1992/1993 are presented in Figures 3.1a, 3.1b, 3.1c, 3.1d. The total amount of rain for the first year was higher than for the second year (1067.5 versus 986.6 mm, respectively). During the second cropping year the month of December was particularly wet (+106% more than December 1991) but January and February (1993) were dryer than 1992. February 1992 was very wet, having +132% more rain than the 60 year average (Fig. 3.1a).

Mean daily maximum and minimum spring and summer temperatures were lower by 1-2°C for the second year than the first year, with an exception for November 1992. In particular, cooler conditions occurred during December, January, and February (flowering period and seed development) in the second year (1992/1993), than in the first year. During these months monthly mean minimum and maximum temperature ranged from 10.8-20.8°C, compared to 11.3-21.9°C in 1991/1992.

Sunshine hours and wind speed over the period of March 1991 to February 1993 and 60 year averages are shown in Figures 3.1c, and 3.1d. Sunshine hours during January and February 1993 were +18.5 and +18.7% more than sunshine during these months than in 1992 (Fig 3.1c), but wind speed during January 1993 was +51% more than in January 1992 (Fig 3.1d).

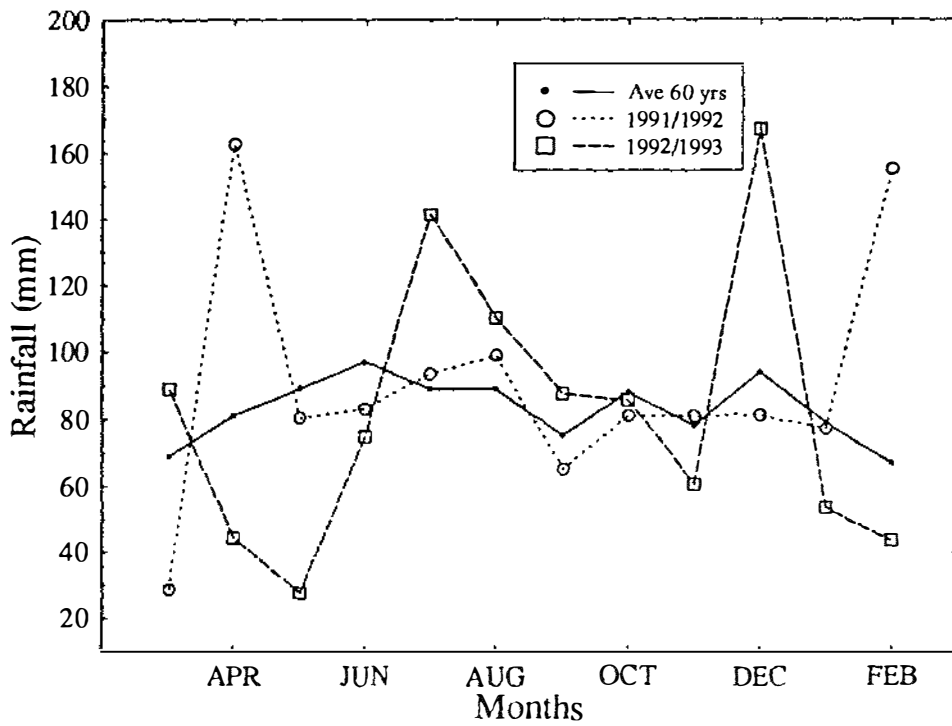


Fig 3.1a Sixty year average rainfall, and rainfall during the 1991/1992 and 1992/1993 cropping seasons at Palmerston North.

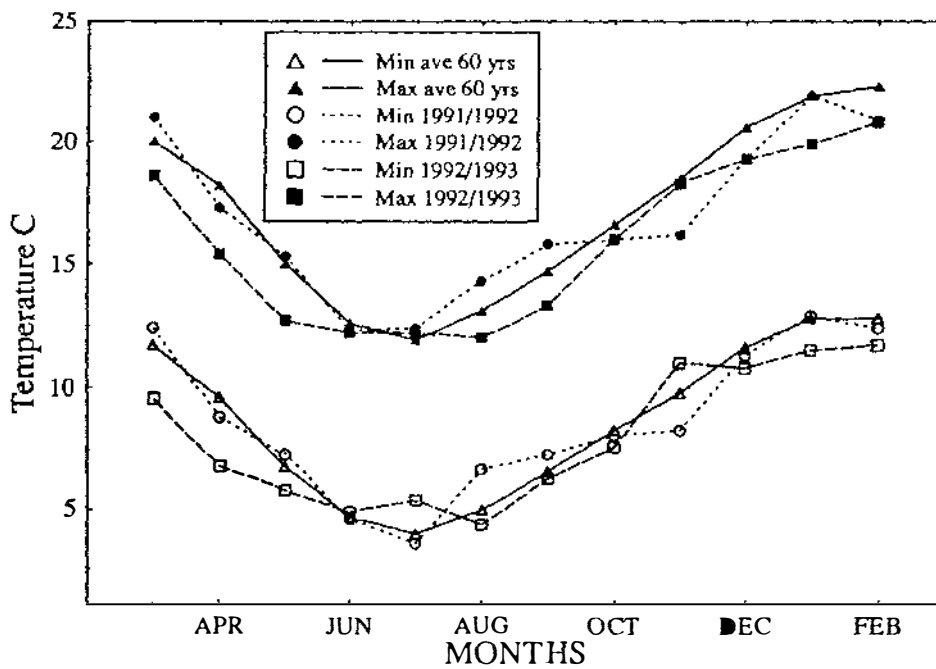


Fig 3.1b: Minimum and maximum temperature during the two cropping seasons (1991-1993) and the sixty year average for Palmerston North

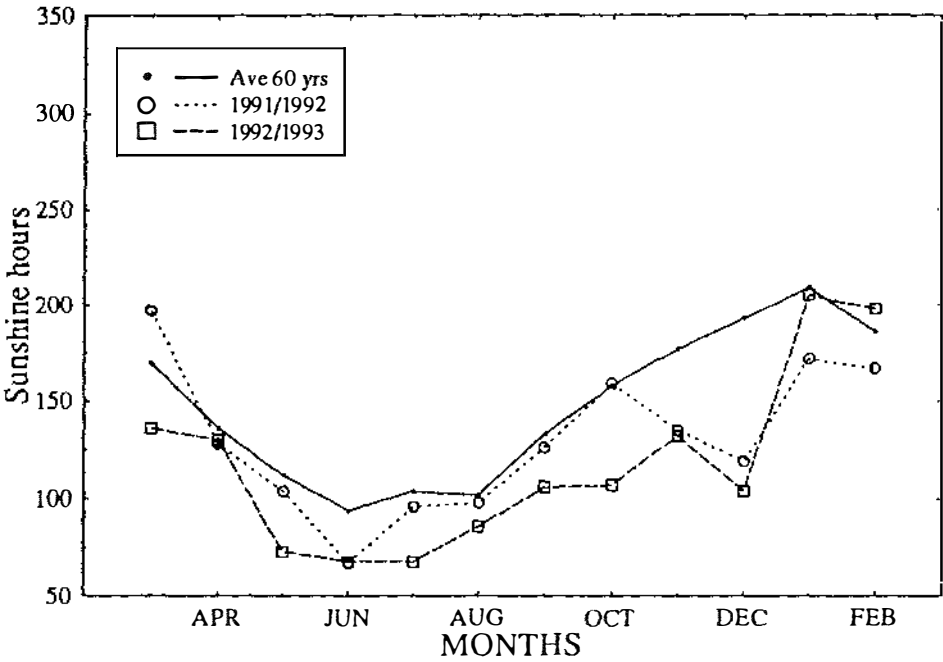


Fig 3.1c: Sunshine hours during the two cropping seasons (1991-1993) and sixty year average at Palmerston North.

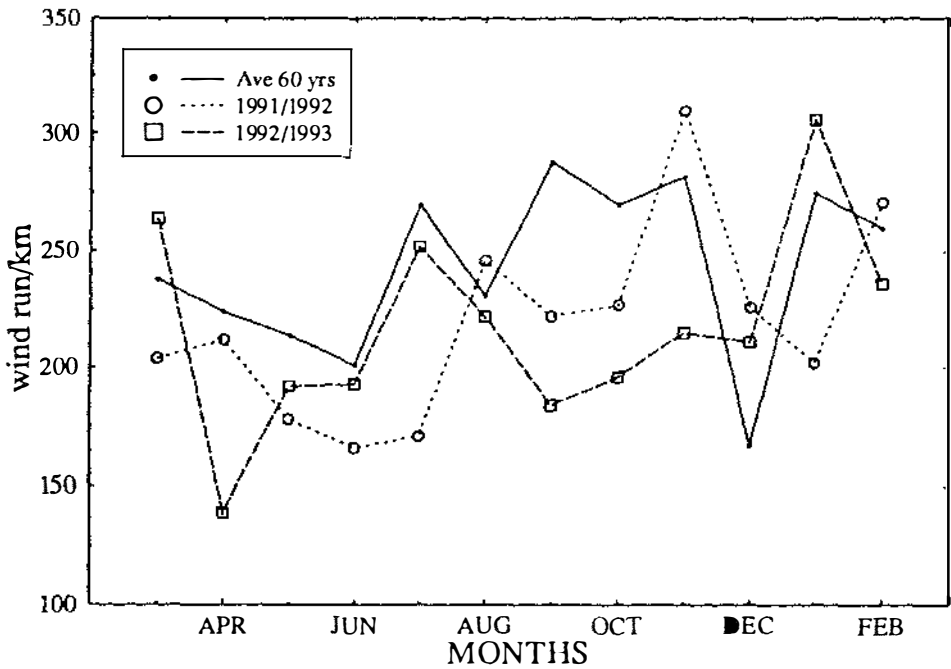


Fig 3.1d: Wind run/km during the two cropping seasons (1991-1993) and sixty year average at Palmerston North

3.4.2 EFFECTS OF ROW SPACING

3.4.2.1 Effects on plant establishment

Row spacing significantly affected plant stand at all four assessment times (Table 3.2). At the first two assessments plants per meter of row increased significantly as row spacing increased but at six and eighteen months after sowing there were no significant differences between the two middle row spacings, although there were significant differences between these two rows and the other row spacings (Table 3.2). The average stands were 11, 20, 25, and 31 plants/m of row after 18 months for row spacings of 15, 30, 45, and 60 cm respectively (Table 3.2). The percentage of plants which established was similar at the first two assessments but plant deaths occurred over winter in both years so that percentage stands were 35, 30, 25, and 23% for the 15, 30, 45, and 60 cm row spacings respectively 18 months after sowing (Table 3.2).

Row spacing also had a significant effect on above ground and root dry matter, and root length of lucerne recorded on 12 June (3 months after sowing). The 15 and 30 cm row spacing above ground and root dry matter did not differ, but was greater than that for the two wider row spacings. The 45 cm row spacing produced significantly less root dry matter than other row spacings (Table 3.3). Row spacing had no effect on plant height but root length was significantly reduced as row spacing increased (Table 3.3).

Row spacing also had a significant effect on dry matter recorded on 8 October (7 months after sowing). The average yields were 46.0, 44.8, 24.9,



Plate 3.4 Lucerne sown at a 15 cm row spacing (photo 5 months after sowing).



Plate 3.5 Lucerne sown at a 30 cm row spacing (photo 5 months after sowing).



Plate 3.6 Lucerne sown at a 45 cm row spacing (photo 5 months after sowing).



Plate 3.7 Lucerne sown at a 60 cm row spacing (photo 5 months after sowing).

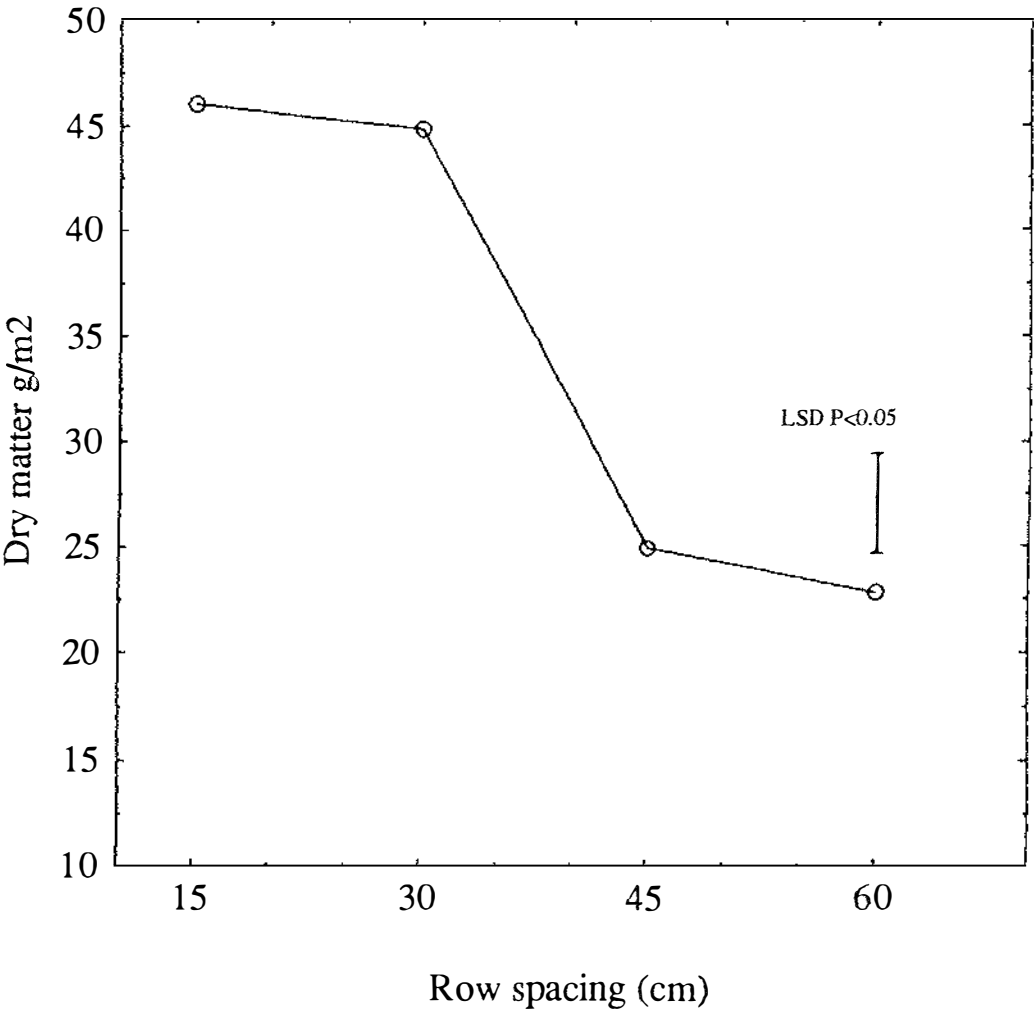


Fig 3.2 Effect of row spacing on vegetative dry matter of lucerne on 8 October 1991

and 22.8 g/m² for row spacings of 15, 30, 45, and 60 cm respectively, with the latter two being significantly lower ($P < 0.05$) than the former two (Fig 3.2).

3.4.2.2 Effects on plant growth

3.4.2.2.1 Main shoots:

In the first season some main shoots remained vegetative (Table 3.4), although the number was significantly affected by row spacing. Plants growing at the 60 cm row spacing had significantly more vegetative shoots/m² than the 30 and 45 cm rows but there was no difference between the 60 and 15 cm row spacings (Table 3.4). Differences in reproductive main shoots were only significant between the 60 and 15 cm row spacings (Table 3.4). All main shoots became reproductive in the second year (Table 3.5), but plants grown at the 45 cm row spacing had more main shoots/plant than those at the 30 and 15 cm row spacings.

3.4.2.2.2: Primary lateral shoots:

In the first year, plants grown at the 60 cm row spacing had significantly more primary lateral shoots/m² at ten days after peak flowering (10DAPF), than plants grown at 15 and 45 cm row spacings. There was no significant difference between the 30 cm and 60 cm row spacings (Table 3.4).

In the second year plants grown at the 45 cm row spacing produced significantly more primary lateral shoots/plant at peak flowering than those at the 15 cm row spacing. There were no significant differences between the other row spacings (Table 3.5).

Table 3.2 Effect of row spacing on plants per meter of row 1, 2, 6, and 18 months after sowing.

Row spacing (cm)	Average seeds/m of row sown	Plants/m of row			
		1 month after sowing	2 months after sowing	6 months after sowing	18 months after sowing
15	31	14d ¹ (45) ²	14d(45)	12c(39)	11c(35)
30	67	37c(55)	36c(54)	30b(45)	20b(30)
45	101	49b(49)	49b(49)	36b(36)	25b(25)
60	135	91a(67)	90a(67)	67a(50)	31a(23)
Significance	-	**	**	**	**
LSD P<0.05	-	9.9	8.5	7.1	5.7
CV %	-	28.0	25.0	27.0	24

¹Means within columns with the same letter are not significantly different at P<0.05.

²Percentage establishment. **. significant at P<0.001

Table 3.3 Effect of row spacing on above ground and root dry matter, and plant and root length on 12 June 1991

Row spacing (cm)	Above ground dry matter g/m ²	Root dry matter g/m ²	Length of plant ¹ (cm)	Length of root (cm)
15	7.8a	4.2a	6.8a	24.7a
30	8.1a	4.8a	6.4a	23.9b
45	4.6c	2.5c	6.4a	21.6c
60	6.8b	3.3b	6.4a	22.6c
Significance	**	**	NS	**
LSD P<0.05	1.26	0.76	0.53	1.32
CV %	12.0	10.0	8.0	11.0

¹length of the plant is the distance from the ground to the tip of the upright plant. Means within columns with the same letter are not significantly different at P<0.05.

*, significant at P<0.05. **, significant at P<0.01. NS - not significant.

Table 3.4 Effect of row spacing on the number of reproductive shoots, vegetative shoots, primary lateral shoots, secondary lateral shoots, tertiary lateral shoots, and total branches/m² 10 days after peak flowering in 1991/1992

Row spacing (cm)	RMS	VMS	PLS	SLS	TLS	Total branches
15	265b	73ab	4158b	4852b	276a	9286b
30	285ab	46b	4647ab	5271ab	252a	9918ab
45	297ab	50b	4128b	5472ab	406a	10006ab
60	332a	93a	5150a	6166a	492a	11808a
Significance	*	*	*	*	NS	*
LSD P<0.05	67.4	39.5	833.3	1073.4	243	2143
CV %	19.0	36.0	12.0	13.0	41.0	31.0

RMS = reproductive main shoots, VMS = vegetative main shoots, PLS = primary lateral shoots, SLS = secondary lateral shoots, TLS = tertiary lateral shoots.

Means within columns with the same letters are not significantly different at P<0.05. *. significant at P<0.05. NS - not significant

Table 3.5 Effect of row spacing on the number of main shoots, primary lateral shoots, secondary lateral shoots, tertiary lateral shoots and total branches/plant 10 days after peak flowering in 1992/1993.

Row spacing (cm)	MS	PLS	SLS	TLS	Total branches
15	3.5b	48.6b	74.9b	25.5b	152.5b
30	3.4b	55.4ab	80.9ab	22.1b	161.8b
45	4.7a	66.8a	102.1a	40.1a	213.7a
60	3.8ab	60.4ab	78.1ab	31.7ab	174.0ab
Significance	*	*	*	*	*
LSD $P < 0.05$	0.72	13.91	24.36	12.35	45.92
CV %	22.6	28.5	34.4	49.1	33.8

MS = main shoots, PLS = primary lateral shoots, SLS = secondary lateral shoots, TLS = tertiary lateral shoots.

Mean within columns with the same letters are not significantly different at $P < 0.05$.

*, significant at $P < 0.05$.

3.4.2.2.3 Secondary lateral shoots:

Plants grown in the widest (60 cm) row spacing in 1991/1992 had produced significantly more secondary lateral shoots/m² by 10 days after peak flowering, than the narrowest row spacing (15 cm) (Table 3.4).

In the second year, plants grown at the 45 cm row spacing produced significantly more secondary lateral shoots per plant than those in the 15 cm row spacing, but there were no significant differences among the former and the other two row spacings (Table 3.5).

3.4.2.2.4 Tertiary lateral shoots:

In 1991/1992 there were no significant differences in the number of tertiary lateral shoots among the row spacings (Table 3.4).

The plants grown at the 45 cm row spacing produced significantly more tertiary lateral shoots/plant than the 15 and 30 cm row spacings in 1992/1993 (Table 3.5), but there was no difference between the 45 and 60 cm row spacings.

3.4.2.2.5 Total branches

The plants grown at the 15 cm row spacing in the first year produced significantly fewer branches/m² than the other row spacings, but there were no differences among the other row spacings (Table 3.4).

In the second year branches per plant were greatest at the 45 cm row spacing, but there were no differences among the other three row spacings (Table 3.5).

3.4.2.2.6 Dry matter production:

Ten days after peak flowering in 1991/1992 plants from the narrowest row spacing (15 cm) had significantly less dry matter/m² than those from the other row spacings (Table 3.6). There were no differences among the other row spacings. At final harvest on 20 March plants from the 15 cm row spacing also had significantly less dry matter/m² than those from the other row spacings (data not presented).

In the second year dry matter/plant was significantly higher at the 45 cm row spacing than the 15 and 30 cm row spacings at peak flowering (Table 3.7). There was no difference between the two wider row spacings. At final harvest row spacing had no effect on total dry matter production per unit area (Table 3.12).

3.4.2.2.7 Plant height:

Mature plant height in the first year was not recorded but in the second year plants grown at the 45 and 60 cm row spacing were significantly taller than those grown at the 15 and 30 cm row spacings (Table 3.7).

Table 3.6 Effect of row spacing on the number of open flowers, flower buds, and developing racemes/m², and dry matter/m² ten days after peak flowering in 1991/1992.

Row spacing (cm)	Open flowers/m ²	flower buds/m ²	Harvestable racemes/m ²	Dry matter (g/m ²)
15	1141b	387a	363a	470.6b
30	1304ab	370a	326a	576.0a
45	1560a	443a	421a	588.8a
60	1429ab	348a	408a	606.6a
Significance	*	NS	NS	*
LSD P<0.05	371.2	160.8	197.8	87.69
CV %	22.0	29.0	39.0	22.0

Means within columns with the same letters are not significantly different at P<0.05.

*, significant at P<0.05. NS - not significant.

Table 3.7 Effect of row spacing on number of open flowers, flower buds, developing racemes, dry matter per plant, and plant height ten days after peak flowering in 1992/1993.

Row spacing (cm)	Open flowers /plant	Flower buds /plant	Harvestable racemes /plant	Dry matter g/plant	Plant height (cm)
15	19.1a	18.3a	0.68cb	15.8b	93.2c
30	19.1a	20.9a	1.5a	15.7b	97.4bc
45	20.3a	22.9a	1.45ab	27.2a	106.0a
60	24.1a	20.0a	0.64c	23.5ab	101.3ab
Significance	NS	NS	*	*	*
LSD $P<0.05$	9.06	8.18	0.803	8.37	7.90
CV %	42.0	37.0	49.0	28.0	9.4

Mean within columns with the same letters are not significantly different at $P<0.05$.

*, significant at $P<0.05$. NS - not significant.

3.4.2.3 Effect on flowering pattern

In the first season, lucerne plants started flowering on 31 December, peak flowering was recorded on 26 January and flowering had virtually ceased at harvest on 20 March 1992, giving a flowering period of 80 days (Fig. 3.3). Peak flowering date did not differ with row spacing, but the 30 cm row spacing produced significantly less flowers/m² at peak flowering than the other row spacings, while the greatest number of flowers was produced at the 60 cm row spacing.

Flowering in the second season started about three weeks earlier than in the first season, the first flower of the season being recorded on 8th December. Peak flowering occurred on the 19 January, and plants were harvested on 17 March 1993. The flowering period was therefore 99 days (Fig 3.4). Differences in climatic conditions (Fig 3.1a, 3.1b, 3.1c, and 3.1d) particularly higher temperature in November, 1992, and lower temperature in December, 1992, and January and February, 1993 probably contributed to this variation. The date of peak flowering was similar in each year. The total number of flowers was higher in the second year than in the first year. In 1992/1993 there were some significant differences among treatments (Fig 3.4); for example on 3 February and 10 February plants grown at the 60 cm row spacing produced significantly more flowers/m² than those in the 15 cm row spacing.

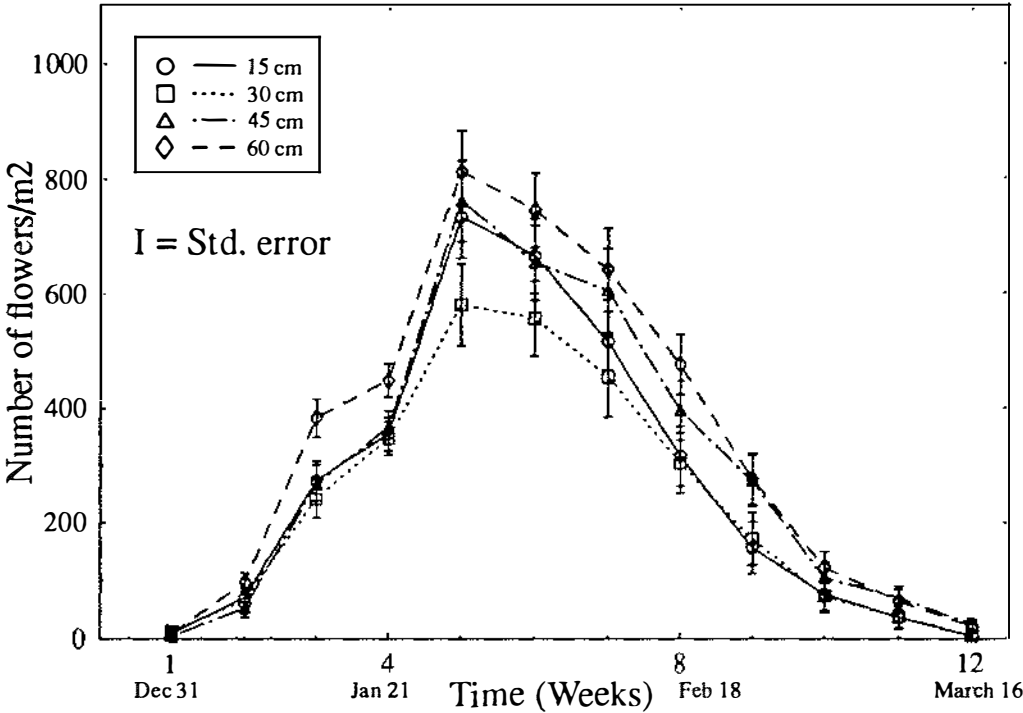


Fig 3.3 Effect of row spacing on flowering pattern in 1991/1992

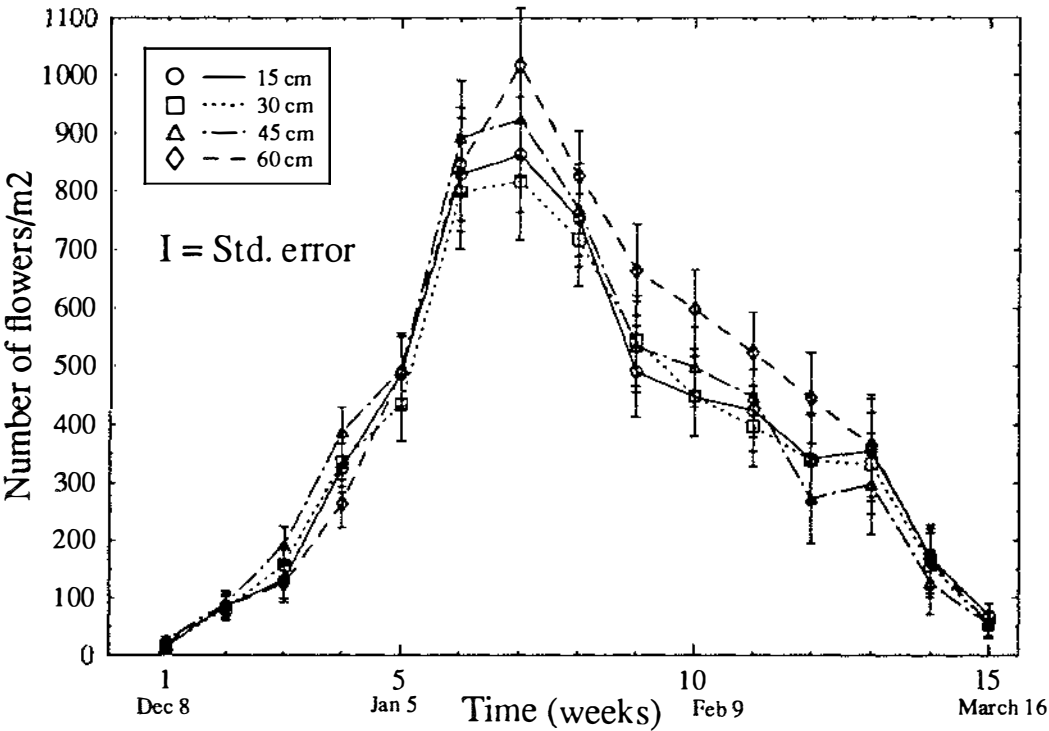


Figure 3.4 Effect of row spacing on flowering pattern in 1992/1993

3.4.2.4 Effects on open flowers, flower buds and harvestable racemes ten days after peak flowering.

Ten days after peak flowering in 1991/1992 there were no significant differences among row spacings for flower buds or harvestable racemes (Table 3.6), but the 45 cm row spacing had more open flowers/m² than the 15 cm row spacing.

In the second year crop harvestable racemes per plant were significantly higher at the 30 cm row spacing than the 15 and 60 cm row spacings but there was no significant differences between the 30 cm and 45 cm row spacings (Table 3.7). Open flower number and flower buds/plant did not differ.

3.4.2.5 Effects on seed yield components

Harvestable racemes: At final harvest in the first season, plants grown at the narrowest and widest row spacings had produced significantly less harvestable racemes/m² than the two middle row spacings (Table 3.8). Row spacing had no significant effect on harvestable racemes/m² at final harvest in the second year crop (Table 3.9).

Pods/racemes: Pods per raceme did not differ among the 15, 30 and 45 cm row spacings in the first year, but there were fewer at the 60 cm than at the 30 cm row spacing (Table 3.8).

Pods/raceme tended to decrease as row spacing increased in the second year (Table 3.9), the number being significantly lower at the widest spacing compared with the two narrowest spacings. Pods per raceme at the 30 cm row

spacing was also significantly greater than at the 45 cm row spacing.

Seeds/pod: Plants grown at the 15 cm row spacing produced significantly more seeds/pod than those at the two highest row spacings in the first year (Table 3.8), but there were no effects on seeds/pod in the second year (Table 3.9). However there was an interaction between the 15 and 30 cm row spacings and the 1 and 3 kg/ha sowing rates. Plants grown in the 30 cm row spacing from the 1 and 3 kg/ha sowing rates produced fewer seeds/pod than plants grown in the 15 cm row spacing from the 1 and 3 kg/ha sowing rates.

Thousand seed weight (TSW): In the first year the narrowest row spacing produced significantly smaller seeds than other row spacings (Table 3.8), but in the second year there were no significant differences in thousand seed weight (Table 3.9).

3.4.2.6 Effects on seed yield, potential harvestable seed yield, seed yield relative to potential seed yield, and harvest index

Plants grown at the 15 cm row spacing in 1991/1992 had a significantly lower seed yield than those from the 30 and 45 cm row spacings (Table 3.10), but there were no significant differences among the other row spacings.

In the second year row spacing had no effect on seed yield. There were no differences in potential seed yield, seed yield as a percentage of

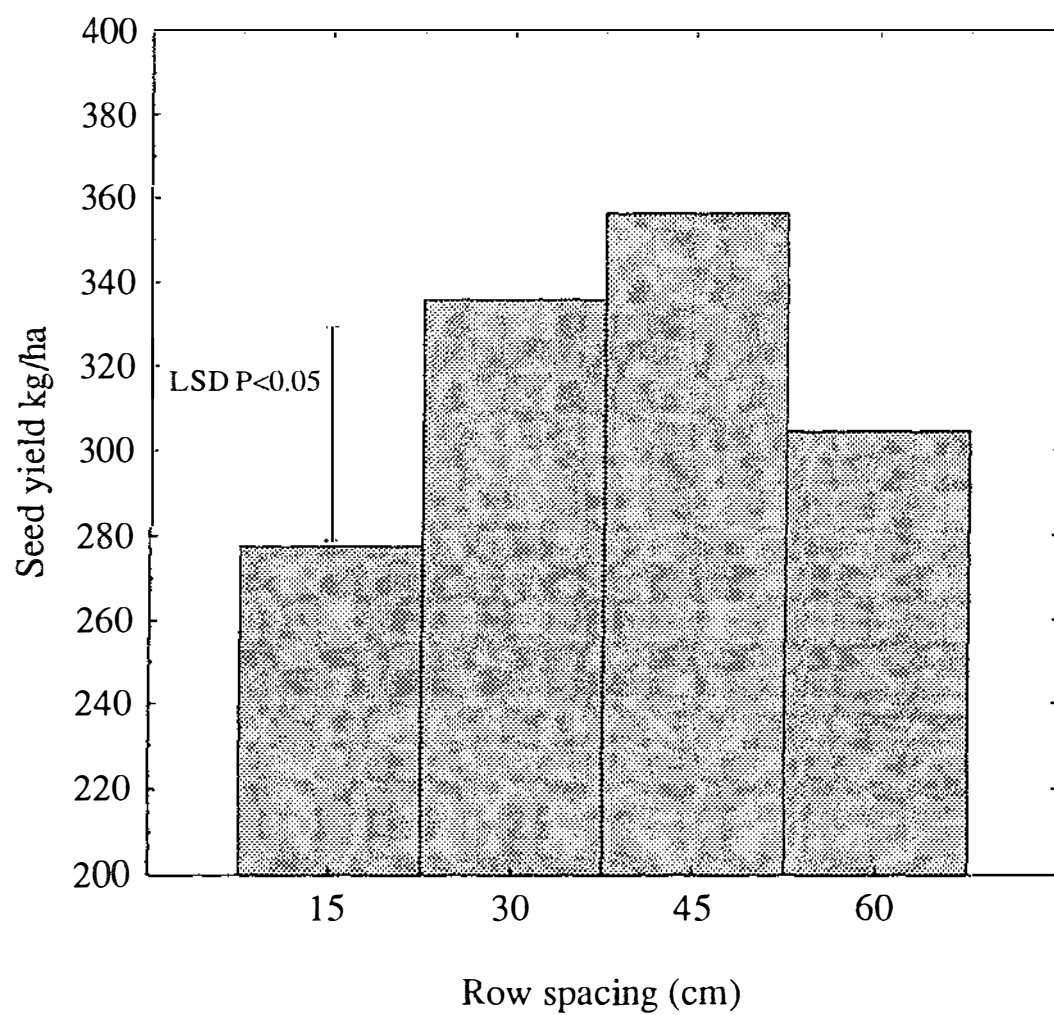


Fig. 3.5 Effect of row spacing on total seed yield, 1991/1993

Table 3.8 Effect of row spacing on the number of harvestable racemes/m² pods/raceme, seeds/pod, and thousand seed weight in 1991/1992.

Row Spacing (cm)	Harvestable racemes/m ²	Pods/ raceme	Seeds/ pod	TSW (g)
15	764b	5.1ab	3.4a	1.51b
30	980a	5.4a	3.1ab	1.62a
45	995a	5.0ab	3.0b	1.62a
60	840b	4.6b	3.0b	1.61a
Significance	*	*	*	*
LSD P<0.05	136.3	0.51	0.26	0.063
CV %	21.0	14.0	11.0	5.6

Means within columns with the same letters are not significantly different at P<0.05.

*. significant at P<0.05.

Table 3.9 Effect of row spacing on number of harvestable racemes/m² and pods per racemes, seeds/pod, and thousand seed weight at final harvest in 1992/1993.

Row spacing (cm)	Harvestable racemes/m ²	pods/ raceme	Seeds/ pod	TSW (g)
15	1163a	5.2ab	3.0a	1.744a
30	1305a	5.4a	2.9a	1.755a
45	1416a	4.6bc	3.2a	1.733a
60	1381a	4.2c	3.0a	1.790a
Significance	NS	*	NS	NS
LSD P<0.05	334.8	0.777	0.403	0.112
CV %	23.8	13.5	12.0	5.7

TSW = thousand seed weight

Mean within columns with the same letters are not significantly different at P<0.05.

*.significant at P<0.05. NS - not significant.

Table 3.10 Effect of row spacing on seed yield, potential harvestable seed yield/ha, seed yield relative to potential seed yield, and harvest index in 1991/1992

Row spacing (cm)	Seed yield kg/ha	Potential harvestable seed yield kg/ha	%Actual/ potential	Harvest index
15	102.3b	840	12.1	2.2a
30	142.7a	772	18.4	2.5a
45	144.0a	869	16.6	2.4a
60	120.0ab	910	13.4	2.0a
Significance	*	NS	NS	NS
LSD $P < 0.05$	29.23	-	-	0.65
CV %	22.0	26.0	23.0	8.6

Means within columns with the same letters are not significantly different at $P < 0.05$.

*, significant at $P < 0.05$. NS - not significant

Table 3.11 Effect of row spacing on seed yield, potential harvestable seed yield and seed yield relative to potential seed yield, and harvest index in 1992/1993.

Row spacing (cm)	Seed yield kg/ha	Potential harvestable seed yield kg/ha	% Actual/ potential	Harvest index
15	171.0a	1427.2a	11.0a	4.3a
30	189.5a	1587.6a	12.4a	3.7a
45	209.4a	1456.8a	12.5a	3.1a
60	177.9a	1212.8a	14.7a	3.8a
Significance	NS	NS	NS	NS
LSD $P < 0.05$	67.34	277.36	6.50	1.52
CV %	20.5	23.0	32.5	5.8

Means within columns with the same letters are not significantly different at $P < 0.05$.

*. significant at $P < 0.05$. NS - not significant.

potential seed yield or harvest index in either season (Table 3.10, 3.11).

When seed yield data for the two seasons were combined the 15 cm row spacing produced significantly less seed than the two middle row spacings (Fig 3.5), but did not differ from the 60 cm row spacing.

3.4.3. EFFECT OF SOWING RATE

3.4.3.1 Effect on plant establishment

As sowing rate increased, plants/m of row increased (Table 3.12), and at 18 months after sowing, the 1, 3, 6, and 12 kg/ha sowing rates had 11, 19, 24, and 30 plants per meter of row respectively. Percentage establishment was always highest for the lowest sowing rate (Table 3.12). At 6 months after sowing percentage establishment was the same for the three highest sowing rates, but was just over half that of the lowest sowing rate (Table 3.12). However one year later, plants as a percentage of seeds sown had dropped to 16% at the 12 kg/ha sowing rate but still remained at 73% for the 1.0 kg/ha sowing rate.

Sowing rate also had a significant effect on dry matter at the first and second cut on 12 June (Table 3.14) and 8 October (Figure 3.6). Three months after sowing (12 June), the two highest sowing rates had more above ground and root dry matter than the two lower sowing rates, while the lowest sowing rate produced the smallest amount of dry matter (Table 3.13). There were significant differences among sowing rates for plant and root

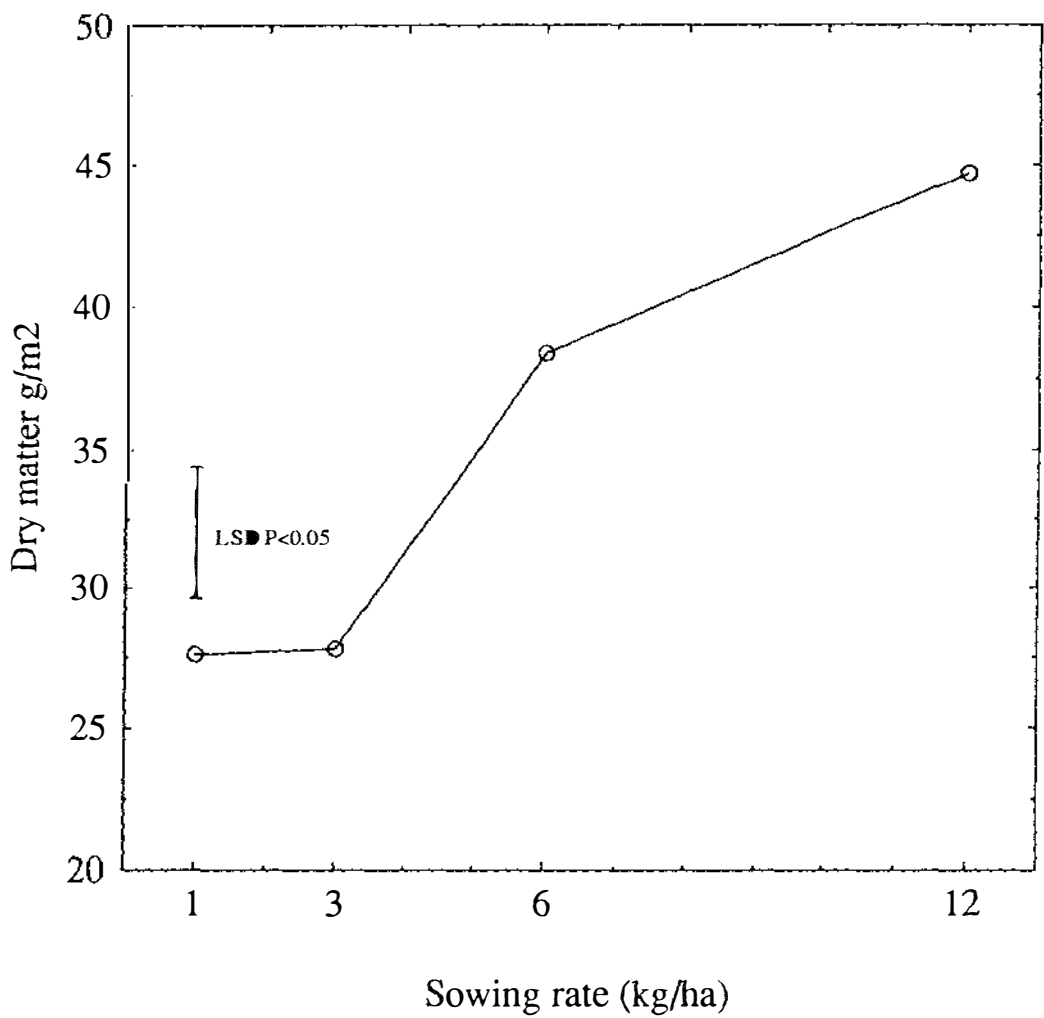


Fig 3.6 Effect of sowing rate on vegetative dry matter of lucerne on 8 October 1991

Table 3.12 Effect of sowing rate on plants per meter of row 1, 2, 6, and 18 months after sowing.

Sowing rate kg/ha	Average seeds/m of row sown	Plants/m of row			
		1 month after sowing	2 months after sowing	6 months after sowing	18 months after sowing
1.0	15	12d ¹ (80) ²	12d(80)	11d(73)	11d(73)
3.0	45	24c(53)	23c(51)	19c(42)	19b(42)
6.0	91	43b(47)	43b(47)	36b(40)	24b(26)
12.0	182	112a(62)	112a(62)	79a(43)	30a(16)
Significance	-	**	**	**	**
LSD P<0.05	-	9.9	8.5	7.1	5.7
CV %	-	28.0	25.0	27.0	24.0

¹Means within columns with the same letters are not significantly different at P<0.05.

²Percentage establishment. *. significant at P<0.05.

**. significant at P<0.01. *. significant at P<0.05.

Table 3.13 Effect of sowing rate on above ground and root dry matter and plant and root length on 12 June 1991.

Sowing rate kg/ha	Above ground dry matter g/m ²	Root dry matter g/m ²	Plant length ¹ (cm)	Root length (cm)
1.0	3.9c	2.1d	6.5b	23.8a
3.0	5.3b	2.9c	7.2a	23.6a
6.0	8.7a	4.5b	6.4bc	23.8a
12.0	9.8a	5.8a	5.9c	21.9b
Significance	**	**	**	*
LSD P<0.05	1.26	0.78	0.54	1.32
CV %	12.0	10.0	8.0	11.0

¹length of the plant is the distance from the ground to the tip of the upright plant.

Means within columns with the same letters are not significantly different at P<0.05.

** significant at P<0.01. *. significant at P<0.05.

length (Table 3.13). The 3 kg/ha sowing rate produced the tallest plants and the 12 kg/ha sowing rate produced the shortest plants, but there were no differences between the two other sowing rates (Table 3.13). The 12 kg/ha sowing rate significantly decreased root length compared with the other sowing rates (Table 3.13).

On 8 October dry matter did not differ between the two lowest sowing rates, but increased significantly as sowing rate increased (Fig 3.6).

3.4.3.2 Effects on plant growth

3.4.3.2.1: Main shoots:

In 1991/1992 the lowest sowing rate (1.0 kg/ha) had significantly less reproductive main shoots than the 6.0 kg/ha sowing rate (Table 3.14), but there were no differences among the 3, 6, and 12 kg/ha sowing rates. No differences in vegetative main shoots/m² were recorded.

In the second cropping season the 12 kg seed /ha sowing rate had significantly fewer main shoots/plant at peak flowering than the 1.0 and 3.0 kg/ha sowing rates (Table 3.15). There were no differences among the first three sowing rates. All main shoots became reproductive.

Table 3.14 Effect of sowing rate on the number of reproductive main shoots, vegetative main shoots, primary lateral shoots, secondary lateral shoots, and tertiary lateral shoots/m² ten days after peak flowering in 1991/1992

Sowing rate Kg/ha	RMS	VMS	PLS	SLS	TLS	Total branches
1.0	247b	50a	4036b	5685a	457a	10180a
3.0	297ab	61a	4472ab	5281a	363a	10117a
6.0	338a	70a	4876a	5443a	303a	10624a
12.0	298ab	82a	4700ab	5351a	302a	10353a
Significance	*	NS	*	NS	NS	NS
LSD P<0.05	67.4	39.5	833.1	1073.1	243.1	2149.2
CV %	19.0	36.0	12.0	13.0	41.0	31.0

RMS = reproductive main shoots, VMS = vegetative main shoots, PLS = primary lateral shoots, SLS = secondary lateral shoots, TLS = tertiary lateral shoots.

Means within columns with the same letter are not significantly different at P<0.05.

*. significant at P<0.05. NS - not significant.

Table 3.15 Effect of sowing rate on the number of main shoots, primary lateral shoots, secondary lateral shoots, tertiary lateral shoots, and total branches per plant ten days after peak flowering in 1992/1993.

Sowing rate kg/ha	MS	PLS	SLS	TLS	Total branches
1.0	4.3a	65.3a	97.4a	34.4a	201.4a
3.0	4.1a	64.1a	99.5a	37.9a	205.5a
6.0	3.6ab	54.5ab	80.2ab	28.4ab	166.7ab
12.0	3.2b	47.3b	58.9b	18.4b	127.8b
Significance	*	*	**	*	**
LSD $P<0.05$	0.72	13.9	24.4	13.7	45.62
CV %	22.5	28.5	34.0	39.0	33.5

Mean within columns with the same letters are not significantly different at $P<0.05$.

MS = main shoots, PLS = primary lateral shoots, SLS = secondary lateral shoots, TLS = tertiary lateral shoots. **. significant at $P<0.01$. *. significant at $P<0.05$.

3.4.3.2.2 Primary lateral shoots:

The lowest sowing rate produced significantly fewer primary lateral shoots/m² 10 days after peak flowering in 1991/1992 than the 6.0 kg seed/ha sowing rate. There were no differences among the 3, 6, and 12 kg seed/ha sowing rates (Table 3.14).

In the second year the 12 kg sowing rate/ha had significantly fewer primary lateral shoots/plant than the two lowest sowing rates. There were no differences between the two highest sowing rates (Table 3.15).

3.4.3.2.3 Secondary and tertiary lateral shoots:

Neither secondary lateral shoot nor tertiary lateral shoot numbers changed with differences in sowing rate in the first year (Table 3.14) but the 12.0 kg/ha sowing rate produced significantly fewer secondary and tertiary lateral shoots than the two lowest sowing rates in the second year (Table 3.15). There were no differences among the first three sowing rates.

3.4.3.2.4 Total branches

In 1991/1992 sowing rate had no significant effect on total branches/m² (Table 3.14). However in the second year, plants grown at the 12 kg/ha sowing rate produced significantly fewer total branches per plant than the 1 and 3 kg/ha sowing rates (Table 3.5). There were no differences among the three lowest sowing rates.

3.4.3.2.5 Dry matter production

Sowing rate had no significant effect on dry matter/m² at 10 days after peak flowering (Table 3.16) or at final harvest in the first year (data not presented). In the second cropping season, while the highest sowing rate significantly decreased dry matter per plant at peak flowering there were no differences among the other sowing rates (Table 3.17). However at final harvest sowing rate had no effect on plant dry matter/m² (data not presented).

3.4.3.2.6 Plant height

Mature plant height was not recorded in the first cropping season but in the second cropping season the plants from the highest sowing rate were significantly shorter than those from the 3.0 kg/ha sowing rate. There were no significant differences among the first three sowing rates (Table 3.17).

3.4.3.3 Effect on open flowers, flower buds, and harvestable racemes

There were no significant differences among sowing rates for the number of open flowers, flower buds, and harvestable racemes/m² ten days after peak flowering in the first year (Table 3.16), but in the second year, the 12 kg seed/ha sowing rate had fewer open flowers, flower buds and harvestable racemes/plant than the lowest sowing rate (Table 3.17). There were no differences among the three lowest sowing rates.



Plate 3.8 Stage of development of lucerne racemes from flower bud to pod maturity (from left to right).

Table 3.16 Effect of sowing rate on the number of open flowers, flower buds, harvestable racemes, and dry matter ten days after peak flowering in 1991/1992.

Sowing rate Kg/ha	Open flowers/m ²	Flower buds/m ²	Harvestable racemes/m ²	Dry matter (g/m ²)
1.0	1459a	403a	475a	591a
3.0	1402a	433a	323a	550a
6.0	1361a	368a	312a	564a
12.0	1211a	344a	461a	537a
Significance	NS	NS	NS	NS
LSD P<0.05	371.2	160.8	197.8	87.7
CV %	22.0	29.0	39.0	22.0

Means within columns with the same letters are not significantly different at P<0.05.

*. significant at P<0.05. NS - not significant.

Table 3.17 Effect of sowing rate on the number of open flowers, flower buds, harvestable racemes, dry matter per plant, and plant height ten days after peak flowering in 1992/1993.

Sowing rate kg/ha	Open flowers /plant	Flower buds/ plant	Harvestable racemes /plant	Dry matter g/plant	Plant height (cm)
1.0	26.6a	27.4a	1.5a	25.0a	100.7ab
3.0	25.8a	23.8a	1.2ab	24.6a	102.4a
6.0	19.6ab	19.4ab	1.0ab	21.6a	101.1ab
12.0	10.6b	11.4b	0.5b	11.0b	93.7b
Significance	**	**	*	**	*
LSD $P<0.05$	9.06	8.18	0.80	8.38	7.89
CV %	42.0	37.0	49.0	9.4	28.0

Mean within columns with the same letters are not significant different at $P<0.05$.

**, significant at $P<0.01$. *, significant at $P<0.05$. NS - not significant.

3.4.3.4 Effects on number of flowers and flowering pattern

Flowering pattern was not affected by sowing rate in either year (Fig. 3.7, 3.8), although the duration of flowering did differ (81 days in the first year, and 99 days in the second year). The date of peak flowering was similar at all sowing rates in each year (28 January in the first year and 19 January in the second year). The total number of flowers was higher in the second year. None of the sowing rates increased flower numbers significantly at peak flowering in the first year but in the second year the 1 and 3 kg/ha sowing rates had more flowers at peak flowering than the two highest sowing rates (Fig. 3.8).

3.4.3.5 Effects on seed yield components

Harvestable racemes/m²: At final harvest in both years the 12 kg/ha sowing rate had a significantly lower number of harvestable racemes/m² compared to the lowest seeding rate (1.0 kg/ha). In both years there were no significant differences among the first three sowing rates (Tables 3.18, 3.19).

Pods/raceme, seeds/pod: Sowing rate did not affect these two yield components in either season (Tables 3.18, 3.19), but there was a significant interaction between the 1 and 3 kg/ha sowing rates and the 15 and 30 cm row spacings. The plants grown from the 1 and 3 kg/ha sowing rates with a 30 cm distance between rows produced fewer seeds/pod than plants grown from the 1 and 3 kg/ha sowing rates with a 15 cm row spacing.

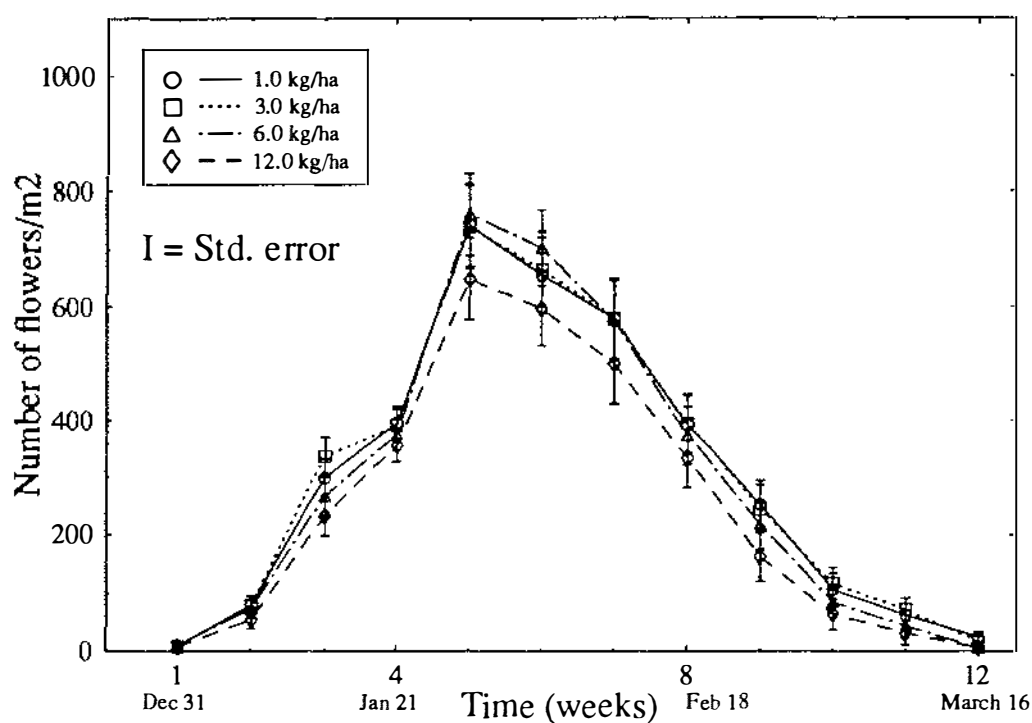


Fig 3.7 Effect of sowing rate on flowering pattern in 1991/1992

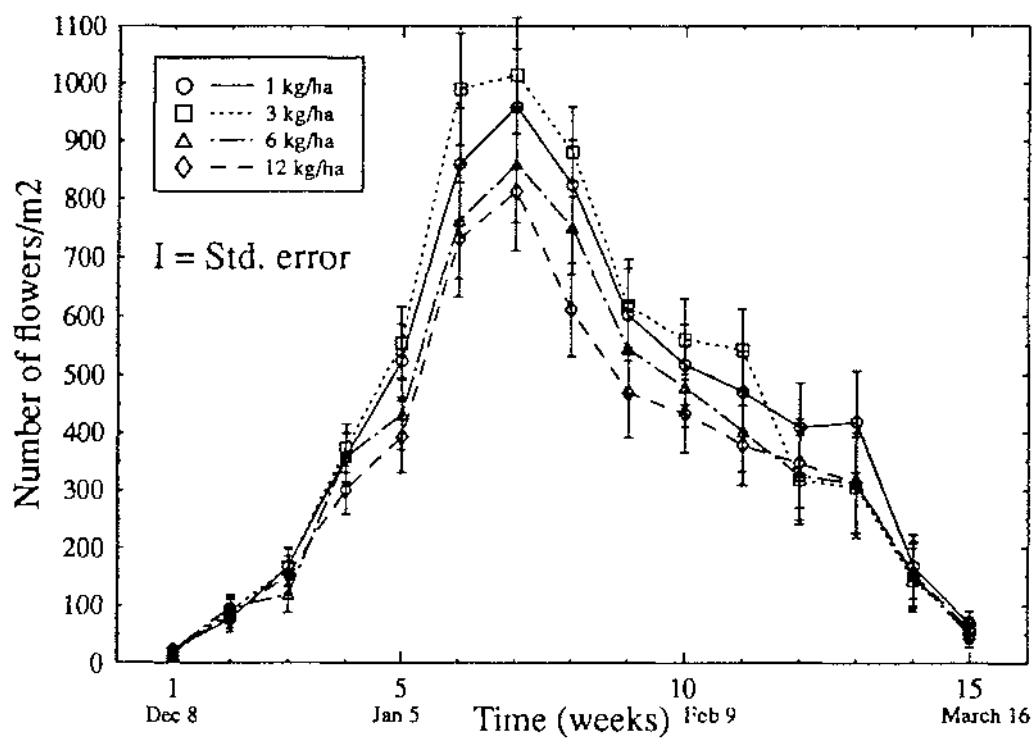


Figure 3.8 Effect of sowing rate on flowering pattern 1992/1993

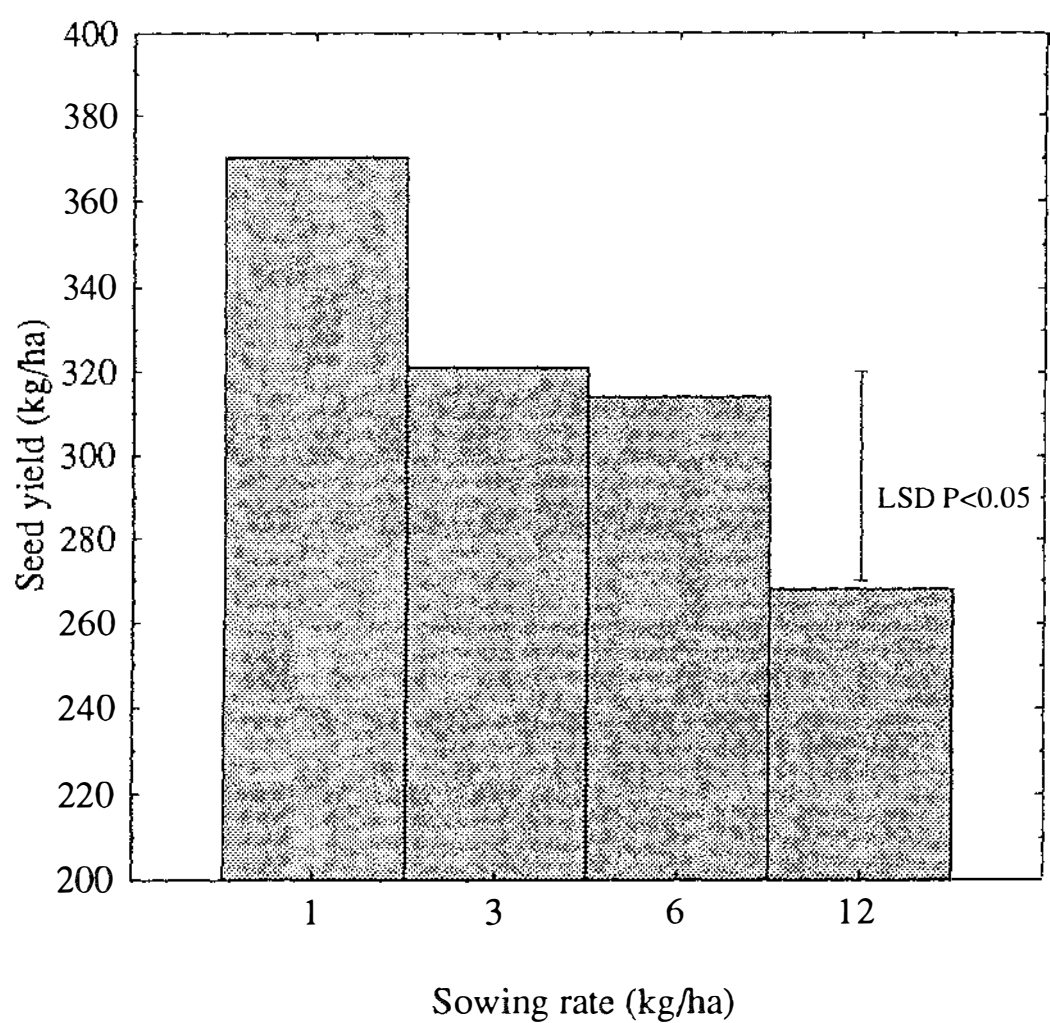


Fig 3.9 Effect of Sowing rate on total seed yield 1991/1993

Table 3.18 Effect of sowing rate on the number of harvestable racemes/m², pods/raceme, seeds/pod, and thousand seed weight, in 1991/1992

Sowing rate kg/ha	Racemes /m ²	Pods/ raceme	Seeds/ pod	TSW (g)
1.0	930.0a	5.0a	3.1a	1.62a
3.0	985.0a	5.0a	3.2a	1.61a
6.0	886.0ab	5.1a	3.1a	1.60a
12.0	778.0b	5.1a	3.0a	1.53b
Significance	*	NS	NS	*
LSD P<0.05	136.6	0.51	0.26	0.061
CV %	21.0	14.0	11.0	5.6

TSW = thousand seed weight.

Means within columns with the same letters are not significantly different at P<0.05.

*, significant at P<0.05. NS - not significant.

Table 3.19 Effect of sowing rate on the number of harvestable racemes/m², pods/raceme, seeds/pod, and thousand seed weight, in 1992/1993

Sowing rate kg/ha	Racemes /m ²	Pods/ raceme	Seeds/ pod	TSW (g)
1.0	1291a	5.4a	2.9a	1.820a
3.0	1155ab	5.2a	3.1a	1.767ab
6.0	1198ab	5.1a	2.9a	1.724b
12.0	1058b	4.9a	3.1a	1.693b
Significance	*	NS	NS	*
LSD P<0.05	195.77	0.58	0.30	0.083
CV %	23.0	13.0	12.0	5.7

TSW = thousand seed weight.

Means within columns with the same letters are not significantly different at P<0.05.

*, significant at P<0.05. NS - not significant.

Thousand seed weight (TSW): The 12 kg/ha sowing rate produced significantly smaller seeds in the first year (Table 3.18), but there were no differences among the other sowing rates. In the second year thousand seed weight decreased with increasing sowing rate (Table 3.19), with the 1.0 kg/ha sowing rate producing heavier seed than the two highest sowing rates.

3.4.3.6 Effects on seed yield, potential harvestable seed yield, percentage of actual seed yield to potential seed yield, and harvest index

Sowing rate had no significant effect on seed yield in the first year (Table 3.20). However in the second cropping season, the lowest sowing rate produced significantly more seed than the two highest sowing rates (Table 3.21). Sowing rate had no effect on potential seed yield, seed yield as a percentage of potential seed yield, or harvest index (Tables 3.20, 3.21).

When seed yields for the two seasons were combined (Fig 3.9), the lowest sowing rate produced 18% and 38% more seed/ha than the two highest sowing rates respectively.

3.4.3.7 Effect on seed germination

The viability, germination percentage and hard seed percentage of lucerne seeds were not affected by row spacing or sowing rate (Appendix 3.4, 3.5). All treatments produced seed which had a viability of over 98%, but germination of around 30% because of the presence of hard seed.

Table 3.20 Effect of sowing rate on seed yield, potential harvestable seed yield, seed yield relative to potential seed yield, and harvest index in 1991/1992

Sowing rate kg/ha	Seed yield kg/ha	Potential harvestable seed yield kg/ha	%Actual/ potential	Harvest index
1.0	139.5a	899	15.3a	2.3a
3.0	137.3a	928	14.6a	2.5a
6.0	124.9a	888	14.2a	2.2a
12.0	107.1a	700	15.7a	2.0a
Significance	NS	NS	NS	NS
LSD $P<0.05$	32.5	-	-	0.65
CV %	21.9	26.0	23.0	8.6

Means within columns with the same letters are not significantly different at $P<0.05$.

*. significant at $P<0.05$. NS - not significant.

Table 3.21 Effect of sowing rate on seed yield, potential harvestable seed yield seed yield relative to potential seed yield, and harvest index in 1992/1993

Sowing rate kg/ha	Seed yield kg/ha	potential harvestable seed yield kg/ha	% Actual/ potential	Harvest index
1.0	223.4a	1642.4a	14.3a	4.5a
3.0	182.2ab	1711.2a	11.5a	4.0a
6.0	178.5b	1287.6a	15.0a	3.7a
12.0	163.7b	1273.6a	13.8a	3.4a
Significance	*	NS	NS	NS
LSD $P<0.05$	44.19	41.32	4.85	1.13
CV %	20.5	23.0	32.5	5.8

Means within columns with the same letters are not significantly different at $P<0.05$.

*, significant at $P<0.05$. NS - not significant.

3.5 DISCUSSION

3.5.1 Lucerne establishment

Lucerne establishment and growth will be discussed in four parts covering the duration of the field experiment; period I will cover from sowing time to one month after sowing, period II from one month to two months after sowing, period III from two months to six months after sowing and period IV from six months to one year after period III (six to eighteen months after sowing).

Period I: the number of lucerne seedlings established per metre of row by one month after sowing was not unexpectedly highest for the highest sowing rate and highest row spacing. However while the percentage establishment was greatest at the widest row spacing (67%), and also reasonably high (62%) at the highest sowing rate, neither was as high as the 80% from the lowest sowing rate. Seveck (1985) also found that percentage establishment was highest at the lowest sowing rate. The percentage lucerne establishment ranged from 45 to 80% but averaged 57% over all treatments, which is consistent with the percentage lucerne establishment recorded by other workers (Morton, 1974; Wynn-Williams, 1982).

During this period, slugs appeared to be a major cause of seedling damage and loss, as noted by Charlton (1977). In Australia, Campbell (1973) has also reported that slugs and insect larvae eat legume seedlings in preference to grasses. The metaldehyde bait (mesurol) used did not initially control the slugs. Symonds (1975) noted that frequent rain (as occurred in April 1991) is conducive to egg hatching and recovery from the effect of the

bait. The first four weeks after sowing represent the critical stage of growth as far as slug damage is concerned, as after this stage, seedlings appear better able to recover from damage (Kueskwa, 1977). Minor damage to the lucerne seedlings by springtails (*Sminthurus sp.*) was noticed three week after sowing but the immediate application of insecticide minimised any damage from this insect.

Three weeks after sowing (8-10 days after seedling emergence) some healthy seedlings were observed to change to a brownish colour and eventually completely rot. Seedlings showing these symptoms were lifted from the soil and examined by the Plant Health Group of the Plant Science Department, Massey University, where fungi of the genera *Pythium* and *Fusarium* were identified. Damage and occasional entire lucerne crop failures brought about by pathogens such as *Pythium spp.* have been previously recorded (Falloon and Skipp, 1982). MacKenzie et al., (1972) found that damping-off in lucerne seedlings caused by *Pythium sp.* became evident within a week of emergence, and seedlings disappeared within a few days. This fungal disease factor is considered to be a major cause of poor establishment of lucerne during the first phase (Falloon and Skipp, 1982) and therefore lucerne seed should probably be fungicide treated before sowing to attempt to reduce such losses.

Period II. From Tables 3.2 and 3.12 it can be seen that during period II no more plants died. Plants which survived for the first two weeks after emergence continued to survive into June, the onset of winter.

There was no evidence of any further slug or insect damage during period II which may have been a result of the drop in temperature (Fig 3.1b). Fungal activity is also decreased by low soil temperature (Leath et al., 1988).

Period III. The number of plants present six months after sowing were less than the number present at end of period II being reduced as both row spacing and sowing rate increased. This reduction in plant number during the winter and early spring may have resulted firstly from white fringed weevil larvae damage to the roots of lucerne plants (Plate 3.2), and secondly from competition between plants. Tesar and Jacobs (1972) noted that some part of low survival was due to competition between plants for light, nutrients and water causing self-thinning, although even at a low sowing rate (2.5 kg/ha), in New Zealand the best survival was only 50% (Wynn-Williams, 1982).

Percentage establishment was significantly higher at the 1 kg seed/ha sowing rate than the other sowing rates, and the percentage establishment after six months was almost double that of the other sowing rates. The reason is not clear, but it has been suggested that a greater seedling mortality caused by damping-off occurs at higher sowing rates (Morton, 1974). However damping off is considered a disease of seedlings/young plants, whereas by September these plants were six months old. Whether this further loss was caused by fungal infection, or by insect damage or competition unfortunately was not determined.

Six months after sowing, the percentage plant establishment ranged from 36 to 73% and averaged around 49% over all treatments which is in accordance with the percentage lucerne establishment noted by Wynn-Williams (1982). Stand losses were 50, 60, 58, and 27% for the 12, 6, 3, and 1.0 kg/ha sowing rate respectively.

Period IV. The percentage of plant stand and number of plants 18 months after sowing was further reduced from that of period III for the three wider row spacings (30, 45 and 60 cm) and the two higher sowing rates (6 and 12 kg/ha). The average stand for row spacing was 28%, and percentage stand

decreased with increased row spacing, as also occurred in period III. Essentially no further plant mortality occurred for the low sowing rate or the lowest row spacing. A decline in the number of plants in wider row spacings and at higher sowing rate between 6 and 18 months after sowing was also observed by Kephart et al., (1992). Carmer and Jackobs (1963) also reported mortalities of 20, 27, and 36% for 9, 13.4 and 17.9 kg sowing rates respectively one year after establishment. Nematode and fungal infection of roots, insect damage, and particularly competition between plants could have caused the death of plants during this period, as mentioned by Falloon and Skipp (1982), but for this trial the reason was not determined.

3.5.2 Dry matter production

From an agronomic point of view it could be expected that lucerne plants grown at closer spacings and therefore with more plants per unit area would produce more dry matter at the first production cut. This was in fact the case, dry matter production being significantly higher ($P < 0.05$) at the 15 cm and 30 cm row spacings than the 45 and 60 cm row spacings and for the two highest sowing rates. It would also be expected that at the closer plant spacings fewer weed seedlings would become established due to the competition from the lucerne plants, and this also occurred. In particular, white clover was a greater weed problem as row spacing increased.

At the second production cut, dry matter production was again significantly higher ($P < 0.05$) at the 15 cm and 30 cm row spacings than the 45 and 60 cm row spacings and at the two highest sowing rates. This result agrees with the finding by Moline and Robison (1971) and Kephart et al., (1992) who stated that dry matter yield of lucerne increased significantly during the year of sowing as seeding rates increased.

Although in the second year individual plant dry matter was markedly depressed by increasing sowing rate, as also observed by Kephart et al., (1992), this effect was more than compensated for by increasing plant population, particularly at the closer spacing, resulting in a similar dry matter production per unit area at final harvest. Volenec et al., (1987) showed that shoots per plant declined rapidly with increased sowing rate. This negative response of shoot weight to sowing rate may have been caused by plant competition related to plant density. High plant density should result in less water and soil nutrients being available per plant, and consequently a restricted shoot growth. Carmer and Jackobs (1963) reported that plant density and competition among plants influenced lucerne yield. At the highest sowing rate (12 kg/ha) plants showed a significant reduction in plant dry matter caused by shortening of the main stems and reduced branch number due presumably to competition for light, nutrients and moisture.

Decreasing sowing rate not only increased main shoots but also encouraged primary, secondary, and tertiary lateral shoot production, as mentioned by Kephart et al., (1992), and increased plant height. Increasing row spacing from 15 to 45 cm increased dry matter, total branches and plant height. Particularly in the second year however wide spaced plants encourage more shoots, more branching while high sowing rates resulted in plants with fewer main shoots.

3.5.3 Flowering pattern

A feature of the lucerne crop is the prolonged flowering period of around three months. Flowering in the second year (1992/1993) started about three weeks earlier than in the first year and although flowering was completed about four days sooner than in the first year (1991/1992), total

flowering period was about seventeen days longer. This could be related to the smaller one year old plants having less reserves for flower production early in the first spring, but also most likely, this variation in the start of flowering was due to variation in climatic conditions, particularly the higher temperature in November of the second year which is known to promote earlier flowering (Fick et al., 1988). A similar shortening of the prereproductive period as temperature increases has also been noted by some workers (Greenfield and Smith, 1973; Harada, 1975). Temperature records showed that the 1992/1993 flowering season was cooler than the 1991/1992 flowering season. During the 1992/1993 flowering season (December to February) the monthly mean minimum and maximum temperatures ranged from 10.8-20.8°C compared to 11.3-21.9°C in the 1991/1992 flowering season.

It has also been supported that dry climatic conditions during November can result in earlier flowering and prolong the formation of flowers, which protracts the flowering period during the second year, as result of moisture stress (Neal, 1983). Also sunshine hours during January and February 1993 were greater (+18%) than in January and February 1992, and this might be another reason for prolonging the flowering period. Temperature and photoperiod appear to be the main factors involved in phenological development in lucerne, and development rate is accelerated by increasing temperature and increasing photoperiod (Fick et al., 1988). Similarly in white clover, high temperature and a long photoperiod have been reported to speed up flowering rate (Thomas, 1961).

Plants at all spacings and sowing rates commenced flowering at the same time. This indicates that the flowering time of the lucerne grown in this study was not affected by row spacing and sowing rates, unlike the finding

of Zambrana (1973) who reported that flowering time in lucerne was delayed when plants were grown at a high population density, but in agreement with similar findings by Kowithayakorn (1978).

Flower production per meter square in the second year at peak flowering was greater under low sowing rate conditions, possibly because of less per plant competition for light and nutrients, resulting in larger plants with more extensive branch development and thus more flowering sites. Kowithayakorn and Hill (1982) reported that lucerne plants grown at low density produced more branches and flowers per plant and also exhibited higher percentage seed set, thereby producing a higher seed yield.

There were no obvious variations in pattern and rate of flowering in this experiment, neither row spacing nor sowing rate altering flowering pattern or flowering duration in either year.

3.5.4 Seed yield

Seed yields in this study differed between the first and the second cropping season of seed production. In the first year, seed yields at all sowing rates and row spacings were low, because plants did not attain enough size and therefore produce enough branches to produce a high seed yield. Al-Dulaimi et al., (1987) and Hacquet (1990) reported that seed yield in lucerne is always low in the seeding year, and reaches a maximum in the year after sowing.

In the first year, sowing rates had no significant effect on seed yield, a result which agrees with that of Seveck (1985) who also reported that sowing rate did not influence seed yield of lucerne. In the second year however, seed yield increased as sowing rate decreased. This result is in

general agreement with the finding by Simko (1992) who reported that seed yield was highest at low stand densities. This higher seed yield at low sowing rates was attributed to significantly more branches and subsequently more racemes/m², and also a heavier seed weight.

The data in this study indicate that because of the significant reduction in yield at the 15 cm row spacing in the first year, lucerne should be planted in 30 or 45 cm rows. These spacings also facilitate inter-row cultivation (Dunbier et al., 1983). This agrees with other studies (Beran 1966; Antoniani ,1971), where optimum seed yields were attained with either 45 or 30 cm between rows respectively, compared to 15, and 60 cm row spacings. Lovato (1987) pointed out that in Italy, high seed yields were achieved with row spacings of from 20 to 50 cm.

It may also be likely that different cultivars of lucerne need to be grown at different spacings to give maximum seed yield. Zambrana (1973) reported that optimum spacing to give maximum seed yield of lucerne cv. Giboa and cv. Galilee were 30 x 30 and 20 x 20 cm respectively, and Kowithayakorn and Hill (1982) reported that cv. Wairau gave a maximum seed yield when grown at a spacing of 20 x 20 cm.

The best sowing rate for optimum seed yield was 1.0 kg/ha, much lower than the commonly used New Zealand rates of 5-10 kg/ha (Palmer and Donovan, 1980) but similar to that recommended by Dunbier et al., (1983), and almost equal to the optimum sowing rate suggested in USA (Rincker et al., 1988).

3.5.5 Yield components

Seed yield is built up from several yield components which relate to plant structure and in turn are determined by a combination of plant and

environmental factors (Adams, 1975). Seed yield in lucerne is the product of seeds per unit area and individual seed weight (Rincker, 1988). Usually the greatest seed yields in herbage species are obtained from maximising seed number (Hampton and Hebblethwaite, 1983b). In the first year study the narrowest row spacing produced a lower seed yield because of fewer racemes per meter square and lower seed weight. In contrast in the second year the low sowing rate produced more racemes/m² and heavier seed weight, because plants had had time to expand in size by developing more branches, and subsequently more racemes and seeds. These results support the finding of Taylor and Marble (1986) who stated that racemes per plant or per stem had the greatest effect on seed yield, and also Dovrat (1969) who found that racemes/plant and pods per raceme were very important. The data from the lower sowing rate which produced the heaviest seed weight are consistent with the accepted concept that individual seed weight declines with increased plant number per unit area. This certainly showed in 12 kg sowing rate.

The number of pods/raceme and seeds per pod were both unaffected by row spacing or sowing rate in this experiment, which confirms the fact that harvestable racemes/m² and thousand seed weight are the most important seed yield components for determining final seed yield in lucerne. In particular, the number of harvestable racemes/m² is an important characteristic to manipulate increases in seed yield, as reported by Hacquet (1990). Branching may also be manipulated to increased seed yield per plant by increasing the number of primary, secondary, and tertiary lateral shoots, at low sowing rates. Widely spaced plants also use less water and seeds mature more uniformly (Melton, 1962). The number of seeds per pod appeared to be an unimportant yield component at different plant densities, a result which agrees with Kowithayakorn (1978) who reported that there was no change in the number of seeds per pod when plants were grown at

different spacings.

3.6 CONCLUSION

Sowing rate and row spacing significantly but independently affected seed yield when analyzed over the duration of this study. The results showed there was no advantage in using high sowing rates 6 and 12 kg/ha, due to progressively increased plant mortality and seed yield decreased as sowing rate increased (Appendix 3.8 and 3.9). At this site, a sowing rate of 1 kg/ha produced the greatest seed yield in both season, although differences were not significant in the first season, and the 3 kg/ha sowing rate produced the same yield in the second season. Lower sowing rates have the added advantage of reducing seed costs and allowing a greater acreage to be planted when seed supplies are limited or seed is expensive.

Row spacing produced significant seed yield difference in the first year, being lower at the narrowest (15 cm) and widest (60 cm) row spacings but there were no significant differences in the second year. The row spacing to use should therefore be designed to allow for movement of cultivation machinery if required e.g. for cultivation for weed control between rows (Dunbier et al., 1983), and the 30 cm and 45 cm row spacings would meet this requirement. Also, if a second year harvest is contemplated, plants at these row spacing (particularly 45 cm) appear capable of producing more reproductive shoots, more flowers, dry matter/plant, more flowers, more harvestable racemes, and consequently a greater seed yield than plants grown in 15 or 60 cm rows (Appendix 3.9).

CHAPTER 4

EFFECT OF THE PLANT GROWTH REGULATORS PACLOBUTRAZOL (PP333) AND CYCOCEL (CCC) ON SEED PRODUCTION OF LUCERNE.

4.1 INTRODUCTION

There have been few studies involving the use of plant growth regulators (PGR's) for enhancing lucerne seed production, but these chemicals have been shown to have potential for increasing seed yield of other pasture species (Hampton, 1988a).

The use of PGR's to improve seed yield and yield components has been reported in many crops with varying degrees of success, depending on chemical application (kinds, rates, methods etc.), plant growth, size, and species or cultivar (Larson, 1985). Both time (i.e. growth stage) and rate are important for growth regulator application (Davis and Andersen, 1989). Greater retardation effects have been reported following PGR treatment prior to flower initiation compared with after flower initiation in *Geranium* (Armitage, 1986). Larter (1967) also found that stem shortening could be achieved if sufficient PGR was maintained in barley (*Hordeum vulgare* L.) during stem elongation. In *Lotus corniculatus* application of paclobutrazol preflowering improved seed yield (Li and Hill, 1989), and in *Lotus* spp. when paclobutrazol was applied before reproductive node initiation (Hampton et al., 1989). This suggested a hypothesis that for lucerne, plant growth regulators should be applied early enough to ensure the chemical is available to suppress

gibberellin biosynthesis, and allow earlier assimilate movement to lateral buds to promote flowering, support seeds and increase yield. However very early application is not recommended since it may prevent plants from reaching an adequate vegetative size prior to reproductive development. Clifford and Hare (1987) found that early (September) application of paclobutrazol did not increase final seed yield in *Lotus corniculatus*, but later application did.

4.1.1 PACLOBUTRAZOL (PP333)

The plant growth regulator paclobutrazol [C2RS-3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-1,2,4-triazol-1-1ylpentan-3-01, also known as cultar, Bonzi, parlay and PP333] has been shown to be successful as a plant regulator chemical for increasing seed yields in several pasture species e.g. - *Lotus corniculatus* (Li and Hill, 1989), *Lotus uliginosus* (Clifford and Hare 1987, Hampton, Li and Hare, 1989, Tabora, 1991), perennial ryegrass (Hampton and Hebblethwaite, 1985a), and white clover (Hampton, 1991).

Paclobutrazol was introduced in 1979 and since then work has been carried out on grasses and other pasture species in the USA, UK, and New Zealand (Hebblethwaite, 1987). This growth regulator has been shown to change plant structure by decreasing apical dominance, promoting tillering or branching, reducing internode length, increasing assimilate translocation to reproductive tissues, preventing lodging and synchronizing flowering (Marshall and Hides 1986,1987). It acts **primarily** by inhibiting the biosynthesis of gibberellin (Davis and Andersen, 1989) and has been shown to shift assimilate partitioning from leaves to roots (Globerson et al., 1989).

When compared with other growth retardants, paclobutrazol is highly active in small dosages.

Paclobutrazol application in perennial ryegrass stimulated root production (Hampton and Hebblethwaite, 1984), reduced stem internode length and strengthened the base of the stem; total stem dry matter was also reduced, but root DM accumulation and leaf area duration were increased (Hampton and Hebblethwaite, 1985). In *Lotus corniculatus* L. paclobutrazol increased branching (Li and Hill, 1989). Lodging control is mediated by stem thickening as well as stem length reduction (Hampton, 1983).

For paclobutrazol application to pasture species there have been conflicting seed yield results reported in different years under different weather conditions and with different cultivars (Barret, 1986). For example a rate of 0.5 kg a.i./ha in USA increased yield of perennial ryegrass (Young et al., 1985) but a rate of 0.75 kg a.i./ha decreased yield of the same species (Young et al., 1984). However increases in seed yield have been generally achieved following the use of paclobutrazol in most pasture species. For example in *Lotus corniculatus* and *Lotus uliginosus* paclobutrazol application at reproductive node initiation increased the number of pods per m² in *L. corniculatus* and number of seeds per pod in *L. uliginosus* (Hampton et al., 1989). In *L. corniculatus* application of PP333 (preflowering) improved seed yield mainly through enhancement of branching (Li and Hill, 1989). These increased seed yields were associated with increased umbels per unit area resulting from more reproductive stems per unit area (Clifford and Hare, 1987). Hebblethwaite and Wiltshire (1987) reported that paclobutrazol increased seed yields of different cultivars of perennial ryegrass by 8% to 136% in different years from 1979 to 1985. These responses were either associated with increases in the number of fertile tillers or seeds per spikelet and consequently seeds per fertile tiller (Hebblethwaite et al., 1982; Hampton and Hebblethwaite, 1985a; Hampton et al., 1985).

Similar responses in grass species have also been obtained in the USA (Young, Chilcote and Youngberg, 1985), and New Zealand (Hampton et al., 1985). Hampton (1991) also reported that paclobutrazol applied when the first inflorescence bud became visible increased seed yield in four New Zealand white clover cultivars, Grasslands Kopu, Grasslands Huia, Grasslands Tahora, and Grasslands Pitau. Seed yield increases were associated either with increased harvestable inflorescences, or increased seeds per inflorescence, but this response differed with cultivar and application time.

Application of paclobutrazol at 0.25, 0.5, and 1 kg a.i./ha also increased mean seed yield in white clover under Belgian climatic conditions. These increases were associated with a large reduction in vegetative crop growth without decreasing peduncle length. In this way flowers were elevated above the leaf canopy, resulting in a more favourable microenvironment for good pollination, more even seed ripening and easier harvesting (Rijckaert, 1991), but the effects varied between years depending on climatic conditions.

Seed weight was not affected by paclobutrazol treatment in *Lotus corniculatus* or *Lotus uliginosus* (Li and Hill 1989) or in onion (Globerson et al., 1989). However, it has been observed in perennial ryegrass (Hampton, 1986) that seed weight in treated plants tended to be reduced.

The only published information on paclobutrazol use in lucerne is that by Kamler (1991) who found that application rates of 1.5-3 kg a.i./ha increased seed yield of lucerne by about 55%, a considerable part of the increase being explained by the prevention of lodging of the lucerne stand.

Paclobutrazol is generally persistent in the soil (William and Edgerton, 1983). It is a soil active, xylem-mobile chemical which inhibits gibberellin biosynthesis (Shearing and Batch, 1982). Apple trees treated with paclobutrazol in one year often showed a carry over effect of reduced shoot

growth during the early part of the following season (Quinlan and Richardson, 1986). Hampton (1988) studied the residual effects of paclobutrazol applied originally to perennial ryegrass and reported no significant effects on following crop emergence and establishment.

Residual activity of paclobutrazol may differ at different sites because of differences in soil type. Paclobutrazol is known to be relatively immobile in soil (Lever, 1986) and bound mainly by organic matter. Binding is also increased by low pH (Leonard, 1986). It can also be quite persistent in checking growth, particularly when soil applied. Because of its persistence, paclobutrazol usually needs to be applied only once. This offers potential for reducing labour and chemical costs for the grower (Davis and Andersen, 1989).

4.1.2 CHLORMEQUAT (CYCOCEL or CCC)

Chlormequat is the common name for the (2-chloroethyl) trimethylammonium ion. It is also known as cycocel, or CCC from the trivial name chlorocholine chloride. Chlormequat retards plant growth by inhibiting the endogenous formation of gibberellins. It was introduced as 'cycocel' by the American Cyanamid Co. in 1959. Cycocel is primarily used in cereal crops such as wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and oats (*Avena sativa* L.), its effect on plants being to shorten plant stems, prevent stem break and lodging and increase grain yields by both increasing the number of fertile tillers and improving the synchrony of tiller growth and development (Kust, 1986).

Chlormequat chloride (cycocel) has apparently not been used on lucerne seed crops in New Zealand but in the forage legume *Lotus uliginosus* increased seed yield (Tabora and Hampton 1992), by enhancing both pods per

umbel and seeds per pod.

Application of cycocel in *Medicago media* [*M. varia*] reduced stem length by 33%, increased the number of seeds per pod by 8%, and seed yield by 15%, but did not affect seed germination or 1000-seed weight (Skalska, 1991).

Niemelainen (1987) reported that the application of chlormequat chloride (CCC) at the start of inflorescence emergence did not increase seed yield in red clover (*Trifolium pratense* L.). Supanjani (1991) also found that chlormequat chloride applied at either the late vegetative stage (October) or early flowering stage (November) did not increase seed yields in *Lotus corniculatus* L.

In other crops, application of cycocel to rice plants increased seed yield as a result of a lower percentage of unfilled spikelets, higher 1000 grain weight and delayed leaf senescence which increased the ripening period by 3-4 days compared with untreated plants (Moody, 1986). Cycocel also increased the number of seeds per spikelet in *Bromus willdenowii* Kunth. and did not affect seed germination (Hampton et al., 1989b). Application of chlormequat chloride at spikelet initiation at a rate of 3.0 kg a.i./ha increased seed yield of perennial ryegrass (*Lolium perenne* L.). This seed yield increase was associated with better tiller survival (Hampton, 1986).

In contrast to paclobutrazol, cycocel is non residual and has no activity in succeeding crops (Hampton, 1988). It is rapidly degraded in soil by enzyme activity (Anon, 1982) and a following crop is therefore unlikely to be affected (Humphries, 1968). The price of cycocel is cheaper (\$ 23.00 per kg a.i) than paclobutrazol (\$ 1107.00 per kg a.i). This difference alone is probably

sufficient justification for the decision to assess the likely value of using cycocel to enhance seed yield in lucerne in the present study. For more information about PGR see chapter 2.

4.1.3 Objectives:

The present work was designed to critically examine how the growth regulators paclobutrazol and cycocel affected plant growth and development and seed production in lucerne (*Medicago sativa* L.) cv.Grasslands Oranga. The objectives of this experiment were:

- *. To evaluate the effects of paclobutrazol and cycocel on seed yield of lucerne grown in the Palmerston North environment.
- * To determine the effect of timing of plant growth regulator application on the growth, development and seed yield of lucerne.

4.2 MATERIAL AND METHODS

4.2.2 Experimental site and layout

The experiment was sited at the Seed Technology Centre Massey University, Palmerston North, New Zealand (40° 20' S, 175° E), and was conducted from July 1991 to March 1992. The soil type was an Ohakea silt loam as detailed in Appendix 4.1.

Seed of the cultivar 'Grasslands Oranga' was inoculated with *Rhizobium meliloti* strain Nitrobug and sown by hand in small pots (jiffy sevens, purchased as compressed peat pellets imported from Norway. These were soaked in water and swelled to a size of 4 cm in diameter and 4.5 cm in height; the peat contents are held together by a fine mesh which the user

opens at one end so that seeds may be sown) approximately 3 seeds per pot, and placed in a glasshouse on 10 July 1991. Daily glasshouse temperature averaged 25°C maximum and 17°C minimum. After seedling emergence plants were thinned to one plant/jiffy seven. Two weeks before transplanting seedlings were placed outside the glasshouse and then two months old lucerne seedlings of uniform size (between 6-8 cm in height) were chosen to be transplanted to the field on 7 September 1991.

Seedlings were planted at a 30 x 30 cm spacing with 20 plants per plot. Some surplus seedlings were planted near the experimental area for replacing those which failed to establish. Three weeks before planting the field was sprayed with glufosinate-ammonium (Buster) at 1 kg a.i./ha to ensure a weed free seed bed, and then the land was thoroughly prepared by firstly ploughing and secondly harrowing. Before the harrowing, 150 kg/ha superphosphate and 2.5 t/ha lime were applied by hand to the experimental area. No nitrogen, irrigation, or pollinators were applied during the experimental period. Table 1 presents management and treatment details.

Treatments consisted of two paclobutrazol (PP333) applications and three chlormequat chloride (cycocel) applications, plus a control. PP333 (1.0 kg a.i./ha) was applied in 250 litres water/ha during active vegetative growth (first November 1991) or at the appearance of the first flower bud (first December 1991) (Li and Hill, 1989), and cycocel applied at a rate of 3 litres a.i./ha at the appearance of the first flower bud (1 December), 10% flowering (23 December) (Tabora and Hampton, 1992 and Skalska, 1991), and at



Plate 4.1 Knapsack application of a plant growth regulator

Table 4.1 Cultural management and experimental detail for the plant growth regulator trial, 1991/1992.

Time of planting	10 July 1991
Time of transplanting	8 September 1991
Site	Seed Technology Centre, Massey University, Palmerston North
Seed source	Ag Research, Grasslands
No. plants/m ²	11
Plot size	1.2 x 1.5 m.
Row spacing	30 cm.
Soil type	Ohakea silt loam, pH 0-15 cm = 5.2, 15-30 cm = 6.1
Lime	2.5 t/ha
Fertiliser	150 kg/ha superphosphate before planting
Grazing	None
Hand weeding	When needed
Weed control	Glufosinate-ammonium 1 kg a.i/ha before transplanting
Insect control	Fluvalinate 0.1 kg a.i/ha 10 October 1991
Flowering started	17 December 1991
Harvesting date	5 March 1992

Date of PGR application Stage of plant growth

1 November (PP333)	Active vegetative growth
1 December (PP333)	Flower bud appearance
1 December (CCC)	Flower bud appearance
23 December (CCC)	10% flowering
1 January (CCC)	Peak flowering

peak flowering (1 January 1992). Applications were made on windless days and for more caution a plastic shield was used at the edge of the plot to prevent spray-drift onto adjacent plots at application time (Plate 5.1). The plant growth regulators were applied by knapsack sprayer.

The five treatments plus the untreated control were arranged in a completely randomized block design with four replicates. Cut 0.5 m widths between plots and 1.5 m widths between blocks were maintained for the duration of the experiment. The size of each plot was 120 x 150 cm.

Unlike cycocel, paclobutrazol is soil active and requires soil moisture for uptake and xylem transport. The November PP333 application was made after heavy rain and rain also fell ten hours after the application in December. Cycocel (CCC) was applied each time on sunny days or on days with no rain.

Snail and slug pellets, Mesurol (Methiocarb, 20 g/kg bait) were broadcast at about 8 kg/ha one week after transplanting. Weed control was achieved by hand hoeing in early October and early November 1991. Later, hand weeding was also done when needed to control weeds around the plants. In early October the crop was sprayed with Mavrik Aquaflow (fluvalinate) 0.1 kg a.i./ha in 240 litres water to control harmful insect such as aphids.

Data were subjected to analyses of variance and means were separated using a LSD test at $P < 0.05$, when the F test was significant. The relationship between seed yield and its components were studied by regression analysis.

4.2.3. Plant growth measurement

Two weeks after peak flowering (when the maximum number of open flowers were counted), leaf area was recorded for 40 leaves chosen at random per plot (measured with a LI 3100 Li-Cor meter (Li-cor Inc., Nebraska, USA)). All 40 leaves were then oven dried at 80°C for 24 hours and leaf dry weight, specific leaf area (leaf area/leaf weight), and specific leaf weight (leaf weight/leaf area) determined.

Growth analysis was conducted at final harvest. All plants material from within each plot (excluding border plants) was harvested by cutting plants to ground level with electric hand shears. This material was then bagged and transported to the laboratory where the number of reproductive shoots (RS), vegetative shoots (VS), primary lateral shoots (PLS), secondary lateral shoots (SLS), tertiary lateral shoots (TLS), open flowers, flower buds, and harvestable racemes were determined for the whole sample at final harvest (all terms defined in chapter 3). After weighing the fresh material, a sub-sample of around 160 grams was weighed and oven dried at 80°C for 48 hours before total dry matter was determined. The length of 25 stems from each plot was also recorded.

4.2.4 Seed yield and its components

Ten days before flowering and at peak flowering, 25 racemes were randomly selected from each plot and the number of floret buds and florets per raceme determined.

Raceme numbers were assessed at 5 day intervals by counting each raceme with one open floret within a 0.5 m² permanent quadrat in each plot.

The five day interval was decided after observing the morphological and colour change in flowers and ensured that each raceme was not counted twice or missed. As a further precaution and to identify racemes, they were tagged using different coloured wires for each counting interval. The number of floret buds/raceme, florets/raceme and pods/raceme were assessed before flowering, at full bloom, and at final harvest respectively, to determine floret and pod abortion, by counting the number of florets in 50 racemes randomly selected from each plot. Floret and pod abortion were calculated as the difference between the number of floret buds and florets at peak flowering for floret abortion, and number of florets at peak flowering and pods at final harvest for pod abortion.

The total number of flowers were obtained by summing the number of new flowers present at each observation.

Harvesting was done on 5 March, 65 day after peak flowering, when the majority of the pods were brown black (Hill, 1975) and seed moisture content was around 22%. (Seed moisture content was determined every three days beginning 35 days after peak flowering, by measuring moisture content of 200 randomly selected seeds using the 130° C method (ISTA 1985)).

The number of harvestable racemes/unit area was counted directly from the harvested racemes. The racemes were then left at ambient temperature in open bags for four weeks to dry. Fifty racemes/plot, which were selected randomly from the harvested racemes, were then dissected and the number of pods per raceme, seeds per pod, percentage pod set, and seed set (percentage of florets with seed) were determined.

Seed was extracted by hand rubbing and using different sized sieves

(1.0 - 2 mm) and the inert matter was removed by means of a vertical column aspirator (Burrows 1836-4 laboratory blower). The blower was set up with an airflow speed of 41.5 km/h and was run for 3 minutes. After seed cleaning, seed yield, seed moisture content and thousand seed weight (ISTA 1985) were determined. Seed yields are expressed at 7% seed moisture content.

Potential seed yield values were obtained by multiplying the following variables: total number of flowers/m², number of pods per raceme, number of seeds per pod, and seed weight (total divided by 1000). The percentage of actual seed yield compared to the potential seed yield was determined by dividing actual seed yield by potential seed yield multiplied by 100.

Harvest index was determined by using the formula: actual seed yield divided by total dry matter production multiplied by 100.

4.2.5. Germination tests

Seed from each treatment was tested for germination. Four replicates of 50 seeds were germinated on top of paper (ISTA 1985), at a temperature of 20 C. Seeds were prechilled at 5°C for 5 days prior to the germination test. The first count was made at 4 days and the final count at the end of the 10 day test period (ISTA, 1985).

4.3 RESULTS

4.3.1 Climate data

The 60 year averages for monthly minimum and maximum temperature, number of sunshine hours and rainfall data are presented in Appendix 4.2, along with deviations from these averages during the 1991/1992 cropping season. During transplanting and establishment (September) temperatures were warmer than average with deviations from the minimum and maximum temperature of +0.7°C and +1.1°C respectively. However for the rest of the trial period, (October-March) temperatures were cooler than average with the exception of January (Appendix 4.2).

In the 1991/1992 growing season, the number of sunshine hours (with the exception of October) was lower than average (Appendix 4.2); particularly for November, December and January. During transplanting and early growth (September and October) and the flowering period (December and January), rainfall was below average but was slightly higher in November (reproductive initiation) well above average in February (seed development and ripening), and above average in March (harvest) Appendix 4.2.

4.3.2. Effect of PGR on plant growth

Reproductive shoots: At final harvest paclobutrazol had no significant effect on the number of main shoots/m², but cycocel applied on 1 December and 1 January reduced main shoot number (Table 4.2) by around 22%.

Primary lateral shoots: Lucerne plots to which paclobutrazol was applied at the vegetative growth stage had significantly more primary lateral shoots than untreated plots, or than when this chemical was applied at flower bud appearance or than the cycocel treatments. There were no significant differences ($P < 0.05$) between untreated plants and PP333 applied on the first of December. Application of cycocel at flower bud appearance or at peak flowering resulted in a significantly reduced primary lateral shoot number at final harvest. There were no significant differences between the control, cycocel applied at 10% flowering or PP333 applied at flower bud appearance (Table 4.2).

Secondary lateral shoots: With the exception of cycocel applied at flower bud appearance and at peak flowering, secondary lateral shoot numbers did not differ (Table 4.2). However, cycocel application at these two times resulted in fewer secondary lateral shoots (Table 4.2).

Tertiary lateral shoots: At final harvest, neither paclobutrazol or cycocel significantly altered the number of tertiary lateral shoots. However, paclobutrazol treated plants and cycocel applied on 1 December had more tertiary lateral shoots than plants to which cycocel had been applied at peak flowering (Table 4.2).

Table 4.2 Effect of paclobutrazol and cycocel on number of shoots at final harvest.

Treatment	Main shoots /m ²	Primary lateral shoots/m ²	Secondary lateral shoots/m ²	Tertiary lateral shoots/m ²
Control	288.9ab	5801.9b	10984.4a	2126abc
Paclobutrazol 1 Nov.	321.9a	7010.3a	11623.3a	2708.1a
Paclobutrazol 1 Dec.	245.2bc	4655.5bc	10411.1a	2565.9ab
Cycocel 1 Dec.	219.2c	3522.2c	7751.bc	2848.1a
Cycocel 23 Dec.	263.3bc	5513.3b	9325.5ab	1755.5bc
Cycocel 1 Jan.	223.7c	3566.3c	6456.1c	1507.4c
LSD P<0.05	46.91	1173.71	2513.21	906.33
Significance	*	*	*	*
% CV	16.6	12.9	14.6	22.1

Means within columns with the same letters are not significantly different at P<0.05. *.significant at P<0.05.

Plant height: The tallest plants (116.9 cm) were produced in the plots where cycocel was applied at 10% flowering (Table 4.3), but other treatments did not differ from the control. However, paclobutrazol applied at the vegetative growth stage resulted in plants which were significantly shorter than those from all other PGR treatments.

Plant dry weight: Neither paclobutrazol or cycocel significantly altered total dry matter production at final harvest (Table 4.3).

Leaf area: All PGR treatments except cycocel applied at peak flowering significantly increased leaf area and leaf dry matter at 14 days after peak flowering (Table 4.4). Specific leaf area was increased by the first paclobutrazol application, but not by other treatments, but this treatment reduced specific leaf weight (Table 4.4).

4.3.3 Effect on flowers/m², flower buds/m², open flowers/m², flowering pattern.

Flowers/m²: Application of paclobutrazol at the vegetative growth stage significantly increased the total number of flowers/m² produced over the season (Table 4.5). while application of paclobutrazol at first flower bud appearance significantly reduced the number of flowers/m². All cycocel treatments reduced flower number, the differences being significant for the first and last cycocel applications (Table 4.5).

Table 4.3 Effect of paclobutrazol and cycocel on plant height and dry matter/m² at final harvest

Treatment	Plant height (cm)	Dry matter g/m ²
Control	97.7bc	993.6ab
Paclobutrazol, 1 Nov.	91.3c	951.7ab
Paclobutrazol 1 Dec.	103.2b	997.3ab
Cycocel 1 Dec.	102.3b	920.6ab
Cycocel 23 Dec.	116.9a	1186.1a
Cycocel 1 Jan.	101.7b	807.0b
LSD P<0.05	6.46	338.15
Significance	*	*
% CV	3.4	19.0

Means within columns with the same letters are not significant at P<0.05.

*, significant at P<0.05.

Table 4.4 Effect of paclobutrazol and cycocel on leaf area, leaf dry matter, specific leaf area, and specific leaf weight two weeks after peak flowering.

Treatment	Leaf area (cm ²)	Dry matter leaf (g)	SPLA (cm ² /g)	SPLW (g/cm ²)
Control	1.415c	0.0061c	232.0b	0.0043a
Paclobutrazol 1 Nov.	2.080a	0.0080a	260.1a	0.0038b
Paclobutrazol 1 Dec.	1.797ab	0.0073ab	246.2ab	0.0041ab
Cycocel 1 Dec.	1.864ab	0.0076ab	245.3ab	0.0041ab
Cycocel 23 Dec.	1.852ab	0.0072ab	257.2ab	0.0039ab
Cycocel 1 Jan.	1.697bc	0.0066bc	257.1ab	0.0039ab
LSD P<0.05	0.3420	0.0011	26.30	0.0004
Significance	*	*	*	NS
% CV	12.7	9.9	7.0	7.6

SPLA = specific leaf area, SPLW = specific leaf weight.

Means within columns with the same letters are not significantly different at P<0.05. *. significant at P<0.05. NS - not significant.

Flower buds/m²: At harvest all treatments except cycocel applied at peak flowering resulted in a significant increase in the number of buds/m², but among treatments paclobutrazol applied on first November or cycocel applied at 10% flowering had significantly more flower buds/m² than the other treatments (Table 4.5).

Open flowers/m²: At final harvest, there were no significant differences among plant growth regulator treatments and untreated plants in the number of open flowers/m² (Table 4.5).

Flowering pattern: The flowering duration was 78 days, from 17 December 1991 until 1 March 1992 (Figures 4.1 and 4.2). Paclobutrazol applied at flower bud appearance slightly delayed the onset of flowering (week 2, Figure 4.2), as flower numbers were significantly lower than for the control. Application of paclobutrazol during vegetative growth significantly increased flower number at peak flowering (week 4, Figure 4.2), but no further significant differences were recorded.

Cycocel did not significantly alter flower numbers at any assessment time (Fig 4.1). Date of peak flowering was similar in all treatments (Figure 4.1, 4.2).

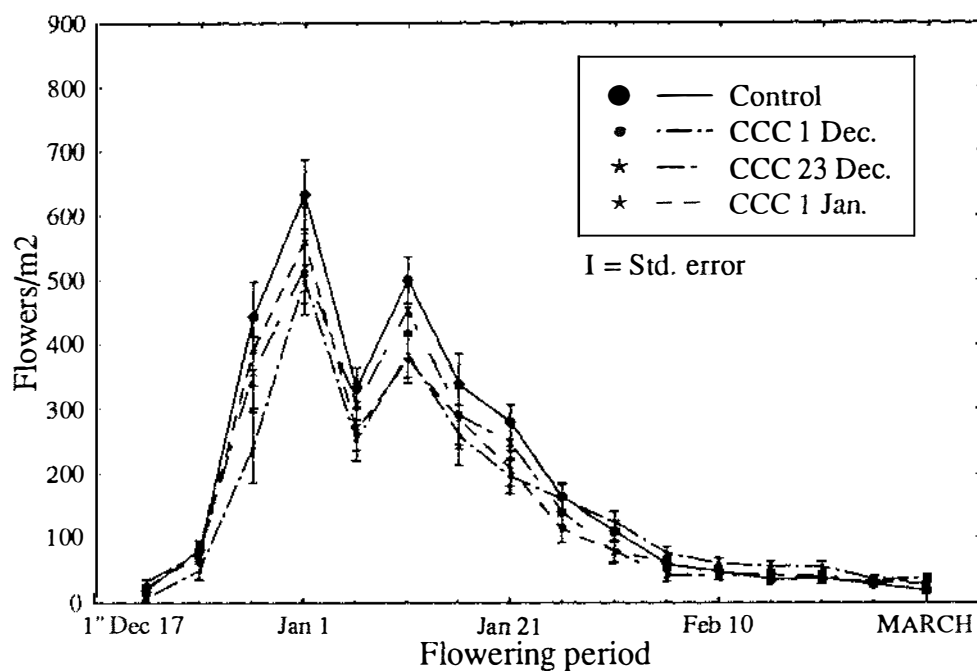


Fig 4.1 Effect of cycocel on flowering pattern 1991/1992

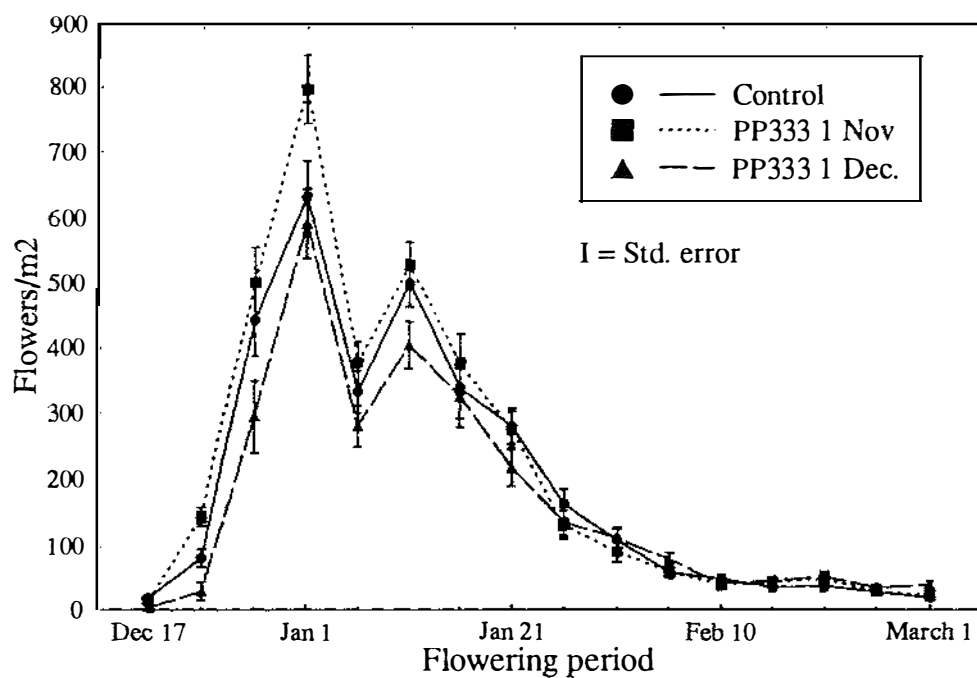


Fig 4.2 Effect of paclobutrazol on flowering pattern 1991/1992.

Table 4.5. Effect of paclobutrazol and cycocel on number of buds and open flowers/m², at final harvest and total number of flowers/m² produced over the whole season.

Treatment	Flower buds/m ²	Open flowers/m ²	Total flowers/m ²
Control	22.8c	17.4a	3101.4b
Paclobutrazol 1 Nov.	49.2a	31.7a	3474.0a
Paclobutrazol 1 Dec.	32.7b	27.2a	2696.0c
Cycocel 1 Dec.	36.3b	35.0a	2496.0cd
Cycocel 23 Dec.	46.6a	35.9a	2744.0bcd
Cycocel 1 Jan.	31.9bc	31.2a	2623.0cd
LSD P<0.05	9.47	18.20	368.44
Significance	*	NS	*
% CV	12.9	21.2	7.1

Means within columns with the same letters are not significant at P<0.05.

*.significant at P<0.05.

4.3.4. Effect on number of floret buds per raceme, florets per raceme and floret abortion

Ten days before flowering began, floret buds/raceme did not differ among treatments (Table 4.6), and there were still no differences in florets/raceme at peak flowering. Floret abortion ranged from 4.7 to 16.8%, but differences were not significant (Table 4.6).

4.3.5. Effect on seed yield components

Harvestable racemes/m²: At final harvest plants from plots where paclobutrazol was applied at the vegetative growth stage (1 November) had significantly more harvestable racemes/m² than the control, but all other treatments had significantly fewer harvestable racemes/m² (Table 4.6).

Pods/raceme: The number of pods per raceme was significantly increased by paclobutrazol application on the first of November (vegetative growth stage), but application of paclobutrazol at flower bud appearance or cycocel had no significant effects on pods/raceme (Table 4.7).

Percentage of florets retained as pods: Paclobutrazol applied at the vegetative growth stage significantly increased the percentage of florets retained as pods (Table 4.7), but other treatment did not differ from the control.

Table 4.6 Effect of paclobutrazol and cycocel on number of racemes/m², number of floret buds per raceme, florets/raceme, and percentage floret abortion.

Treatment	Harvestable racemes/m ²	Floret buds/raceme 10DBF	Florets/raceme at peak flowering	%Florets aborted
Control	2457.6b	29.0a	24.1a	16.8a
Paclobutrazol 1 Nov.	3347.8a	27.0a	24.5a	9.3a
Paclobutrazol 1 Dec.	1542.0cd	26.9a	25.3a	5.9a
Cycocel 1 Dec.	1546.0cd	25.2a	24.0a	4.7a
Cycocel 23 Dec.	1776.3c	26.7a	24.9a	6.7a
Cycocel 1 Jan.	1165.3d	25.4a	24.0a	5.5a
LSD P<0.05	600.3	5.724	5.22	12.56
Significance	*	NS	NS	NS
% CV	16.5	14.6	18.9	9.5

10 DBF = 10 day before flowering.

Means within columns with the same letters are not significantly different at P<0.05. *. significant at P<0.05. NS - not significant.

Table 4.7 Effect of paclobutrazol and cycocel on number of pods/raceme, % florets retained as pods, seeds/pod, and % pods containing seed at final harvest.

Treatment	Pods/raceme	% Florets retained as pods	Seeds/pod	% Pods containing seeds
Control	4.62b	19.1b	3.7ab	94.7a
Paclobutrazol 1 Nov.	7.99a	36.8a	4.3a	97.3a
Paclobutrazol 1 Dec.	6.02b	23.8b	3.9ab	94.7a
Cycocel 1 Dec.	5.20b	21.7b	3.7ab	93.3a
Cycocel 23 Dec.	5.90b	23.7b	3.6ab	96.0a
Cycocel 1 Jan.	5.10b	21.2b	3.3b	92.0a
LSD $P<0.05$	1.74	9.33	0.83	8.40
Significance	*	*	*	NS
% CV	16.1	14.2	12.1	17.5

Means within columns with the same letters are not significantly different at $P<0.05$. *, significant at $P<0.05$. NS - not significant.

Seeds/pod and percentage of pods containing seeds: At final harvest neither paclobutrazol application nor cycocel had any significant effects on seeds per pod or the percentage of pods containing seed (Table 4.7).

4.3.6. Effect on actual seed yield and thousand seed weight

The November paclobutrazol application significantly increased seed yield (by 36.7%) but no other increases were recorded (Table 4.8). Three treatments (the second paclobutrazol application, and the first and last cycocel application) reduced seed yield, although for potential seed yield, these treatments did not differ from the control (Table 4.8). As expected, paclobutrazol applied on 1 November significantly increased potential seed yield (by 161%). However, this size of response was not converted into actual seed yield, as the actual/potential ratio did not differ from the control. No significant differences were recorded for harvest index or thousand seed weight (Table 4.8).

4.3.7. Relationship between seed yield and its components

Multiple regression analysis showed that among seed yield components, harvestable racemes/m² explained most of the variation in seed yield ($r = 0.81$, $P < 0.05$).

4.3.8. Effect on seed germination

No treatments affected the germination percentage of lucerne seed (Table 4.9). Germination of lucerne seed for paclobutrazol treatments ranged from 58-80%, hard seed from 20-40%, dead seed from 0-2%, and viable seed from 98-100%.

Normal germination for cycocel treatments ranged from 56-74%, hard seed 28-42%, abnormal and dead seeds from 0-4%, and viable seed from 98-100%. There were no fresh ungerminated seeds (Table 4.9).

Table 4.8 Effect of paclobutrazol and cycocel on actual seed yield, potential seed yield, actual seed yield as a percentage of potential seed yield, harvest index and thousand seed weight.

Treatment	Actual seed yield kg/ha	Potential seed yield kg/ha	% Actual/ potential seed yield	Harvest index	TSW (g)
Control	466.1b	1272.0bcd	36.6a	4.7	2.425ab
Paclobutrazol 1 Nov.	637.6a	2955.6a	21.6ab	6.7	2.468a
Paclobutrazol 1 Dec.	239.1d	1543.6b	15.5b	2.4	2.417ab
Cycocel 1 Dec.	244.0d	1045.0cd	23.3ab	3.4	2.150b
Cycocel 23 Dec.	401.6bc	1301.2bc	30.9ab	3.6	2.245ab
Cycocel 1 Jan.	287.3cd	973.5cd	29.5ab	3.2	2.219ab
LSD P<0.05	140.81	328.04	18.396	NS	0.283
Significance	*	*	*	NS	*
% CV	48.9	11.5	38.2	25.2	6.71

Means within columns with the same letters are not significant different at P<0.05. *. significant at P<0.05. NS - not significant.

Table 4.9 Effect of paclobutrazol and cycocel on seed germination

	Control	PP333 1 Nov.	PP333 1 Dec.	CCC 1 Dec.	CCC 23 Dec.	CCC 1 Jan.	LSD<0.05
% Normal seedlings	55.5	62.5	70.0	65.0	63.0	63.5	NS
Range	52-58	58-74	60-80	56-74	50-70	58-68	
% Abnormal seedlings	0	0.5	0.5	0.5	0.5	0	NS
Range		0-2	0-2	0-2	0-2		
% Hard seed	44.0	36.5	29.0	34.0	36.5	36.5	NS
Range	38-46	26-40	20-34	28-42	26-48	32-42	
% Dead seed	0.5	0.5	0.5	0.5	0	0	NS
Range	0-2	0-2	0-2	0-2			
% Viable seed	99.5	99.5	99.5	99.5	100	100	NS
Range	98-100	98-100	98-100	98-100			
Moisture content	6.02	6.30	7.70	7.52	7.61	6.97	NS

NS - not significant

4.4: DISCUSSION

Application of the plant growth regulators paclobutrazol (PP333) and cycocel (CCC) at different stages of growth had different effects on plant growth, seed yield, and seed yield components of lucerne (*Medicago sativa* L.) cv. Grasslands Oranga.

4.4.1: Plant growth

At final harvest plants treated with paclobutrazol at the vegetative growth stage were shorter compared to the all other PGR treatments, but not the control. Cycocel applied on 23 December significantly increased plant height. Similar responses to these PGRs have been reported in *Verbena venosa*, where plants treated with cycocel resulted in taller growth, while those treated with paclobutrazol gave shorter shoots and a more bushy habit (Norremark, 1988). Application time or growth stage may also result in different plant height responses. This effect has been reported in other herbage legume species by Tabora (1991), Supanjani (1991), Li and Hill (1989) Clifford and Hare (1987), as well as in lucerne by Skalska (1991) and Kamler (1991). However, Niemelainen (1987) found in red clover that paclobutrazol and cycocel applied at similar rates to those used in this study at the start of flowering had no significant effect on shoot height measured at peak flowering.

It is possible that the different results between this study and Kamler's experiment might be due to a different application rate and different age of plants used in the experiment. Kamler (1991) applied paclobutrazol at 1.5 to 3 kg a.i/ha by spraying a two year old stand of lucerne, while in this experiment paclobutrazol was applied at 1.0 kg a.i/ha to four months old plants grown from seeds.

Paclobutrazol has been successfully used to increase the number of lateral branches in other plants, for example in *Lotus uliginosus* (Tabora and Hill, 1992) or to increase tiller number in *Lolium perenne* (Hampton and Hebblethwaite, 1985a). Similarly paclobutrazol applied at the vegetative growth stage (1 November) increased the number of primary lateral shoots. Li and Hill (1989) also reported that paclobutrazol applied in November increased the weight of lateral branches in proportion to the weight of the main shoots, and promoted branching in *Lotus corniculatus*.

Shoot development in terms of shoot number monitored in this experiment shows the important role of branching on subsequent seed yield in lucerne (Table 4.2). Application of paclobutrazol in November resulted in more primary lateral shoots than other treatments. Paclobutrazol is known to reduce apical dominance and hence increase shoot growth with the response being greater when the growth retardant is applied early (Froggatt et al., 1982).

The effects of paclobutrazol and cycocel on the number of main and lateral shoots were not similar, although all main shoots became reproductive in all treatments. In contrast both paclobutrazol and cycocel decreased the

number of reproductive and primary lateral shoots when applied in early December or early January (Table 4.2). This can be attributed partly to the fact that the effect of application date is confounded with the growth stage of the plant, as on later dates of application there was a shorter period between spraying and data collection. Another possibility might be the conflict between PGR's and endogenous hormones during active reproductive growth. Consequently, PGR's appear to have less effect at the later application date. This aspect needs further investigation.

4.4.2: Flowering period, flowering pattern and flowers number

Results in the present experiment showed that plant growth regulators had no effect on the flowering period of lucerne, which extended over three months. The number of flowers changed dramatically with time, showing a peak flowering at 20 days after first flowering and a small subsequent peak about 10 days later. The reason for this double peak is not clear, but was probably due to low average daily temperature over that period (Appendix 4.3). In the case of paclobutrazol, the results disagree with the findings of Hampton et al., (1989) and Tabora and Hill (1992) who reported that paclobutrazol reduced the flowering period of *L. corniculatus* and *L. uliginosus*. Again this variation is possibly due to difference in plant or weather conditions. Weather conditions often have a greater influence on flowering period and harvest time (Hare and Lucas, 1984), than chemicals.

Application of paclobutrazol at flower bud appearance (1st December) delayed flower appearance and agrees with the observation of Tabora and Hill (1992) who reported that paclobutrazol applied in early December delayed

flower appearance in *Lotus uliginosus*. Hampton (1991) also suggested that paclobutrazol applied at flower bud appearance initially delayed flower appearance in white clover.

In this study only paclobutrazol had the potential to increase flower number. Paclobutrazol application during the vegetative stage (early November) produced more flowers per metre square than other treatments. This increase was most likely caused by paclobutrazol being directly involved at a hormonal level, and the increased number of primary lateral shoots which resulted thus provided more sites for raceme production, as suggested for white clover by Marshall and Hides (1986). In *Lotus uliginosus* Clifford and Hare (1987) and Tabora and Hill (1992) reported that paclobutrazol increased the number of reproductive shoots, and Hampton (1991) reported increased flower numbers in white clover. In contrast, Supanjani (1991) found that paclobutrazol had no effect on the number of inflorescences in *Lotus corniculatus*. Application of paclobutrazol in early November increased flower number at early flowering and at peak flowering, while application of cycocel at bud appearance and at peak flowering reduced the number of flowers, primarily because main shoots and primary and secondary lateral shoots were reduced by these treatments.

4.4.3: Seed yield and seed yield components

The results from this study showed that only plants treated with paclobutrazol applied at the active vegetative growth stage (1 November)

significantly increased seed yield (Table 5.8). Hebbelthwaite et al., (1986) have suggested that in ryegrass, it is important that plant growth retardant application should be carried out early to ensure the chemical is available in the plant when rapid stem growth begins, and Li and Hill (1989) found that early application of PP333 during active vegetative growth was more favourable for enhancing seed yield than later application in *Lotus corniculatus* L.. Observation in this study suggested that the early November application, when plants were under going rapid vegetative growth, proved to be more favourable for increasing seed yield. The seed yield increase recorded from this treatment came from i) a 21% increase in primary lateral shoots, presumably due to the inhibiting effect of paclobutrazol on gibberellin biosynthesis, blocking the apical dominance of the main shoots; ii) a 12% increase in total flower number/m², with the greater number of primary lateral shoots providing more potential flower sites, iii) a 36% increase in harvestable racemes at least partially explained by the first two factors, and iv) a 72% increase in pods per raceme. This last response was possibly due to an increase in leaf area which presumably allowed greater photoassimilate accumulation and may therefore have resulted in less pod abortion, or to a change in endogenous hormones which allowed greater pod retention, again possibly through changes in assimilate movement and/or supply. This response requires further investigation.

This range of plant reaction to paclobutrazol application on 1 November resulted in an increase in seed yield. However, many of pods must have contained very light or immature seeds, because after cleaning, the yield from this paclobutrazol treatment was only 37% above that of the control.

This finding is in agreement with other workers for grass species (Hampton, 1986; Hampton et al., 1989b), white clover Hampton (1991), lotus Hampton et al., (1989a); Tabora and Hill (1992), and Li and Hill (1989), and lucerne Kamler (1991).

The results in the present trial show the importance of paclobutrazol time of application for increasing seed yield and seed yield components. Paclobutrazol applied at flower bud appearance (1 December) had no effects on shoot production, and as the total number of flowers was reduced, harvestable racemes and seed yield were also reduced. Late application, although it may promote a larger number of small lateral branches is not beneficial in increasing the seed yield, as the late-season weather conditions do not allow these small branches to become fertile (Li and Hill, 1989). This result is similar to that of Phetpradap (1992) who found that late application of paclobutrazol did not increase seed yield and seed yield components in hybrid dahlia.

Application of paclobutrazol had no effect on seeds per pod. This result is in agreement with the finding by Li and Hill (1989) who reported that paclobutrazol treatment did not affect the number of seeds per pod in *Lotus corniculatus*, However Hampton et al., (1989a) found that the application of paclobutrazol to *Lotus uliginosus* increased the number of seeds per pod by 58%.

As explained earlier, in this study, although paclobutrazol applied at the active vegetative growth significantly increased actual seed yield through

promoting primary lateral branches, total flowers and pods per raceme, actual seed yield relative to potential seed yield was lower than the control. This difference is possibly due to greater cleaning losses of immature seeds. As peak flowering time did not differ the increase in immature seeds is thought to have been caused by an inability of the plant to fill all the seeds present to the same extent. This aspect needs more investigation.

Application of cycocel (chlormequat or CCC) at different times had inconsistent effects on seed yield and seed yield components. Application of cycocel on 23 December had no effect on seed yield, despite a 28% reduction in harvestable racemes/m², as a 28% increase in pods/raceme compensated for this reduction. These results support the recent studies by Supanjani (1991), Oskarsen (1990), Khodzhakulov (1992), and Hampton *et al.*, (1992) who reported that the application of cycocel had no effect on seed yield of *Lotus corniculatus*, spring wheat, and barley respectively. However the results conflict with those found by Skalska (1991) who suggested that cycocel application at the 3rd leaf stage or at flowering increased seed yield by 15.4% in *Medicago media*, and with those of Hampton *et al.*, (1989b) for *Bromus willdenowii*, Hampton (1986) for *Lolium perenne* L., Moody (1986) for tropical rice and Tabora and Hampton (1992) who noted this chemical improved seed yield in *Lotus uliginosus*. The seed increases recorded by these authors were due to increased pods per umbel and seeds per pod, and by reduced flower and pod abortion. This conflict in results may arise because of differences in application time and/or rate, and by differences in location and plant species which may have different flowering requirements in terms

of day length and other climatic factors.

Application of cycocel at flower bud appearance and at peak flowering significantly reduced seed yield by over 40%, because shoot production was decreased, and hence flower production and harvestable racemes per unit area were reduced. This finding agrees with Abdurashidov (1991) who noted that the application of cycocel (chlormequat) at certain times reduced seed yield and seed size below that of the control in white head cabbage. However they disagree with the result of Tsybul'ko and Buryak (1988) who found that the application of 3 kg tur (chlormequat)/ha to *Medicago sativa* at the early bud formation stage increased seed yield by 14%. This may have been due to the difference in time of application, and in location or weather conditions, as rainfall and temperature, in particular, can influence the crop's response to cycocel treatment. Hot and dry weather conditions accelerate flowering and pod ripening, whereas wet and cooler weather delayed flowering and harvesting (Tabora and Hampton, 1992).

Cycocel treatments had no effect on pods per raceme or seeds per pod. This also contrasted with Hampton et al., (1989) who recorded an increase in the number of seeds per spikelet following cycocel application in *Bromus willdenwii* cv. Grasslands Matua.

4.4.4: Seed quality

Paclobutrazol and cycocel had no effect on seed germination and thousand seed weight. The percentage of dead seeds and abnormal seedlings

was small. The germination percentage was comparatively low due to the presence of high levels of hard seed. This could be attributed to the fact that the plants were harvested by hand and dried at ambient temperature (Tabora, 1991). The viability of seed in all treatments was high at 97.5%. Similar results have been noted in the same species by Skalska (1991) and in some other herbage legumes such as *Lotus corniculatus* (Li and Hill, 1989) and *Lotus uliginosus* (Tabora and Hampton, 1992).

Thousand seed weight was not affected by the plant growth retardant treatments as also observed by Skalska (1991) and by Li and Hill (1989) and Hampton et al., (1987) in *Lotus* spp.

4.5 CONCLUSION

1. Paclobutrazol applied during active vegetative growth increased seed yield in lucerne through increasing primary lateral shoots/m² and hence the number of flowers, harvestable racemes/m² and pods/raceme.
2. Paclobutrazol can be used to increase seed yield of lucerne, but there is a need for precise timing of application to obtain the response, as application at the appearance of the first visible bud reduced seed yield.
3. Cycocel did not increase seed yield, and in fact reduced lucerne seed yield at two of three application times.
4. Neither paclobutrazol nor cycocel affected seed quality.

CHAPTER 5

EFFECT OF PACLOBUTRAZOL ON LUCERNE SEED YIELD AND SEED YIELD COMPONENTS.

5.1. INTRODUCTION

Results from the previous experiment (Chapter 4) showed that paclobutrazol, if applied at 1.0 kg a.i./ha during active vegetative growth improved seed production in lucerne cv. "Grasslands Oranga", but that the lucerne plant's response to paclobutrazol depended on application time. In 1991/1992 (Chapter 4) seed yield increases were achieved following paclobutrazol application because of a significant increase in the total number of branches, mature racemes per unit area and pods per raceme. However these results were obtained from small plots (1.5 x 1.2 m) and consequently very small samples. To determine whether this response could be repeated, a new experiment was conducted to compare the effects of paclobutrazol at 0.5 and 1.0 kg a.i./ha on seed yield during 1992/1993.

5.2 MATERIAL AND METHODS

5.2.1 Experimental site

This experiment was conducted from spring 1992 to autumn 1993. The experimental area was the same as described in Chapter 3 i.e. a one year old lucerne stand from which one seed crop had been taken in 1992. Row width was 30 cm and the original sowing rate was 3 kg/ha. Plot size was 2.5 x 3 m². No fertiliser or irrigation were applied during the experimental period. To control weeds, hexazinone at a rate of 1.0 kg/ha was applied on 30 September. Management and treatment details are presented in Table 5.1.

5.2.2 Treatment and experimental design

Two rates of paclobutrazol, (using Cultar which contains 250 g/l paclobutrazol in the form of a suspension concentrate), 0.5 and 1 kg a.i/ha as used in the 1991/1992 experiment, were selected for further evaluation. The chemical was applied during active vegetative growth on 25 October 1992 when the plant height was 20-25 cm. The plant growth regulator was applied with water at a volume equivalent to 400 l/ha by a knapsack sprayer with one nozzle held 25-30 cm above the herbage.

All treatments were replicated four times in a randomized complete block design (RCBD). Data were subjected to analyses of variance and means were separated using an LSD test at $P < 0.05$ when the F test was significant. The indices of seed yield and relative seed yield components were subjected to simple linear correlation to determine if associations existed.

Table 5.1. Experimental detail

Soil type	Manawatu fine sandy loam
Plot size	2.5 x 3 m
Sowing rate	3 kg/ha
Stand age	1 year
Previous harvests	One
Grazing	Early August 1992
Weed control	Hexazinone 1.0 kg/ha in 400 litres water on 30 September 1992
Insect control	Fluvalinate 0.1 kg a.i/ha 20 November and 15 December 1992.
Disease control	Benlate 0.25 kg a.i/ha 15 December 1992.
PP333 application	
Date:	25 October 1992
Rate:	0.5 and 1.0 kg a.i/ha
Flowering started	16 December 1992
Peak flowering	27 January 1993
Seed harvest	22 March 1993

5.2.3 Data collection

5.2.3.1 Leaf area

Two weeks before first flowering (2 December), 10 days after flowering started (26 December) and 10 days after peak flowering (27 January), 48 leaves from each plot were randomly selected and leaf area measured using a LI 3100 Li-Cor meter (Li-Cor Inc., Nebraska, USA). All counted leaves were then oven dried at 80°C for two days (48 hours) and dry matter of leaves determined. From these data specific leaf area (leaf area/leaf dry weight), and specific leaf weight (leaf dry weight/leaf area) were obtained.

5.2.3.2 Flower number

Before flowering started an area of 25 x 40 cm was randomly selected and pegged out in each plot. The dates of first flowering, peak flowering, and completion of flowering were recorded. These data were obtained by counting the number of inflorescences with one single open floret within the quadrat every 7 days from the start of flowering to the end. The number of such flowers at each count was then summed and the total number of flowers per meter square determined.

5.2.3.3 Plant height and stem length

After flowering started five plants were chosen at random from each plot and plant length from ground level to the highest point of the plant was recorded on 20 December 1992. Average stem length was recorded by

measuring 20 stems selected at random from each plot at harvest time.

5.2.3.4 Number of floret buds and florets/inflorescence

Ten days before flowers opened, 25 inflorescences were randomly selected from each plot and the number of floret buds per inflorescence recorded. Every 15 days during the flowering period 25 inflorescences were randomly selected from each plot and the number of florets per raceme was assessed. The percentage of florets aborted was calculated as follows:

$$Y = 100 - (b \times 100)/a$$

where

Y = percentage of florets aborted

a = number of floret buds/raceme 10 days before the first flower opened.

b = number of florets/raceme at full bloom.

The percentage of florets retained as pods was then calculated as follows

$$X = (d \times 100)/c$$

where:

X = percentage of florets retained as pods.

c = number of florets/raceme at peak flowering.

d = number of pods/raceme at final harvest.

5.2.3.5 Plant growth analysis

A 25 x 40 cm area was sampled at random from each plot for growth analysis eight days after peak flowering. Plants were cut at ground level and the number of main stems, primary lateral shoots, secondary lateral shoots, tertiary lateral shoots, open flowers, flower buds, harvestable racemes, and



Plate: 5.1 October treated lucerne plant (50 days after paclobutrazol application) A. Control, B. 0.5 kg a.i./ha, C. 1.0 kg a.i./ha

total branches were determined. Internode length of main shoots was measured using the material sampled for growth analysis. After these measurements plant material was oven dried at 80°C to a constant weight (48 hours) before dry weight was recorded.

5.2.3.6 Plant lodging

Eight days after peak flowering, plant lodging was scored using a scale from one for the most prostrate plant to 10 for the most erect plant.

5.2.3.7 Ovules per ovary (carpel)

The number of ovules per ovary was determined at peak flowering on 27 January, 1993. Forty racemes per plot were randomly selected and stored in formalin-acetic-acid (FAA) solution [90% ethanol (70%), 5% glacial acetic acid, and 5% formalin (40%)] for ten days. A binocular stereoscope (X 40 magnification) was then used to determine ovule numbers.

5.2.3.8 Pods per raceme

Fifty randomly selected mature racemes were picked from each plot at harvest time and the number of pods per raceme counted.

5.2.3.9 Seeds per pod

Twenty five pods were randomly selected from those picked from each plot, the seeds separated by hand from the pods and the number of seeds per pod determined.



Plate 5.2 Stem with contrasting pod set A: poor set B: good set

5.2.3.10 Seed harvest

Seed was harvested when 80% or more of the pods had turned black brown (Hill, 1975). This occurred 54 days after peak flowering (22 March 1993).

Seed yield from two randomly selected 0.5 m² areas/plot (excluding border rows) was obtained by hand cutting all plants at ground level on 22 March. Seed heads were separated from the plants by hand, the number of racemes per meter square determined and racemes dried at ambient temperature for one month. They were then threshed by hand rubbing, and cleaned using the same methods as described earlier in Chapter 3. Plant material was oven dried for 2 days at 80°C and dry matter determined.

Harvest index (HI = seed weight/ total dry matter) was calculated. Potential seed yield (PSY = number of inflorescences/m² x number of pods/raceme x number of seeds/pod x seed weight) and percentage of actual seed yield relative to potential seed yield were also calculated.

Thousand seed weight was determined using 8 samples of 100 seeds from each plot. Means were calculated to obtain an average 1000 seed weight (ISTA, 1985). Seed yields were expressed at an ambient seed moisture content of 8%.

5.2.3.11 Germination test

Germination tests were done using 4 replicates of 100 seeds. The top of paper method was used, wherein 2 moist blotting pads were placed in small

plastic boxes upon which 100 seeds were placed. The boxes were covered with tight fitting lids to retain moisture and were kept at 20°C. First and final counts were made at 4 and 10 days respectively. At the first count, normal seedlings and dead mouldy seeds were removed and recorded. All other seeds and seedlings were left until the final count. At the final count all remaining seedlings and seeds were examined and recorded in the appropriate categories: normal seedlings, abnormal seedlings, hard seeds and dead seeds. Seedling evaluation was based on internationally agreed rules (ISTA, 1985).

5.3 RESULTS

5.3.1 Effects on plant growth

5.3.1.1 Effect on main shoots

Eight days after peak flowering application of paclobutrazol had no significant effect on the number of main shoots/m² (Table 5.2). In this study all main shoots became reproductive.

5.3.1.2 Primary lateral shoots

Paclobutrazol at 1.0 kg a.i/ha significantly increased (+40%) the number of primary lateral shoots compared with control plants, but there was no significant difference between the two paclobutrazol application rates (Table 4.2).

5.3.1.3 Secondary and tertiary lateral shoots

Although the higher paclobutrazol application rate induced more

secondary lateral shoots and tertiary lateral shoots (+44% and +32% respectively), these differences were not significant (Table 5.2).

Table 5.2 Effect of paclobutrazol on the number of shoots/m² eight days after peak flowering

Treatment	MS/m ²	PLS/m ²	SLS/m ²	TLS/m ²
Control	267.5a	3612.5b	3702.0a	755.0a
PP333 0.5 kg a.i./ha	260.0a	3955.0ab	3875.0a	702.5a
PP333 1.0 kg a.i./ha	330.0a	5047.0a	5317.5a	997.5a
LSD P<0.05	104.89	1339.0	1704.0	569.64
Significance	NS	*	NS	NS
CV %	21.2	19.5	33.7	40.2

MS = main shoots, PLS = primary lateral shoots, SLS = secondary lateral shoots, TLS = tertiary lateral shoots.

Means within columns with the same letters are not significantly different at P<0.05. *. significant at P<0.05. NS - not significant.

5.3.1.4 Total number of branches

Paclobutrazol applied at 1.0 kg a.i./ha significantly increased the total number of branches/m² eight days after peak flowering, but there was no difference between the low rate of paclobutrazol and control plants (Table 5.3).

5.3.1.5 Effect on number of open flowers, flower buds, and harvestable racemes/m² eight days after peak flowering

While paclobutrazol application at 0.5 kg a.i./ha had no significant effect on the number of flower buds, open flowers, and harvestable racemes/m² eight days after peak flowering compared to the untreated control (Table 5.4), application of paclobutrazol at 1.0 kg a.i./ha significantly increased the number of flower buds present (Table 5.4).

5.3.1.6 Internode length and lodging score

Paclobutrazol application had no significant effect on plant lodging score (Table 5.3) or internode length of main shoots (Fig 5.1).

5.3.1.7 Effect on dry matter and plant height

Chemical treatment had no significant effect on total plant dry matter eight days after peak flowering (data not presented) and at final harvest (Table 5.5). Although both rates of paclobutrazol retarded plant growth and produced

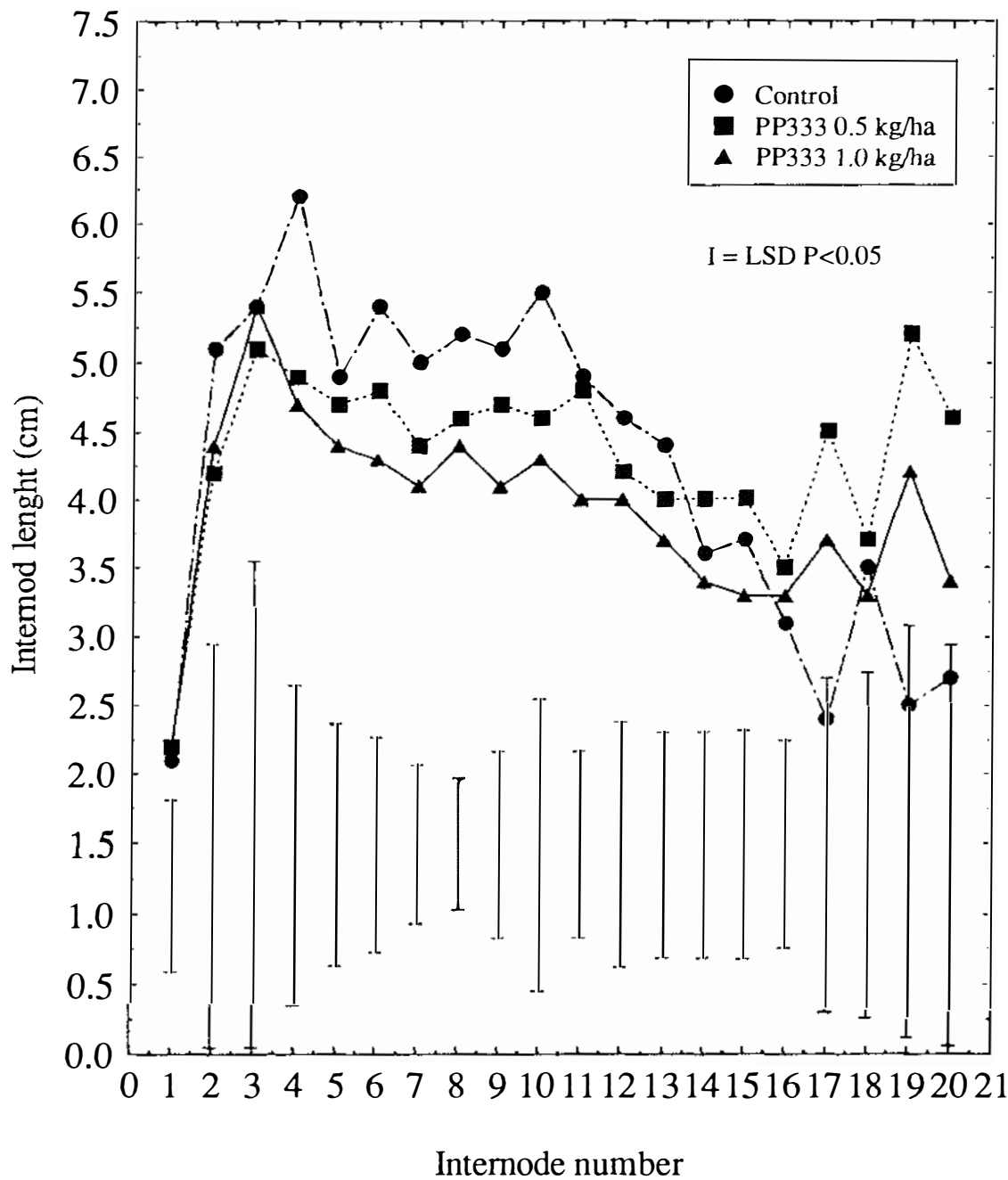


Figure 5.1 Effect of plant growth regulators on the internode length of lucerne

Table 5.3 Effect of paclobutrazol on the total number of branches/m², and lodging score eight days after peak flowering.

Treatment	Total number of branches/m ²	Lodging score
Control	8070.0b	7.75a
PP333 0.5 kg a.i./ha	8532.0ab	7.75a
PP333 1.0 kg a.i./ha	11037.0a	7.90a
LSD P<0.05	2509.5	0.558
Significance	*	NS
CV %	31.7	1.2

Means within columns with the same letters are not significantly different at P<0.05.

*. significant at P<0.05. NS - not significant.

Table 5.4 Effect of paclobutrazol on the number of flower buds, open flowers, and harvestable racemes/m², eight days after peak flowering and the total number of flowers/m² produced over the whole season.

Treatment	FLB/m ²	OPF/m ²	HR/m ²	TOTFL/m ²
Control	487.5b	947.5a	102.5a	3310.1ab
PP333 0.5 kg a.i./ha	640.0ab	1170.0a	107.5a	2240.0b
PP333 1.0 kg a.i./ha	882.5a	1597.5a	110.0a	3937.1a
LSD P<0.05	309.4	817.91	17.37	1261.10
Significant	*	NS	NS	*
CV %	26.7	38.2	29.2	15.7

FLB = flower buds, OPF = open flowers, TOTFL = total flowers, HR = harvestable racemes.

Means within columns with the same letters are not significantly different at P<0.05.

*. significant at P<0.05. NS - not significant.

Table 5.5 Effect of paclobutrazol on plant height on 20 December and stem length and dry matter at final harvest

Treatment	Plant height (cm)	Stem length (cm)	Dry matter g/m ²
Control	72.4a	88.7a	427.6a
PP333 0.5 kg a.i./ha	63.7b	81.6a	436.4a
PP333 1.0 kg a.i./ha	63.2b	80.1a	463.7a
LSD P<0.05	6.48	9.92	104.6
Significance	*	NS	NS
CV %	9.6	27.6	25.6

Means within columns with the same letters are not significantly different at P<0.05.

*, significant at P<0.05. NS - not significant.

significantly shorter plants than the control on 20 December (Table 6.5), by final harvest there were no significant differences in stem length among treatments (Table 5.5).

5.3.2 Effect on leaf area

Prior to the start of flowering paclobutrazol treatments had no significant effect on leaf area, leaf dry matter, specific leaf area, or specific leaf weight (Table 5.6). However after flowering had started paclobutrazol applied at 1.0 kg a.i/ha significantly reduced leaf area and reduced leaf dry matter compared with paclobutrazol applied at 0.5 kg a.i/ha and control plants (Table 5.6). There were no significant differences between the paclobutrazol rates for specific leaf area and specific leaf weight (Table 5.6).

Ten days after peak flowering plants treated with paclobutrazol at 1.0 kg a.i/ha had a significantly reduced leaf area, and specific leaf area, but increased specific leaf weight when compared with control plants (Table 5.6), but chemical treatment had no effect on leaf dry matter. There were no significant differences between the paclobutrazol treatments (Table 5.6).

5.3.3 Effect on total number of flowers/m² and flowering pattern

Plants treated with paclobutrazol at 0.5 kg a.i/ha produced significantly fewer flowers/m² over the season than plants treated with paclobutrazol at 1.0 kg a.i/ha, but there were no significant differences between the chemical treatments and untreated plants (Table 5.4).

Flowering began on 16 December 1992. All plots had a similar flowering pattern, with two peaks, the first occurring on 27 January and a small peak two weeks later (Fig 5.2). There were some significant differences

Table 5.6 **Effect of paclobutrazol on leaf area, leaf dry matter, specific leaf area, and specific leaf weight 14 days before flowering(1), 10 days after flowering started(2), and 10 days after peak flowering(3).**

	Control	PP333 0.5 kg a.i/ha	PP333 1.0 kg a.i/ha	LSD<0.05
LA1 (cm ²)	1.546a	1.425a	1.375a	NS
DML1 (g)	0.0076a	0.0076a	0.0071a	NS
SPLA1 (cm ² /g)	203.4a	187.5a	193.7a	NS
SPLW1 (g/cm ²)	0.0049a	0.06053a	0.0052a	NS
LA2 (cm ²)	1.546a	1.375ab	1.187b	*
DML2 (g)	0.0084a	0.0076ab	0.0069b	*
SPLA2 (cm ² /g)	184.0a	180.9a	172.1a	NS
SPLW2 (g/cm ²)	0.0054a	0.0055a	0.0058a	NS
LA3 (cm ²)	1.025a	1.025a	0.896b	*
DML3 (g)	0.0052a	0.0056a	0.0049a	NS
SPLA3 (cm ² /g)	197.1a	183.0b	182.8b	*
SPLW3 (g/cm ²)	0.0051b	0.0055a	0.0055a	*

LA = leaf area, DML = dry matter leaf, SPCLA = specific leaf are, SPLW = specific leaf weight. 1,2,3, respectively show time of recording as mentioned.

Means within columns with the same letters are not significant at P<0.05. *. significant at P<0.05. NS - not significant.

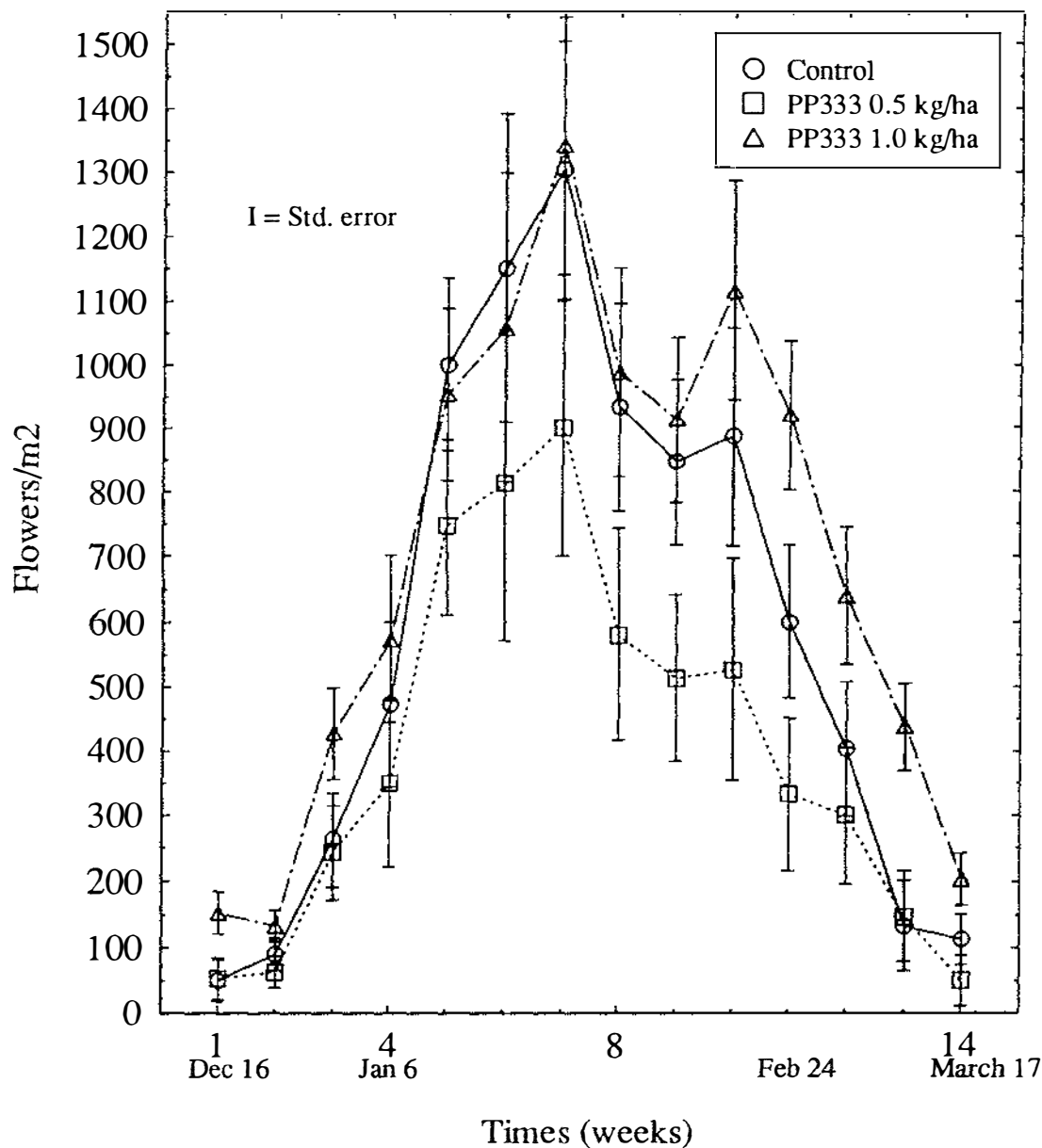


Figure 5.2 Effect of paclobutrazol on flowering pattern in the 1992/1993 crop season.

among treatments; for instance on 16 and 23 December, plots treated with paclobutrazol at 1.0 kg a.i/ha had more open flowers than the other treatments. There were no significant differences between this treatment and the control plants in later recordings, but there were differences between the two paclobutrazol rates, and between the control and paclobutrazol applied at 0.5 kg a.i/ha at various times during the flowering period (Fig 5.2). No treatment consistently increased flower number.

5.3.4 Effect on seed yield components

Paclobutrazol applied at 1.0 kg a.i/ha significantly increased the number of racemes/m² and floret buds per raceme 10 days before flowering (Table 5.7). While there was a significant difference between chemical treatments for the number of racemes/m², there were no significant differences among paclobutrazol treatments and untreated plants for the number of florets/raceme at peak flowering, or the percentage of florets aborted (Table 5.7). Neither rate of paclobutrazol affected the number of ovules per ovary or seeds per pod (Table 5.8), but paclobutrazol at 1.0 kg a.i/ha significantly increased the number of pods per raceme and the percentage of florets retained as pods (Table 5.8).

Number of florets per raceme showed less sensitivity to the chemical than inflorescence numbers. Paclobutrazol applied at 1.0 kg a.i/ha increased the number of florets per raceme at two of the recording dates (31 January and 15 February), compared with control plants, but there was no difference between the chemical treatments (Fig 5.3).

Simple linear correlation coefficients between seed yield and its components were + 0.94, + 0.74, + 0.32, and + 0.67 for number of racemes/m², pods per raceme, seeds/pod, and thousand seed weight

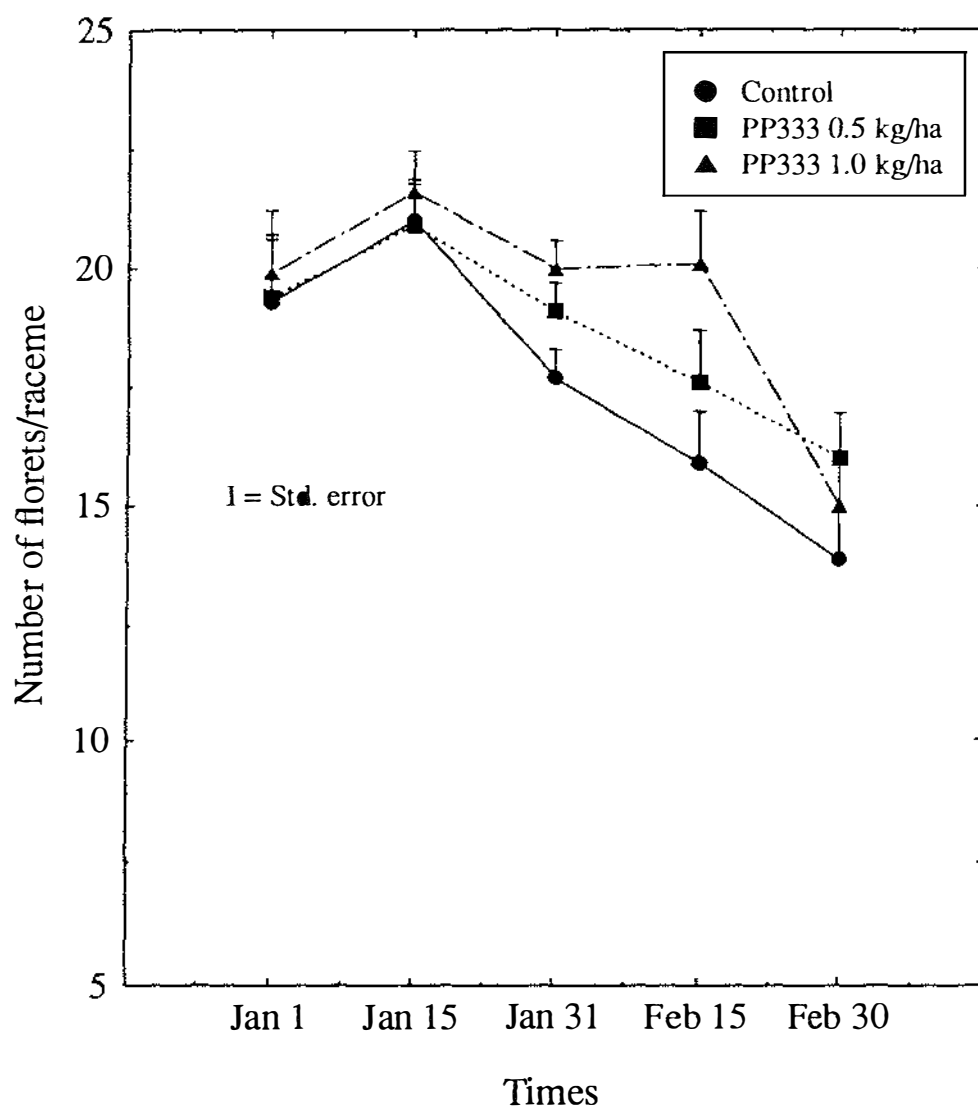


Figure 5.3 Effect of paclobutrazol on number of florets/raceme

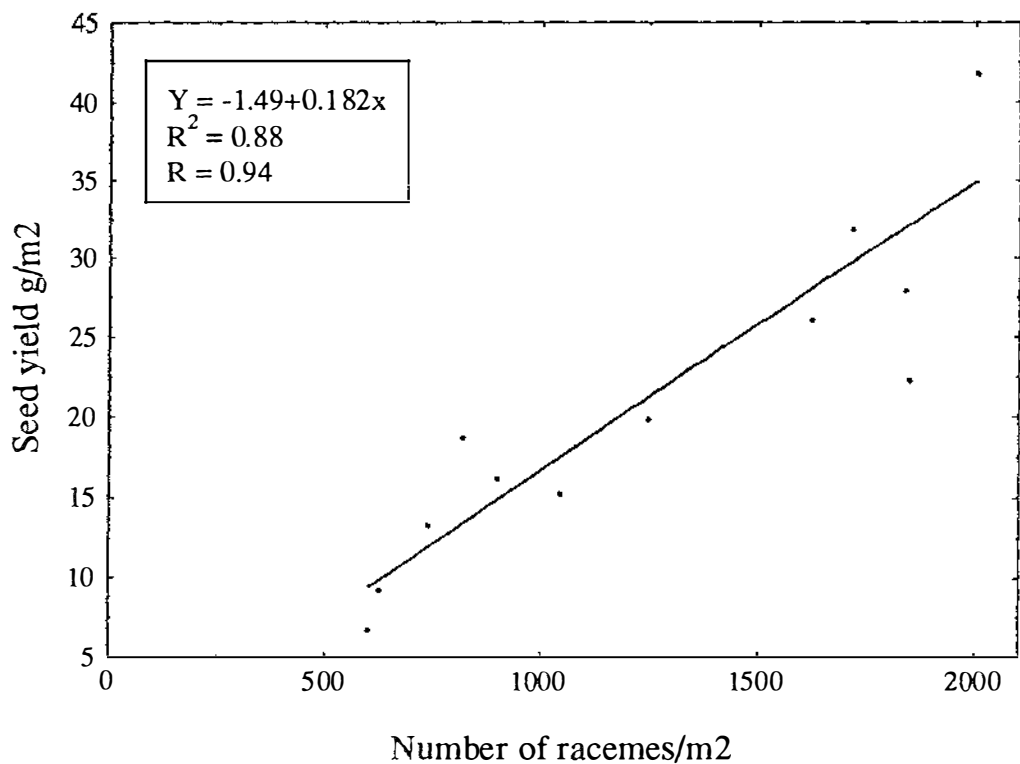


Fig 5.4 Relationship between number of harvestable racemes and seed yield

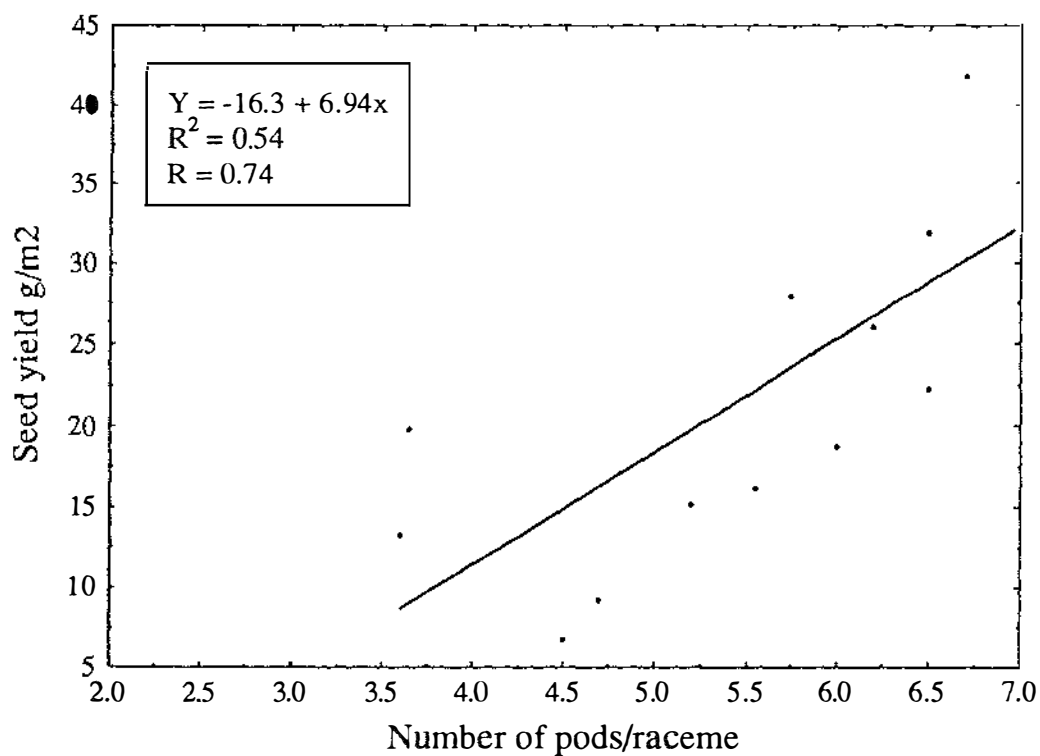


Fig 5.5 Relationship between pods per raceme and seed yield

respectively and those for number of racemes/m², pods per raceme, and thousand seed weight were significant. These results indicate that seed yield is highly and positively correlated with firstly the number of harvestable racemes/m², but less strongly related to pods per raceme, and thousand seed weight (Figures 5.4, 5.5 and 5.6).

5.3.5 Effect on seed yield

Application of paclobutrazol at 1.0 kg a.i/ha significantly increased seed yield, potential harvestable seed yield, harvest index, and thousand seed weight (Table 5.9), but seed yield following paclobutrazol application at 0.5 kg a.i/ha did not differ from the control. There was no difference between paclobutrazol treatments for the percentage of actual seed yield relative to potential seed yield, harvest index, or thousand seed weight (Table 5.9).

5.3.6 Effect on seed germination

Paclobutrazol treatment had no significant effect on the percentage germination, hard seed, dead seed or seed viability (Table 5.10).

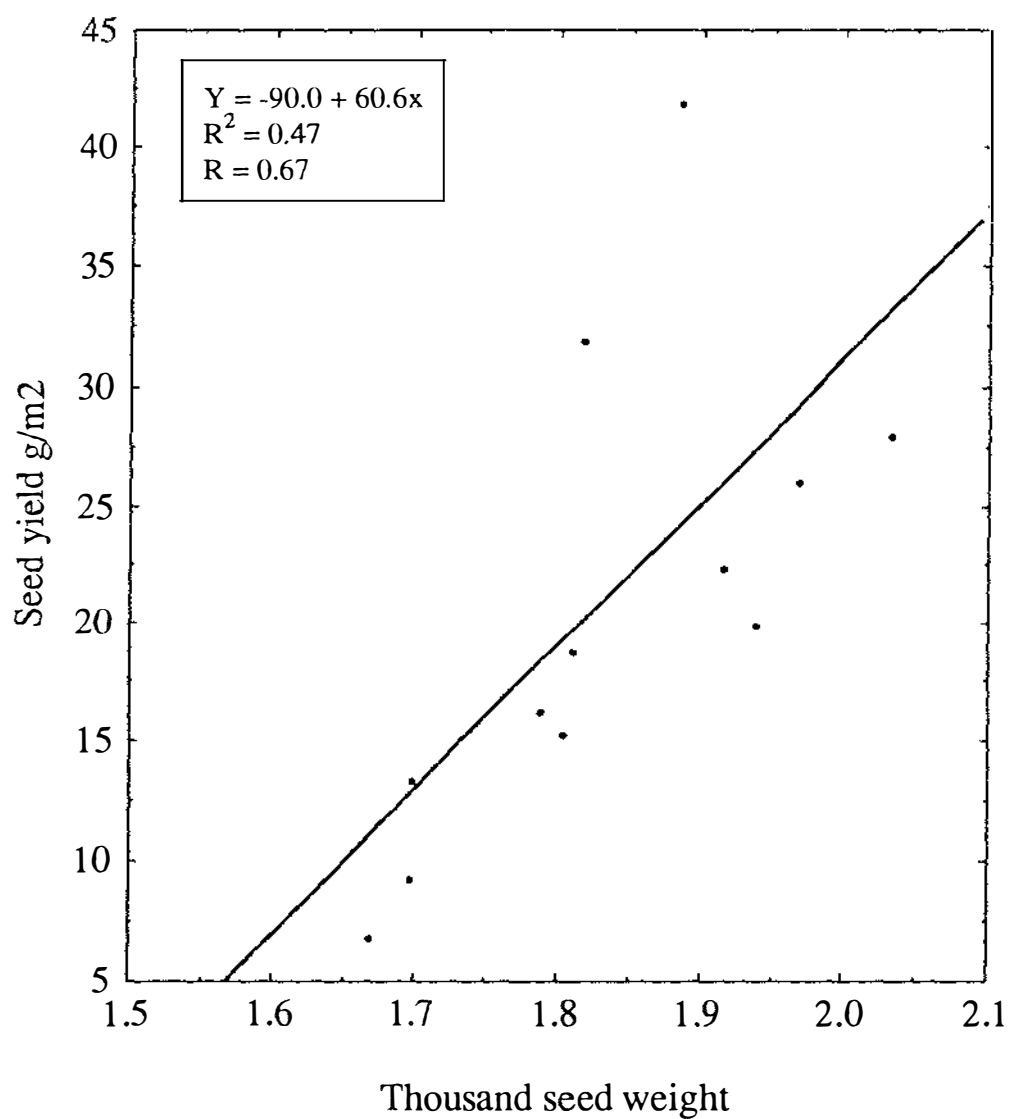


Fig 5.6 Relationship between thousand seed weight and seed yield

Table 5.7 Effect of paclobutrazol on number of harvestable racemes/m² at final harvest, number of floret buds per raceme, florets/raceme, and percentage floret abortion.

Treatment	Harvestable racemes per m ²	FLB/ raceme 10DBF	FL/raceme at peak flowering	% Florets aborted
Control	821.5b	23.4b	20.0a	15.0a
PP333 0.5 kg a.i./ha	1080.0b	25.9a	20.9a	19.3a
PP333 1.0 kg a.i./ha	1853.5a	26.8a	22.6a	15.7a
LSD P<0.05	554.07	1.72	2.12	5.7
Significance	*	*	NS	NS
CV %	25.5	3.9	5.7	11.3

Rac. = racemes, FLB = floret buds, 10DBF = 10 days before flowering, FL = florets.

Mean within columns with the same letters are not significantly different at P<0.05. *. significant at P<0.05. NS - not significant.

Table 5.8 Effect of paclobutrazol on number of ovules per ovary at peak flowering, pods/raceme, % florets retained as pods, and seeds/pod, at final harvest.

Treatment	Ovules/ ovary	Pods/ raceme	% Florets retained as pods	Seeds/ pod
Control	9.3a	4.7b	22.3b	3.1a
PP333 0.5 kg a.i/ha	9.2a	5.1b	24.4ab	3.0a
PP333 1.0 kg a.i/ha	9.2a	6.4a	28.3a	3.4a
LSD $P<0.05$	0.83	0.96	3.99	0.77
Significance	NS	*	*	NS
CV %	5.2	10.3	9.1	14.1

Means within columns with the same letters are not significantly different at $P<0.05$.

*, significant at $P<0.05$. NS - not significant.

Table 5.9 Effect of paclobutrazol on seed yield/ha, potential harvestable seed yield, thousand seed weight, and actual seed yield as a percentage of potential seed yield.

Treatment	Seed yield kg/ha	PHSY kg/ha	% Actual /PHSY	Harvest index	TSW (g)
Control	128.5b	852.9b	15.1b	3.1b	1.739b
PP333 0.5 kg a.i/ha	184.4b	628.4b	29.3a	4.1ab	1.853ab
PP333 1.0 kg a.i/ha	324.9a	1635.4a	19.9ab	7.02a	1.926a
LSD P<0.05	109.84	280.2	12.3	3.82	0.1629
Significance	*	*	*	*	*
CV %	29.8	20.3	32.9	37.4	5.1

PHSY = potential harvestable seed yield, TSW = thousand seed weight.

Means within columns with the same letters are not significantly different at P<0.05. *. significant at P<0.05.

Table 5.10 Effect of paclobutrazol on seed germination

Treatment	% Normal seedlings	% Abnormal seedlings	% Hard seed	% Viable seed
Control	58.5a	0.5a	40.5a	99.5a
Paclobutrazol 0.5 kg a.i/ha	62.5a	0.5a	36.5a	99.5a
Paclobutrazol 1.0 kg a.i/ha	63.5a	0.0a	36.0a	99.5a
LSD P<0.05	6.25	1.25	6.75	1.25
Significance	NS	NS	NS	NS
% CV	8.0	10.0	8.8	5.6

Means within columns with the same letters are not significantly different at P<0.05. NS - not significant.

Different between % viable seed and the sum of % normal seedling, abnormal seedling and hard seed are accounted by dead seed (ISTA, 1985).

5.4. DISCUSSION

Lucerne responded well to the application of paclobutrazol at 1.0 kg a.i/ha. Plant length was initially reduced by paclobutrazol when recorded eight weeks after application. Paclobutrazol reduces vegetative growth by inhibiting gibberellin through blocking the oxidation of kaurene to kaurenoic acid (Danziel and Lawrence, 1984). However retardation effects had disappeared when measurements were taken twelve weeks later. It may be possible that the rate used in the present study was not high enough to compete with the higher level of endogenous gibberellin induced by active plant growth at a later stage. Paclobutrazol also induced only short term growth retardation in china aster (*Callistephus chinensis* L.) (Phetpradap, L., 1992), in dahlia (Phetpradap, S. 1992) and in white clover (Budhianto, 1992). However Hampton and Hebblethwaite (1984a) reported that paclobutrazol reduced stem length in ryegrass from 14 days after application until to harvest. The reason for these differences may be due to plant growth habit. Indeterminate plants have the characteristic of active vegetative growth which continues during the reproductive growth stage, and it is also possible that such plants may have a capacity to relatively rapidly overcome the interference of paclobutrazol in blocking gibberellin biosynthesis. Whether this actually did occur is not clear. This aspect needs to be further investigated.

The effect of paclobutrazol in decreasing stem length in ryegrass is to delay and/or prevent lodging (Hampton, 1986). Lodging is recognised as being responsible for poor floret site utilisation (Hebblethwaite et al., 1980) and to therefore impose a severe restraint on the attainment of high seed yield (Hebblethwaite et al., 1978). In lucerne Kalmer (1991) reported that after

application of paclobutrazol at 1.5-3 kg a.i/ha, seed yield was increased on average by 55%, and considered that a large part of the increase resulted from the prevention of lodging of the lucerne stand. However there are few reports of lodging being considered a problem for lucerne seed production, and whether a PGR is actually needed to prevent lodging requires clarification. Lodging was minimal in the present trial, and no treatment differences in lodging score were recorded.

Paclobutrazol reduced leaf size when recorded ten days after flowering started, and ten days after peak flowering. The fact that dry weight did not change was presumably because total leaf area for the whole plant did not change, since paclobutrazol increased the number of branches which in turn increased the number of leaves. This result conflicts with the finding in chapter 4 where paclobutrazol applied during active vegetative growth significantly increased leaf size. These results may indicate a difference between sward sown plants and individually spaced plants (Chapter 4), as competition for assimilate in individual plants is lower than competition under sward conditions (Budhianto, 1992). Hampton (1991) also reported that paclobutrazol reduced leaf area of white clover cv. Grasslands Pitau when measured at peak flowering.

Although there were alterations to the morphological structure of plants following paclobutrazol treatment (particularly paclobutrazol at 1.0 kg a.i/ha), total dry matter was not affected. In this case, the result was similar to that found in the previous year (Chapter 4). This showed that paclobutrazol altered plant growth, without necessarily reducing plant assimilate production. Paclobutrazol at 1.0 kg a.i/ha produced a higher number of nodes/m², as indicated by the significantly increased total number of branches. This may

be due to the inhibiting effect of paclobutrazol on gibberellin biosynthesis, blocking the apical dominance of the main shoots. While paclobutrazol at 1.0 kg a.i/ha produced shortened internode length from the 4th to 15th nodes (Fig 6.1), this difference was not significant. However significant reductions in internode length have been reported in many crops, such as *Lotus corniculatus* (Li and Hill, 1989), perennial ryegrass (Hampton, 1983), and white clover (Marshall and Hides, 1987).

Paclobutrazol again (see Chapter 4) had no effect on the flowering duration or flowering pattern. This contrasts with the findings of Hampton et al., (1989a) and Tabora and Hill (1992) who reported that paclobutrazol applied at 1.0 kg a.i/ha in October shortened the flowering time of treated *Lotus* plants relative to untreated plants. The number of flowers changed dramatically with time, showing a peak flowering at 35 days after first flowering and a small subsequent peak flowering about 20 days later. These two peaks of flowering may be attributed to high rainfall and low temperature over the period between the two flowering peaks, mean minimum and maximum temperature between 29 January and 7 February fell from 11.7°C to 7.7°C and 20.1°C to 19.3°C respectively, and then subsequently increased (Appendix, 6.1). Guy et al., (1971) pointed out that decreasing temperature from 27 to 17°C generally decreased the number of lucerne flowers.

Unlike previous studies, application of paclobutrazol at 1.0 kg a.i/ha did not affect the total number of flowers/m² produced. This also contrasts with the findings by Li and Hill (1989) in *Lotus corniculatus*, and Tabora and Hill (1992) in *Lotus uliginosus* where paclobutrazol increased the number of flowers/m². This difference also may be due to seasonal differences, because the temperature during the flowering period (December to February) was

cooler than in 1991/1992. The number of flowers per shoot in lucerne has been reported to increase with increasing temperature from 17 to 27°C (Guy et al., 1971), but the results agree with those of Marshall and Hides (1989) who reported no increase in inflorescence number following paclobutrazol application in white clover cv. Olwen, and Supanjani (1991) who found that paclobutrazol had no effect on the number of inflorescences in *Lotus corniculatus*.

Although the number of ovules per carpel averaged about 9.3 at peak flowering, only about 3.2 seeds per pod reached maturity. This indicates a 66% loss. Cooper et al., (1937) reported that an average 9.3 ovules per carpel are normal in lucerne, but few of these ovules develop into seeds (Free, 1970), and Dovrat et al., (1969) reported that the number of seeds per pod ranged from 4.4-6.3. These losses in seeds per carpel might be due to intra-floret competition for assimilates. Insufficient assimilate during ovule provisioning may result in higher seed abortion (Clifford, 1986a). Hampton et al., (1989a), and Tabora and Hill (1991) noted that competition for assimilates has been implicated as a reason for low seed yield in *Lotus* spp. Lower partitioning of assimilate to the reproductive sink is likely to result in seed abortion. Whether this also occurs in lucerne is not known. This matter needs to be investigated further.

Paclobutrazol at 1.0 kg a.i/ha, as in the previous year, increased pods per raceme. It could be that as paclobutrazol reduced plant height, there was a reduction in the level of relative humidity within the canopy, an increase in light penetration and accessibility of flowers, and therefore more visits to flowers by bees, because in lucerne, flowers that are not tripped do not set seed (Free, 1970). Early main stem removal or growth retardant application can increase the movement of assimilates to lateral buds (Thomas, 1962)

making more assimilate available, which is possibly an advantage for pod set or pod retention. Dawkins and Almond (1984) reported that growth retardants could enhance seed yield in oil seed rape by changing the canopy structure which would allow greater penetration of light into the canopy, giving better utilisation of available light. It is also possible that the reduction in plant height in paclobutrazol treated plants at the beginning of pod set increased the competitive ability of the pods for assimilates and aided seed set and pod retention (Attiya et al., 1983), thereby promoting the retention of more pods per raceme and eventually harvestable racemes/m². Hodgson and Blackman (1957) reported that pod abscission in field beans was decreased when competition for assimilates was decreased by removal of upper reproductive nodes or by shading of the shoot apex. Hampton and Hebblethwaite (1985b) reported that paclobutrazol reduced floret abortion in *Lolium perenne* L. as a result of better assimilate supplies to the basal, intermediate and terminal sections of the ear. The result in the present trial are in agreement with the previous experiment (Chapter 4) and also Hampton (1991) who reported that an October application of paclobutrazol significantly increased the number of harvested inflorescences for white clover cv. Grasslands Pitau. This increase in the number of harvestable racemes/m² and hence seed yield must have resulted from an increase in the percentage of florets retained as pods and pods per raceme. However exactly why more florets and pods were retained needs further investigation.

Thousand seed weight, unlike in previous experiments, differed between paclobutrazol treatments and untreated plants. Paclobutrazol at 1.0 kg a.i./ha increased seed weight. Paclobutrazol appeared to modify the partitioning of assimilate in favour of the seed fraction, as seed weight increased. Another possible reason for this may be due to improved assimilate availability for

ovule provisioning as a result of increased net photosynthetic rate (Jaggard et al., 1982). Budhianto (1992) reported in three genotypes of white clover that paclobutrazol increased thousand seed weight. However this result differed from those achieved in chapter 4, where paclobutrazol had no effect on thousand seed weight in individual plants, and from the findings of Skalska (1991) in the same species, and in lotus species, where Li and Hill (1989) and Hampton et al., (1987) all reported that thousand seed weight was not affected by application of plant growth regulators.

As in the previous experiment, the number of seeds per pod was not affected by treatment. The racemes developed more than four months after application of paclobutrazol, by which time the chemical was perhaps no longer effective and hence did not reduce seed abortion. However, paclobutrazol has a promising potential for reducing seed abortion in white clover (Budhianto, 1992).

Seed yield after paclobutrazol treatment at 1.0 kg a.i/ha was increased by 153%. This result is in agreement with the result reported in Chapter 4. This increase was associated with an increase in the number of harvestable racemes/m², in the number of pods per raceme and in thousand seed weight. This results agrees with Hampton (1991) and Budhianto (1992) who reported that paclobutrazol increased white clover seed yield mainly by increasing harvestable inflorescences. Seed yield of *Lotus* spp. was also increased following paclobutrazol treatment, e.g. in *Lotus corniculatus* through enhancement of branching (Li and Hill, 1989) and through an increase in the number of pods per m² (Hampton et al., 1989).

Seed yield potential of paclobutrazol treated plants (1.0 kg a.i/ha) was greater than at the lower rate of chemical and in the control, because of a significant increase in the number of harvestable racemes/m² and pods per

raceme. From the present study the actual seed yield of lucerne was between 15.1-29.3% of the potential seed yield, and on a percentage basis, paclobutrazol at 0.5 kg a.i/ha gave a greater return (although a lower actual seed yield). The reason for this is due to the greater proportion of inflorescences which had developed into harvestable racemes.

Paclobutrazol applied at 1.0 kg a.i/ha significantly increased harvest index compared with untreated plants. There were no significant differences in dry matter production among treatments, but paclobutrazol at 1.0 kg a.i/ha significantly increased seed yield, therefore the proportion of seed yield to dry matter (harvest index) increased. Paclobutrazol is an anti-gibberellin (Shearing and Batch, 1982) that alters the distribution of dry matter from stem to ear in perennial ryegrass where it increased seed yield and harvest index (Hebblethwaite et al., 1982). This experiment gave similar results.

Paclobutrazol had no effect on seed germination. This result agrees with the finding in Chapter 4 and also with the finding by Skalska (1991) who reported that plant growth regulators had no effect on lucerne seed germination.

5.5 Conclusion

Based on the results from the present experiment and Chapter 4, the application of paclobutrazol at 1.0 kg/ha was considered to be an acceptable rate for increasing lucerne seed yield. However, timing of application is important. Any decision to apply paclobutrazol using calendar dates is not recommended, as crop age, crop management, weather conditions (particularly rainfall) and location, may all modify plant growth and development patterns.

Therefore, application timing based on the growth stage and development stage of the plant is likely to be more effective.

CHAPTER 6

THE EFFECT OF WEEDS, PARTICULARLY WHITE CLOVER, ON SEED PRODUCTION IN LUCERNE.

6.1 INTRODUCTION

Before the advent of selective herbicides, weeds in lucerne seed crops were controlled mainly by management and cultural practices such as fallowing, suitable seedbed preparation, and inter-row cultivation (Peters and Linscott, 1988). Selective herbicides came into use in the mid-1940s, but were used very little in lucerne because they were expensive, not entirely effective, and the hazard from herbicidal injury was high. The most effective herbicides that were safe on seedling lucerne were preplant incorporated herbicides such as EPTC, benefine, and profluralin for controlling grass weeds and some broadleaved weeds, and for which lucerne had considerable tolerance. Prior to 1982, postemergence herbicides that controlled emerged weed grasses caused too much injury to lucerne, but recently developed herbicides such as propyzamide, sethoxydim and fluazifop are tolerated by lucerne and have potential for controlling grass weeds in seedling as well as in mature lucerne (Peters and Linscott, 1988).

It was estimated that in the USA weeds reduce production of lucerne seed by 12% (USDA, 1965). An additional 4% of the seed is lost in cleaning, and a further 2% loss results from lower prices because of low quality.

6.1.1 WEEDS

What is a weed? All definitions of a weed are concerned with the relationship between the plant and the activities or desires of mankind. As examples, Crafts (1975) noted that a weed is a plant out of place, Numata (1982) defined weeds as a category of plants as opposed to crops, Anderson (1977) suggested that a weed is any plant growing where it is not wanted, and Popay (1990) defined a weed as an undesirable plant or a plant which negatively affects the growth of another plant.

Weeds reduce the yield of plants through competition for water, nutrients and light. Lawson (1974) and Popay (1990) reported that weeds may adversely affect crops in the following ways:

- i) producing allelochemicals which reduce crop growth.
- ii) acting as alternative hosts to crop pathogens and disease.
- iii) interfering with harvesting machinery, handling and quality.
- iv) increasing the cost of production by, for example, delaying seed drying.
- v) weeds also compete with crops for pollinating agents, especially in insect pollinated crops (such as lucerne) where some weeds may attract insects better than the crop, with the result that some of the crop flowers are left unpollinated, which consequently affects final seed yield.
- vi) weeds can smother crops reducing yields.
- vii) compete directly with crops for light, water and nutrients.

Weeds reduce yield and profits of all crops and also the quality of the seed lot for subsequent sowing (Hampton, 1988).

6.1.2 HERBICIDES:

Herbicides are valuable tools that may be substituted for some cultural practices in controlling unwanted vegetation, for example in limited tillage systems. In general, they represent an additional approach to weed control that should be integrated with other good cultural practices (Peters and Linscott, 1988).

Herbicides are used in forage seed crops to improve seed quality through reduced weed seed contamination, reduced seed cleaning losses and seed processing costs and reduced competition from weeds (Rolston, 1991).

Large monetary losses occur when weed-infested lucerne is grown for seed. These losses result from reduced production as well as from increased costs involved with growing, and cleaning of combined seed to provide weed-free seed. Weeds (not specified) can be successfully controlled in lucerne seed crops by using benfluralin (1.4 kg a.i/ha) in the first year and sebumeton (2 kg a.i/ha) in the second and third year (Dimitrova, 1984a), while Waddington (1985) found that in established stands, seed yield was increased 60% following four years of applying metribuzin (1.6 kg a.i/ha) at the onset of each growing season to control established dandelion (*Taraxacum officinale*) but primarily smooth brome (*Bromus inermis*). When seedling lucerne was kept weed free, it yielded 820 kg seed/ha compared with 45 kg/ha from weedy lucerne (Dawson and Rincker 1982). Mikhalev (1992) also reported that applying herbicides for weed control in lucerne gave higher seed yields than sowing without weed control, but the herbicides and weed spectrum were not given. Canevari et al., (1991) found that grasses in seedling lucerne were controlled effectively by propyzamide or paraquat.

Herbicides may be used in a variety of ways and in a variety of situations. Some may be more effective in an aquatic environment, others when applied to the soil, and still others when applied to the foliage of land plants. Within these various environments some herbicides may be '*non-selective*', *i.e.* they kill all of the vegetation, and others may be '*selective*' in that certain plants are killed off while other are unaffected. Fischer (1981) suggested that selective herbicides can be classified as:

- i) Preplant - incorporated not more than 5 cm into the soil before planting.
- ii) Preemergence - applied on the soil surface after planting but prior to germination of lucerne and weed seeds.
- iii) Postemergence - applied after the lucerne and weeds are growing or after the lucerne is established but prior to weed growth. Rainfall or irrigation is essential after application to activate the herbicides.

Herbicides may be applied as liquid sprays or as solid particles.

Hand weeding is laborious and in most cases expensive (Gilreath, 1989) and mechanical weed control or inter-row cultivation is often impractical because of the narrow row spacing used (Gilreath, 1986). Dimitrova (1986) reported that highest lucerne seed yields were obtained in wide-rows when weeds could be controlled by cultural and chemical methods.

Results from several experiments have shown that herbicides can be used to control weeds selectively in established lucerne (Kapusta and Stricker, 1976; Harvey et al., 1976; Swan, 1978). In some studies weed control has resulted in increased lucerne forage yields (Kapusta and Stricker, 1976; Harvey et al., 1976), but in others, yields were similar or lower than

the untreated control (Swan, 1978). However a limited number of reports have shown that weed competition can significantly reduce lucerne seed yield; for example Waddington (1985) reported that control of primarily smooth brome (Bromus inermis Leyss.) increased seed yield by 68%.

6.1.3 HERBICIDE INFORMATION

The herbicides selected for this study were chosen because they represent major herbicide groups and are recommended for use on lucerne forage crops.

The information presented below on the use and application rates of the herbicides was extracted from "Herbicides and Plant Growth Regulators", (Fletcher and Kirkwood, 1982)', and "The New Zealand Agrichemical and Plant Protection Manual" (O'Connor, 1990).

6.1.3.1 SIMAZINE

Simazine [2-chloro-4,6-bis-(ethylamino)-s-triazine] is a member of the s-triazine group of herbicides. Trade names in New Zealand are Chemagro Simazine 500 FL, Flowable Simazine, Gesatop 500 FW, and Simatox 900 WG. Simazine is a selective pre-emergence herbicide for weed control in many agricultural crops. It is very effective in preventing the germination of a wide range of annual and perennial grass and broadleaf weeds, but has little effect on established weeds. Rain or irrigation is needed to move the chemical into the soil as simazine is root absorbed by the germinating weeds. The soil residual life ranges from 3-12 months depending on rate,

soil type and rainfall. Simatox 900 WG contains 900 g/kg simazine in the form of a water dispersible granule. All other products contain 500 g/litre simazine in the form of a concentrated suspension (O'Connor, 1990).

Simazine is widely used as a selective herbicide for control of broadleaf and grass weeds in established lucerne in New Zealand. At higher application rates (>4.4 kg/ha) simazine is used as a non selective herbicide for vegetation control in non agricultural areas. Simazine should be applied in winter when lucerne is dormant and weeds are young. Usually simazine is mixed with other herbicides to provide knockdown of existing vegetation. For grass and broadleaf weed control in established lucerne, the recommendation is to use 0.75 - 1.5 kg a.i/ha of simazine and 0.4 - 0.6 kg a.i/ha of paraquat in 200-300 litres of water (O'Conner 1990).

Simazine and paraquat generally are applied when lucerne is dormant to avoid injury (Peters et al., 1984). For example, in South Dakota, weed control and crop injury increased with herbicide applications in April as compared with March application (Arnold and O'Neal, 1973).

6.1.3.2 PARAQUAT (GRAMOXONE)

Paraquat (1,1'-dimethyl-4,4'-bipyridilium ion, normally formulated as the dichloride salt) is sold under the trade names Gramoxone, Dextrone X, Esgram, and Weedol. It is a non-selective contact herbicide which destroys photosynthetic tissues and is used for a variety of purposes including stubble cleaning, inter-row weed control, desiccation of various crops, and killing out of old pasture which can then be resown without ploughing. It is very fast acting, the first effects being noticeable after a few

hours, and plants are usually completely killed in 3-4 days. It kills the tops of broad leaved weeds and many grass weeds. It is quickly adsorbed onto soil particles so that sowing can follow soon after application (Calderbank, 1968). In lucerne for weed control, the recommendation is to use 0.4 - 0.6 kg a.i/ha in 250-350 litres water/ha, applied in winter when lucerne is dormant and weeds fresh and clean, or after cutting before regrowth (Peters and Linscott, 1988). The product used in the present trial was Gramoxone which contains 200 g/litre paraquat as the dichloride salt in the form of a soluble concentrate (O'Connor, 1990).

6.1.3.3 **HEXAZINONE (VELPAR L)**

Hexazinone[3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione], is selective for weed control in lucerne and radiata pine, and also used non-selectively for general weed and brush control. Hexazinone is a herbicide with contact and soil residual activity. It has maximum effect when applied during periods of active plant growth (Lane and Cornwell, 1981). In lucerne it should only be used in stands that have been established at least 12 months. It should be applied when weeds are actively growing i.e. September - January, at 1 kg a.i/ha in around 300 litres water/ha, to control a wide range of weeds, including annual poa (*Poa annua*), white clover (*Trifolium repens*), and subterranean clover (*Trifolium subterraneum*). Spraying should be delayed if rainfall is likely to fall within 1 hour following treatment. The use of hexazinone to control problem weeds in lucerne has gained wide acceptance in New Zealand and overseas. Those

weeds not easily killed by other chemicals, such as browntop (*Agrostis tenuis*) woolly mullein (*Verbascum thapsus*), nodding thistle (*Carduus nutans*) and white clover (*Trifolium repens*), can be readily controlled with this herbicide (Lane and Cornwell 1981, James and Mortimer, 1983). A significant increase in the forage yield of lucerne is usually associated with control of these weeds (Lane and Cornwell, 1981).

Usually, weeds are controlled in lucerne while the crop is dormant (winter) but it has been shown that better weed control can be obtained by using hexazinone after the first or second cut in the spring (Dumont and Delaude, 1981). However, there have been occasional reports of damage to lucerne from spring application, ranging from a yellowing of the stand for about 2 weeks after application to a reduction in yield at the first cut after application (Allen and Butler 1980; Lane and Cornwell, 1981).

Velpar L, the product used in this work, contains 250 g/litre hexazinone in the form of water soluble concentrate.

6.1.4 WEED SPECIES

The second year lucerne block used for this trial (see Chapter 3) contained some grasses such as Poa annua, but broad leaved weeds, particularly white clover (Trifolium repens L.) dominated. Other weeds present in the field included prickly sow thistle (*Sonchus asper*), broad-leaved dock (Rumex obtusifolius), willow weed (Polygonum persicaria), dandelion (Taraxacum officinale), annual mouse-ear chickweed (Cerastium glomeratum), and twin cress (Coronopus didymus).

6.1.5 Objectives

1. To assess the effect of weed competition on lucerne seed yield and quality.
2. To examine methods for weed control, principally of white clover, in a lucerne seed crop.

6.2 MATERIAL AND METHODS

The evaluation was carried out at the Massey University 'Frewen's Block', Palmerston North, New Zealand, on an 18 months-old lucerne stand sown in 30 cm rows from which one seed crop had been taken. The stand was on a fine sandy loam soil, as described in Chapter 3. Weeds present were well established. Weed control treatments were simazine plus paraquat and hexazinone, in addition to hand weeding and an unweeded control. The simazine plus paraquat was applied on 30 August 1992 when the lucerne plants were dormant, at a rate of 2.25 kg a.i/ha simazine and 0.6 kg a.i/ha paraquat. Hexazinone (Velpar L) was applied on 30 September 1992 at a rate of 1.0 kg a.i/ha. Herbicides were applied using a small gas pressure sprayer in 400 litres water per hectare at 200 kPa. In hand weeded plots, weeds were removed by hand or by push hoeing every two weeks from 30 September. Honey bees at 9 colonies/ha were located near the plots to pollinate the lucerne, starting about 24 December 1992 when the lucerne had sufficient bloom. Experimental detail is described in Table 6.1.

6.2.1 Experimental design and statistical analysis

Treatments were assigned in a randomized complete block design (RCBD) with 3 replicates. Plot size was 1.5 X 2 m. Data were analysed by analysis of variance (ANOVA) using the SAS programme (SAS, 1991). Where differences were found at the 5% level, means were compared by LSD test. Graphs were drawn using a microsoft chart program (GLE 3.2, 1991). Some data were recorded as percentages and were therefore transformed to an angular scale ($\arcsin \sqrt{y}$) (Steel and Torrie, 1987), before analysis.

The relationships between seed yield and seed yield components, and seed yield and weed dry matter were studied by regression analysis, using minitab (Minitab Inc, 1989).

6.2.2 Data collection

Treatment effects were assessed by visual estimates of plant ground cover on 1 November 1992 and 1 February 1993. The percentage ground cover of lucerne and weeds within a 0.5 m² quadrat in each plot was determined. Each 0.5 m² quadrat was divided by using string into 50 smaller quadrats (10 x 10 cm) each representing 2% of the total quadrat area (Plate 6.1).

Herbage mass was determined on 1 December 1992, and 21 March 1993 by cutting at ground level all plant material from within a randomly selected 0.1 m² quadrat in each plot. The cut herbage was separated into lucerne, and broad leaved and grass weeds. Herbage samples were dried in



Plate 6.1 Handweeded plot with quadrat used to assess percentage ground cover.



Plate 6.2 Unweeded plot demonstrating white clover incidence.

an oven at 65°C for 96 hrs and weighed to determine dry matter production for each component.

To assess flowering date, the field was inspected daily from the time when flower buds first started emerging.

Lucerne seed yields were recorded on 21 March 1993, following hand harvesting of all plants within two randomly selected 0.25 m² quadrats for each experimental plot. The lucerne racemes were separated from the material, the number of racemes/m² determined and then left at ambient temperature for four weeks to dry. After drying, seeds were separated from the pods by hand rubbing. They were then cleaned and purity determined as described in previous experiments (see Chapters 3, 4). Seed yield was corrected to 7% seed moisture content.

The number of harvestable racemes/m² were counted directly from harvested plants. Fifty racemes/plot, which were selected randomly from the harvested racemes, were dissected to give the number of pods/raceme. The number of seeds/pod were counted from 50 pods/plot which were selected randomly from a bulk of pods dissected from the harvested racemes. Thousand seed weight (TSW) was determined by counting 8 x 100 seeds which had been air-dried at ambient temperature for five weeks (corrected to 7 per cent seed moisture content).

Seed quality was assessed using the germination procedure prescribed in the ISTA rules (ISTA, 1985) with four replicates of 100 seeds per plot.

Table 6.1 Cultural management and experimental details.

Site	Frewen's block, Massey University Palmerston North.
Soil type	Manawatu fine sandy loam
Stand age	18 months
Sowing rate	3 kg/ha
Row spacing	30 cm
Grazing	5 August 1992 (5-7 cm height)
Fertiliser	Nil
Herbicides and rate (kg a.i./ha):	
Simazine + Paraquat	2.25 + 0.6, 30 August 1992
Hexazinone	1.0 , 30 September 1992
Hand weeding	Every two weeks from 30 September 1992
Insect control	Fluvalinate 0.1 kg a.i./ha, 21 Oct., 22 Dec. 1992
Disease control	Benomyl 0.5 kg a.i./ha, 22 Dec. 1992
Recording times:	
Plant ground cover recorded	1 November 1992, 1 February 1993.
Dry matter recorded	1 December 1992, 21 March 1993
Seed harvest	21 March 1993

6.3 RESULTS:

6.3.1 Effect of herbicides and hand weeding on plant ground cover and its components.

On 1 November 1992, total % ground cover was greatest for the unweeded control, followed by the two herbicides treatments, with the hand weeding treatment having just over one third ground cover (Table 6.2). However for the control, only 13% of this cover was lucerne with white clover constituting 60% and other weeds (such as broad leaved dock, twin cress, dandelion, and annual mouse-ear chickweed) 26% of the cover.

All treatments significantly increased the percentage of lucerne in the plant ground cover (Table 6.2), and significantly decreased the percentage of white clover compared with unweeded control plots, although hexazinone and hand weeding were more effective than simazine plus paraquat (Table 6.2). Herbicide treatment had no effect on percentage of other weeds in the ground cover (Table 6.2).

On 1 February 1993, percentage ground cover did not differ among treatments. Both of the herbicide treatments and hand weeding significantly increased the percentage of lucerne in the plant cover (Table 6.3). Hexazinone application and hand weeding eliminated white clover from the plant cover by 1 February 1993 but there was no significant difference in the white clover cover of the unweeded plots and those treated with simazine and paraquat by this date (Table 6.3). Also there were no significant differences between herbicides for the percentage of other

Table 6.2 Effect of herbicides and hand weeding on percentage plant ground cover and its components, 1 November, 1992.

Treatment	%ground cover			
	total	lucerne ¹	white clover ¹	other weeds ²
Unweeded	90.0a	13.3b	60.5a	25.7a
Hand weeding	36.4c	36.3a	3.3c	0.0b
Hexazinone	69.2b	42.1a	13.8c	22.7a
Simazine + Paraquat	84.2ab	36.8a	31.9b	34.3a
LSD P<0.05	16.79	12.52	12.35	12.39
Significance	*	*	*	*
CV %	12.0	19.5	22.5	26.8

Means within columns with the same letters are not significantly different at P<0.05.

¹original percentage data were transformed to an angular scale ($\arcsin \sqrt{y}$) (Steel and Torrie, 1987) for analysis, and presentation of results. Applies to all appropriate tables.

²other weeds included broad leaved dock, twin cress, dandelion, annual mouse-ear chickweed. *. significant at P<0.05.

Table 6.3 Effect of herbicides and hand weeding on percentage plant ground cover and its components, 1 February, 1993.

Treatment	% ground cover			
	total	lucerne	white clover	other weeds ¹
Unweeded	90.0	27.8c	38.4a	37.0a
Hand weeding	90.0	90.0a	0.0b	0.0b
Hexazinone	90.0	70.7ab	0.0b	19.3ab
Simazine + paraquat	90.0	54.8b	28.6a	16.1b
LSD $P < 0.05$	0.0	25.79	19.9	20.77
Significance	NS	*	*	*
CV %	0.0	21.2	39.4	37.4

Means within columns with the same letters are not significantly different at $P < 0.05$.

¹other weeds broad leaved dock for hexazinone

and broad leaved dock, twin cress, dandelion, annual mouse-ear chickweed.

*, significant at $P < 0.05$. NS - not significant.

weeds in the plant cover, but simazine plus paraquat and hand weeding had significantly fewer other weeds than the control (Table 6.3).

6.3.2. Effect of herbicides and hand weeding on dry matter (g/m^2) of lucerne and weeds

On 1 December, the unweeded control had 424 g/m^2 dry matter, but only one quarter of this was lucerne (Table 6.4). Hexazinone had significantly more lucerne dry matter than the control, but hand weeding and simazine plus paraquat did not differ from the control. All treatments eliminated grass weeds, and hand weeding and hexazinone significantly reduced the broad leaf weed content (Table 6.4).

At final harvest both herbicide treatments and hand weeding had produced significantly more lucerne dry matter than the unweeded control, and had also decreased the dry matter of weeds. However, hexazinone and hand weeding had significantly less weed dry matter than simazine plus paraquat (Table 6.5).

6.3.3 Effect of herbicides and hand weeding on lucerne seed yield components, and seed yield

Harvestable racemes/ m^2 : At final harvest, hand weeding and hexazinone significantly increased the number of harvestable racemes/ m^2 in contrast with simazine plus paraquat and the unweeded control where there were no significant differences (Table 6.6).

Table 6.4 Effect of herbicides and hand weeding on dry matter of weeds and lucerne, 1 December 1992.

Treatment	Dry matter g/m ²			
	Lucerne	Broad leaf weeds ¹	Grass weeds ²	Total
Unweeded	105.0b	310.5a	8.3a	423.9a
Hand weeding	174.4ab	1.3b	0.0b	175.7b
Hexazinone	218.8a	34.8b	0.0b	253.7ab
Simazine + Paraquat	170.8ab	166.9ab	0.0b	337.7ab
LSD P<0.05	95.9	174.71	4.23	180.97
Significance	*	*	*	*
CV %	21.1	38.1	41.0	22.0

Means within columns with the same letters are not significant at P<0.05.

¹includes white clover, broad leaved dock, dandelion, twin cress, annual mouse-ear chickweed. ²Poa annua, *. significant at P<0.05.

Table 6.5 Effect of herbicides and hand weeding on lucerne, and weed dry matter (g/m²) at final harvest on 25 March 1993.

Treatment	Dry matter of lucerne	Dry matter of weeds ¹
Unweeded	75.2b	374.1a
Hand weeding	410.4a	6.4c
Hexazinone	509.7a	45.0c
Simazine + Paraquat	405.6a	202.8b
LSD P<0.05	178.8	70.8
Significance	*	*
CV %	26.9	24.0

Means within columns with the same letters are not significantly different at P<0.05.

¹major species were white clover, broad leaved dock, twin cress, dandelion and annual mouse-ear chickweed. *.significant at P<0.05.

Pods/raceme: Only hexazinone and hand weeding significantly increased the number of pods/raceme. There was no significant difference between simazine plus paraquat and the unweeded control (Table 6.6).

Seeds/pod: Hand weeding significantly increased the number of seeds/pod, but differences from the control were not significant for herbicide treatments (Table 6.6).

Thousand seed weight: Neither herbicide treatments nor hand weeding had any effect on thousand seed weight (Table 6.6).

Seed yield/ha: Hand weeding and hexazinone significantly increased seed yield, but there was no significant difference between hexazinone and simazine plus paraquat. Simazine plus paraquat had no significant effect on seed yield (Fig. 6.1).

6.3.4 Relationship between seed yield and its components

A simple linear correlation coefficient between seed yield and its components indicated that seed yield was significantly and positively

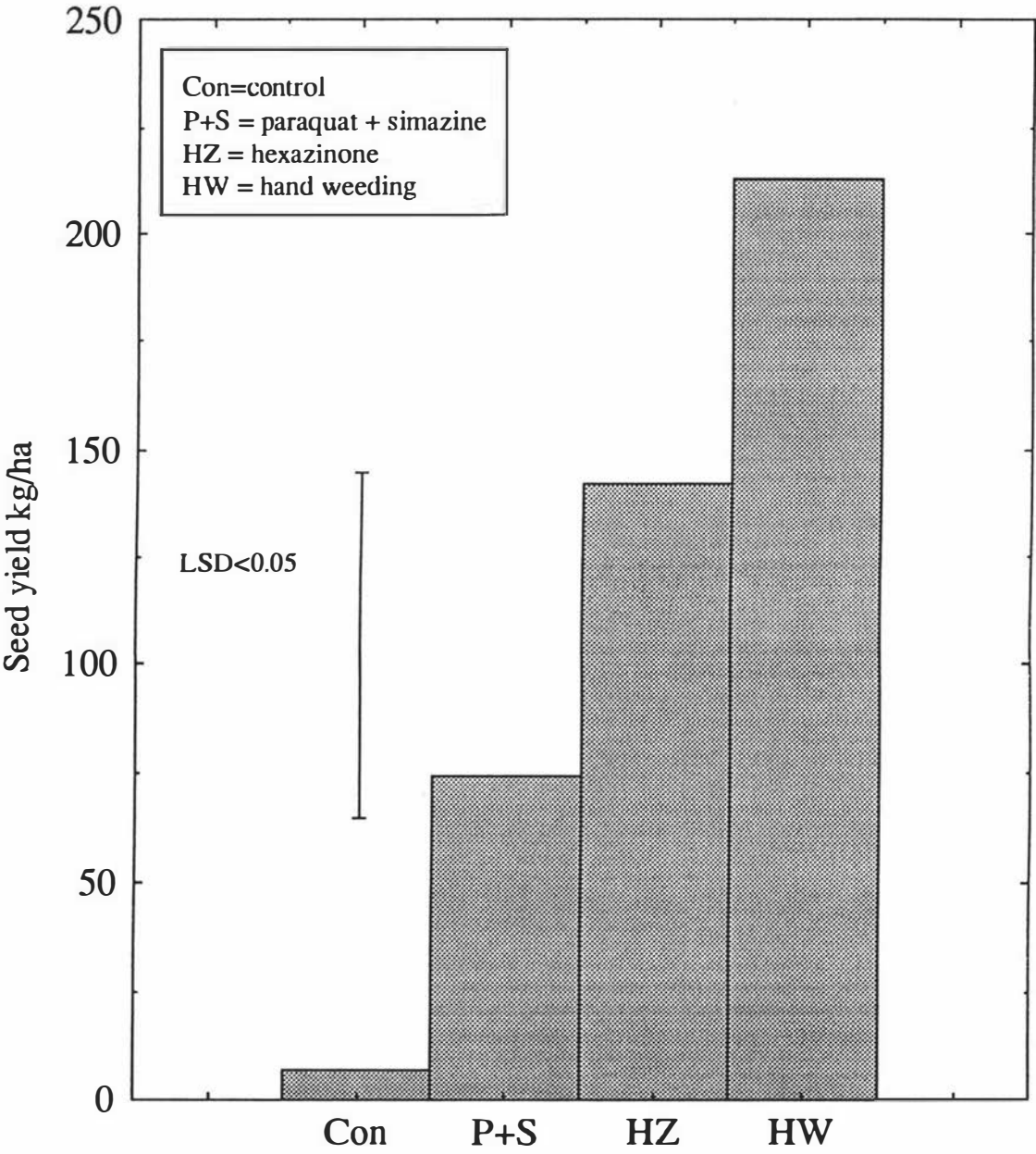


Figure 6.1 Effect of herbicide application and hand weeding on lucerne seed yield.

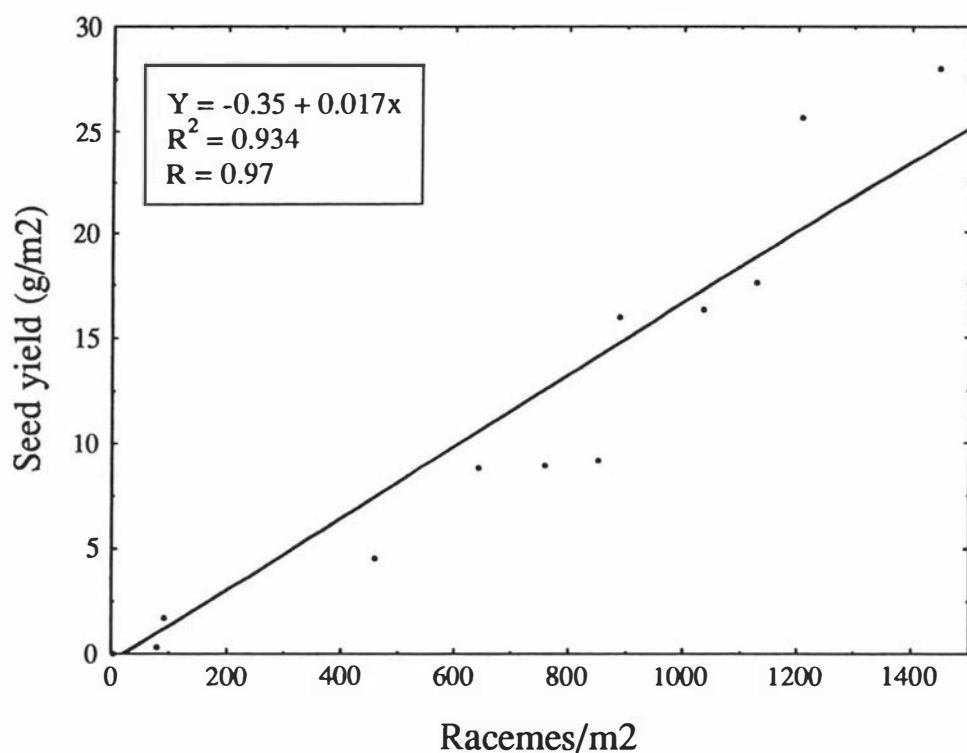


Fig 6.2 Effect of racemes/m² (x) on lucerne seed yield (y)

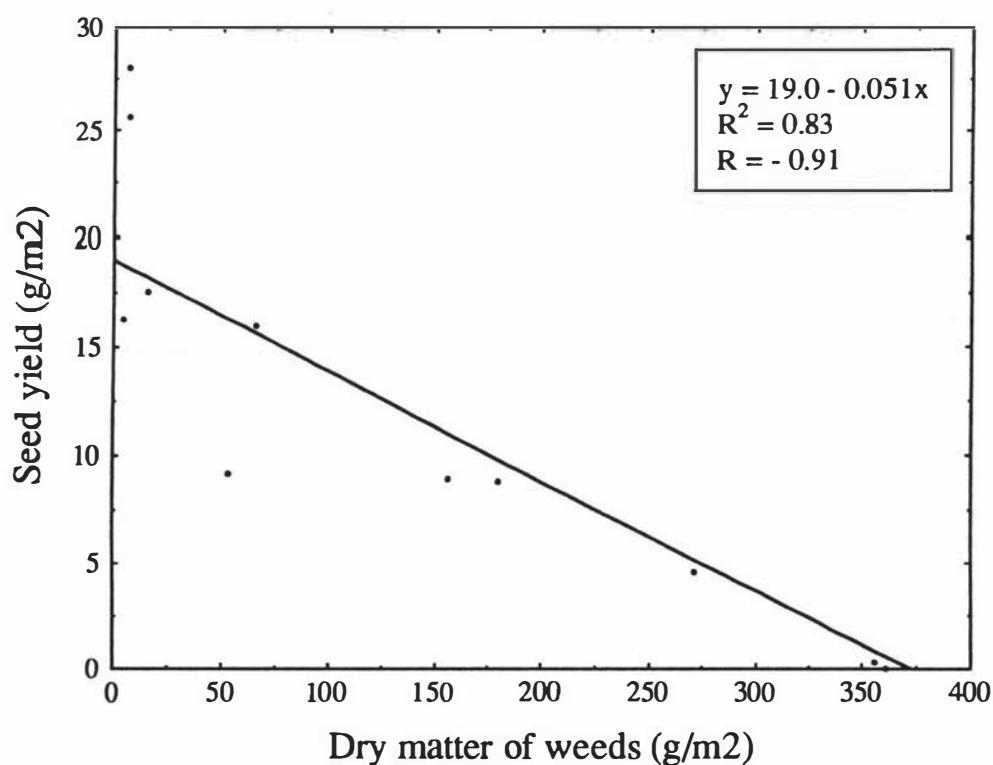


Fig 6.3 Effect of weed dry matter (x) on lucerne seed yield (y)

correlated with the number of racemes/m² ($r = 0.97$, $P < 0.001$) (Fig 6.2), and pods per raceme ($r = 0.62$, $P < 0.05$), but seeds per pod and thousand seed weight had no significant effect on seed yield.

6.3.5 Relationship between seed yield and dry matter of weeds/m²

The simple linear correlation coefficient between seed yield and dry matter of weeds at final harvest showed there was a negative correlation $r = -0.91$ between the seed yield and dry matter of weeds/m² (Fig 6.3).

6.3.6 Effect on seed germination

Neither hand weeding nor herbicide treatments affected the percentage of viable seed, abnormal seedlings or dead seed. However hand weeding and herbicide treatments significantly increased germination (% normal seedlings) by reducing hard seed levels. This response was greatest for the hexazinone treatment (Table 6.7).

Table 6.6 Effect of herbicides and hand weeding on lucerne seed yield components.

Treatment	Harvestable racemes/m ²	Pods/raceme	Seeds/pod	TSW (g)
Unweeded	89.3b	3.5b	2.57b	1.785a
Hand weeding	1230.8a	5.5a	3.68a	1.623a
Hexazinone	956.0a	6.0a	3.49ab	1.837a
Paraquat + Simazine	370.6b	4.5ab	3.27ab	1.753a
LSD P<0.05	296.64	1.65	0.962	0.215
Significance	*	*	*	NS
CV %	22.1	16.9	14.8	6.1

TSW = thousand seed weight.

Means within columns with the same letters are not significantly different at P<0.05. *. significant at p<0.05. NS - not significant

Table 6.7 Effect of herbicides and hand weeding on lucerne seed germination

Treatment	% Normal seedlings	% Hard seed	% Viable seed
Unweeded	23.0c	75.0a	99.0a
Hand weeding	32.4b	63.0b	99.5a
Hexazinone	53.0a	41.5c	98.5a
Simazine + Paraquat	37.0b	59.0b	99.0a
LSD $P<0.05$	6.54	9.18	2.26
Significance	*	*	NS
CV %	11.1	9.6	1.4

Means within the columns with the same letters are not significantly different at $P<0.05$.

*. significant at $P<0.05$. Ns - not significant.

Differences between % viable seed and the sum of % normal seedlings and hard seed are accounted for by abnormal seedlings (ISTA, 1985).

6.4 DISCUSSION

Application of herbicides proved effective in controlling most broadleaf weeds and eliminated the Poa annua present in this experiment. Good selective control of annual weeds has also been obtained with 2.5 kg mixture of sebumeton plus simazine, and 1.5 kg/ha hexazinone (Dimitrova, and Benkov, 1990). Reduction in the weed population lead to better growth of the lucerne by elimination of competition between lucerne plants and weeds. Much research has been done which shows that deficiencies in light, nutrients and moisture during flowering causes reduced flower capacity by increasing flower abortion and hence reducing the number of flowers. For example Hicks et al., (1969) found that light penetration within soybean canopies influences yield and severe weed growth creates a canopy over soybean plants and decreases light penetration (McWhorter and Hartwig, 1972). In the control plots in the present experiment, lucerne plant growth was severely suppressed due to the presence of a large number of weeds, particularly white clover, which presumably competed with the lucerne crop for nutrients, moisture, and particularly light. Severe competition between weeds and the lucerne plants also killed some lucerne plants. However the major effect of weeds was to reduce the number of harvestable racemes/m². Competition from weeds resulted in an 82% reduction in total dry matter production because when compared with hand weeded plots, racemes/m² were reduced by over 90%. The net effect of this for seed production was a 97% reduction in seed yield due to the presence of weeds, a result very similar to the 95% reduction reported by Dawson and Rincker (1982). Initially at this site, most of this weed competition cam from white clover, but as the season progressed, other weed species including dandelion, broad leaved dock, twin cress and annual

mouse-ear chickweed also became important. However by final harvest the major weed component was still white clover. White clover plants reached their maximum height in January and began to lodge, forcing the lucerne plants to lodge as well. This occurred during lucerne flowering, and it is possible that, in addition to the competition for light, nutrients and water provided by the weeds, lodged lucerne flowers were less accessible to pollinators.

The effect of weed competition on lucerne seed production has not been obtained directly but a yield increase of over 30% was obtained when lucerne was kept weed free by applying terbacil or dichlobenil at the start of growth (Waddington, 1980).

Slight yellowing of lucerne foliage occurred after the early spring application of hexazinone to actively growing lucerne. This effect was present for about two weeks, but treated plants recovered and no effects on the later growth of lucerne were recorded. This chemical increased both the percentage of lucerne cover and hence lucerne dry matter/m², and no delay in flowering was recorded. Any effect this might have had on yield was masked by positive response of lucerne to the reduction in weed competition. These findings are consistent with the findings of Waddington (1985) who stated that lucerne was often damaged initially by application of hexazinone but recovery was rapid. Soil moisture and age of the lucerne stand at treatment are important in determining the degree of lucerne tolerance. Younger stands growing in lighter soils and under lower moisture conditions were more susceptible to damage (Lane and Cornwell, 1981).

Hexazinone is a selective herbicide for lucerne and gave good control

of white clover and many broad leaved weeds, but can not be used in stands less than twelve months old (O'Connor, 1990) because of the risk of damage to young lucerne plants. Once applied, this chemical provided good weed control until harvest time, the only exception being broad leaved dock, which grew to a height of over one metre in hexazinone treated plots. It is possible that the reason the seed yield from hexazinone treated plots was lower (but not significantly different) than that from the hand weeded plots was because of the presence of broad leaved dock, but this was not determined conclusively. Hexazinone at 1.0 kg/ha also eliminated grass weeds. This result agrees with Peters et al., (1984) who reported that hexazinone reduced dry matter of grass weeds.

Hexazinone application and hand weeding also increased the number of racemes/m² due to the improved plant growth which ultimately resulted in the production of a greater number of pods/raceme and therefore increased seed yield. Dawson and Rincker (1982) found that when lucerne was kept weed free, it yielded 820 kg seed/ha compared with 45 kg/ha from weedy lucerne, and Waddington (1985) reported that lucerne seed yield was increased by applying 1.0 kg a.i/ha hexazinone. In this trial with hexazinone alone lucerne yielded 19 times more than the control.

Simazine plus paraquat had no effect on lucerne seed yield, primarily because of the failure of this treatment to control white clover. This result agrees with Waddington (1980) who found that simazine plus diuron did not affect lucerne seed production significantly, although both simazine and diuron reduced the weed population.

Simazine plus paraquat did initially decrease the percentage cover of white clover, but it recovered quickly, so that by five months after application

the white clover content did not differ from the control. This indicated the need for either a higher rate at the initial application or a second herbicide application to provide season long weed control (Phetpradap and Hampton, 1991).

Simazine plus paraquat also showed no effects on lucerne dry weight in the first recording on 1 December, but increased dry matter of lucerne at final harvest. These chemicals also significantly increased percentage cover of lucerne by 1 November 1991 and 1 February, 1992.

Some weeds, for example broad leaved dock, which grow from a strong regenerating crown, were not controlled by any herbicides in this study.

There was a strong negative correlation ($r = -0.91$) between the dry matter of weeds and lucerne seed yield. This result is similar to the general pattern reported for many herbage seed crops. In a review on yield effects of herbicides on competition between crop and weed communities Hawton (1980) reported that the relationship between crop and weed top dry matter yields at harvest time is often linear. This result also agrees with the findings of Rolston and Hare (1986) who reported that there was a negative relationship between seed yield and percentage weed cover in grass seed crops. Although the lucerne dry matter in the unweeded plot was reduced relative to all treatments (Table 6.6), the major effect was on plant size. Individual lucerne plants were much smaller, as shown by reduced dry matter at final harvest, and produced less seed.

Results in this experiment show that by controlling severe weed infestations with hexazinone, there could be an increase in lucerne

productivity, as also suggested by James and Atkinson (1979), and Lane and Cornwell (1981).

One unexpected result from this experiment was the effect of the treatment on hard seed levels. Viability did not differ among treatments, yet both complete and partial removal of weeds significantly reduced hard seed levels. Hard seed development is strongly influenced by environmental factors (Rolston, 1978) particularly relative humidity and temperature. It is possible that the environment during seed maturation differed between the unweeded plots, where lucerne seed pods were overgrown and smothered by weeds, and plots where weeds were absent or partially removed. However this was not recorded.

One important aspect of management of a commercial seed crop is the cost of production. While hand weeding in this experiment produced more seed per hectare (30 times more than unweeded), hand weeding is laborious and in most cases expensive and therefore not practical (Fretz, 1972, Gilreath, 1989), resulting in a lower profit potential for the grower (Yadav, and Bose, 1987). Lamont et al., (1985) estimated that labour costs for manual weeding in Australia can exceed A\$ 10,000 per hectare, depending on the severity of weed infestation. This is expensive compared to herbicide costs of around NZ\$ 160/ha for hexazinone and NZ\$ 101/ha for simazine plus paraquat.

Further research might examine whether the use of a lower rate of hexazinone will result in reduced damage while maintaining weed control until after the seed is harvested, and whether the chemical could be used for weed removal from lucerne seed crops in the establishment year. This requires investigation.

CHAPTER 7

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Lucerne (*Medicago sativa* L.) has been called "the queen of forage crops" because of its remarkable ability to produce a high yield of rich, palatable, nutritious forage under a wide range of soil and climatic conditions (Hanson and Barnes, 1972). In normal practice it is common for farmers to cut lucerne herbage and then harvest for seed later in the same season. Lucerne seed production is influenced by a number of factors: genetic variability, climate, soil type, pollinator activity, pest and diseases, management, and interactions between them (Hacquet, 1990).

Various aspects of the agronomy and seed production of lucerne cv. 'Grasslands Oranga' were examined in the experiments described in chapters 3 to 6 of this thesis, including several possible factors influencing plant establishment (chapter 3), seed production of lucerne under different row spacings and sowing rates (chapter 3), plant growth regulators (chapter 4 and 5) and weed control (chapter 6). The following discussion is divided into several sections which address the main findings.

7.1 Plant establishment

Some of the problems associated with the establishment of lucerne cv. Grasslands Oranga are demonstrated in Chapter 3. Despite the fact that the standard germination of the seed lot before sowing was 99% and there was no

hard seed, the overall mean for seedling emergence one month after sowing was 57% for all treatments. Average seedling establishment 6 months after sowing was 46%, a result which agrees closely with Wynn-Williams (1982) who reported that in New Zealand, the best survival was usually only 50%. However sowing rate had a significant effect on plant establishment 18 months after sowing, being highest (73%) at the lowest sowing rate (1 kg/ha). The average over all treatments was only 34% because plant establishment was particularly poor at the 12 kg/ha sowing rate. As discussed in chapter 3, reductions in plant establishment were presumably due to seedling and plant mortality caused by pathogens and pests, and also competition between lucerne plants and between lucerne plants and weeds. For improvement of plant establishment, it is suggested that seed should be treated with a suitable fungicide before sowing to control damage by pathogens (Falloon and Skipp, 1982). Secondly, the early application of a post-emergence pesticide for control of harmful pests, particularly slugs (Morton, 1974) can be recommended. Seedlings emerging from an autumn sowing tend to have more competition with winter annual weeds and increased seedling mortality (Wynn-Williams, 1982), which suggests that lucerne seed should be sown in early spring, or if autumn sown, an early post-emergence herbicide should be applied for weed control (Butler, 1982). If the crop is being sown for forage production, then these recommendations should be followed. However for seed production only, establishment can be improved by reducing the sowing rate substantially, although as demonstrated in Chapter 6, weed control is extremely important. The failure of this study was that although seedling mortality was demonstrated, the actual reasons for these deaths were not conclusively determined. The results therefore have simply confirmed those of previous studies. Factors which require further study include: i) the

identification of pathogens and pests responsible for seedling death and the determination of appropriate chemical (or alternative) control methods. ii) the effect of seed vigour on lucerne seedling establishment.

7.2. Seed production

Seed yield of lucerne varies from year to year because the growth and development of the seed yield components is strongly affected by the environment. Successful lucerne seed production is favoured in regions that are characterized by clear, sunny, warm summer days in combination with little or no rain fall during flowering. These climatic conditions promote good flowering of lucerne and provide an environment conducive to the pollinating activity of bees, two factors that are essential for seed production (Rincker et al., 1988). However, Palmerston North is characterized by humid and often cloudy conditions. Rain which fell readily during the flowering stage in both years (Fig 3.1a) is not suitable for good lucerne flowering or bee activity (Rincker et al., 1988), and as a result, the seed yield was low when compared with average seed yields in Marlborough and Canterbury (Hampton, pers. comm., Chapters 1 and 3). Therefore, the Manawatu province with around 1000 mm rainfall per year, average minimum and maximum temperatures during the flowering period (December, January and February) of around 12.4 and 21.6° C respectively (Fig 3.1b) and windy weather (Fig 3.1d) is not recommended for lucerne seed production.

Plant density is known to be an important factor in seed production, although a number of studies have reported sometimes conflicting results on the influence of row spacing and sowing rate (Pedersen and Nye, 1962; Rincker, 1979; Kowithayakorn and Hill, 1982; Lovato and Montanari, 1987)

on lucerne seed production. Thin uncrowded stands are recognised as capable of producing higher seed yields than thick stands in a solid plant field (Marble, 1970). Low seed production from dense stands can be explained in part by low nectar production, unattractiveness to pollinators, and increased floral abortion (Rincker et al., 1988). Increased seed yields from lucerne planted at low density can be attributed to both physiological and morphological changes in the plants (Kolar and Torell, 1970). Plants at low densities are shorter, lodge less, resist frost injury, flower earlier, and are more attractive to bees because of an increase in nectar secretion and nectar sugar concentration, and thus seed yield is usually increased.

The effect of row spacing and sowing rate on plant structure, vegetative morphology and seed yield was striking (Chapter 3). Increasing the sowing rate resulted in a decreased seed yield per unit area. One explanation for this might be that plants produced from low sowing rates are more attractive to bees (Rincker et al., 1988), but this was not determined. Kowithayakorn and Hill (1982) reported that at the same site as in the present study, the highest seed yields in lucerne cv. Wariua were obtained from a density of approximately 11-25 plants/m². This plant density was much lower than that used in Chapter 3, where for example the 1 kg/ha sowing rate produced approximately 35 plants/m². This could indicate that an even lower sowing rate than 1 kg/ha may have produced a greater seed yield, or could suggest that because different cultivars of lucerne have different growth habits (Dehghanshoar pers. comm.) they may need to be grown at different spacings to give maximum seed yield. For example, Zambrana (1973) reported that the optimum plant spacings to give maximum seed yield of cv. Gilboa and cv. Galilee were 30 x 30 and 20 x 20 cm respectively. Results from this study indicated that at this site the 30-45 cm (particularly 45 cm) row spacing and

1.0 kg sowing rate favoured high seed yield because such plants tended to develop more reproductive shoots and flowers, and to be more amenable to higher levels of pollination. The optimum row spacing to give optimum seed yield in this trial agrees with the recommendation of Lovato and Montanari (1987), but not with spacings reported by other such as Abu-Shakra et al., (1969), Anotoniani (1972), and Ibraimove (1973) who recorded optimum row spacings of between 45-60 cm. The differences between these results might be due to the use of different cultivars or differing soil type and environments. However for cultivar Grasslands Oranga, a sowing rate of 1 kg/ha and row spacing of 30 or 45 cm should be used for seed production, a recommendation originally suggested (but without any published evidence) by Dunbier et al., (1983) for other New Zealand cultivars.

7.3 Effect of plant growth regulators (paclobutrazol and cycocel)

Protracted flowering is created by the continuous growth of main stem shoots and their respective lateral branches, with a sequential development of flowers and seeds. So, production from new nodes is a continuous process which sustains the lengthy flowering period. The manipulation of branches and shoot status seems to be a realistic approach in attempting to improve seed production in lucerne. For this reason, besides the effect of crop density (Chapter 3), the use of plant growth regulators as another option for improving lucerne seed yield was explored (see section 2.4, and chapter 4).

Plant growth regulators have been used to increase seed yield and seed yield components in many pasture plants (Hampton, 1988). Some workers such as Marshall and Hides (1986, 87, 89, 91a,b), Hampton (1991), Tabora

and Hampton (1992), Tabora and Hill (1992), and Skalska (1991) used plant growth regulators to increase seed yield in white clover, lotus spp. and *Medicago media*, but results have often been inconsistent, varying with plant species, type of plant growth regulator used, rate and time of application, cultivar, site and season (see chapter 4).

In this study, paclobutrazol temporarily decreased plant height by decreasing main stem and lateral shoot length. The decrease in the main stem length was due to shortened internode lengths. However dry matter yield did not alter (Chapters 4 and 5). The results also showed the importance of application time for this chemical. The earlier the application the greater the retardation effect, similar to results recorded in china aster (Phetpradap, 1992), dahlia (Phetpradap, 1992), and in other herbage species (Hampton, 1983; Li and Hill, 1989; Tabora and Hampton, 1992). However the retardation effect of paclobutrazol in lucerne was transitory, since paclobutrazol treated plants in this study (chapter 5) were retarded only at an early stage of growth and these effects had mostly disappeared by final harvest (Chapters 4 and 5). It may be possible that the rate used in the present studies was not enough to compete with the higher level of endogenous gibberellin induced by active plant growth at a later stage. However whether lodging is in fact a problem for seed production and therefore plant growth needs to be retarded, is still not determined.

Results from paclobutrazol application (Chapters 4, 5) at different stages of plant development suggested that early application (during active vegetative growth) was more suitable for enhancing seed yield than any later applications. This increase in seed yield was associated with the promotion of branching and hence an increase in the number of racemes per unit area (Chapter 4), harvestable racemes, and pods per raceme (Chapters 4, 5). This

supports the findings of Li and Hill (1989), and Hampton et al., (1989) who reported that paclobutrazol treatment increased seed yield of *Lotus corniculatus* through enhancement of branching and through an increase in the number of pod per m² respectively, and Hampton (1991) and Budhianto and Hampton (1992) who reported that paclobutrazol increased white clover seed yield mainly by increasing harvestable inflorescences.

Late application, even though it did promote a larger number of small lateral branches was not beneficial in increasing the current year's seed production, since the late season weather conditions did not allow these to become fertile.

Paclobutrazol was the plant growth regulator which showed the most potential value for lucerne seed production. It increased both potential seed and actual seed yield (Chapters 4, 5). Thus paclobutrazol at a rate of 1.0 kg a.i./ha could be recommended for use in lucerne seed production. However, this should be put into an economic context. Paclobutrazol is expensive, at around NZ \$1000-1200/ha. The retail price of lucerne seed is around NZ \$12 per kg. This suggests that an increase of 100 kg/ha in seed yield would be needed to recover the cost of paclobutrazol application. Since paclobutrazol application at 1.0 kg/ha in both years increased lucerne seed yield by around 200 kg/ha (Chapters 4 and 5) when compared with the control plot, the use of this chemical for commercial seed production may well be economically viable. However before any definite recommendations could be made, the PGR should be trailed at other sites and with other cultivars.

Results from the present study showed that cycocel did not retard growth in lucerne (Chapter 4), in contrast with the finding by Skalska (1991), but confirming those reported by Budhianto (1992) in white clover. This

inconsistency in cycocel's growth retarding effects in different crops suggests that it is not only species specific but may also be cultivar specific (Kust, 1986). However, because of cycocel's cost-effectiveness and its non residual effect on succeeding crops, its use was worth considering.

In the present work, cycocel reduced seed yield at two of the three application times. This decrease in seed yield resulted from fewer lateral branches and racemes per unit area. Some possible reasons for this reduction are discussed in chapter 4, but the reason why response was recorded still need further investigation.

Neither seed viability nor seed germination percentage were affected by the growth regulators used in these studies, a result which agrees with findings by Tabora and Hampton (1992) and Tabora and Hill (1992) in *Lotus uliginosus* and Budhianto and Hampton (1992) in white clover.

Some questions remain unanswered and probably need further research. This study (Chapter 5) showed a great difference between the number of ovules per carpel at peak flowering and the number of seeds per pod at final harvest, only approximately 33% of the seeds surviving to maturity. What are the factors that affect low seed number per pod? Is ovule sterility, gamete incompatibility, pollinator activity, fertilization deficiency, or a combination of some or all of these factors responsible? These are some of the questions, raised from the results of the present study, which could form the basis for further research.

7.4. Weeds and herbicides

Weed control in forage lucerne in New Zealand is well documented (Butler, 1982, Palmer, 1982, O'Connor, 1990), but there is little research on weed control in crops grown for seed (Dunbier et al., 1983). Weeds reduce yield and profits of all crops and also the quality of the seed lot for subsequent sowing (Hampton, 1988). Since weed, and particularly white clover, density at the site used in this study was very high, effective herbicide treatments were necessary for successful seed production. Competition from weeds resulted in an 82% and 90% reduction in total lucerne dry matter production and racemes/m² respectively compared with hand weeded plots (Chapter 6). The net effect of this was a 97% reduction in seed yield due to the presence of weeds, a result very similar to the 95% reduction reported by Dawson and Rincker (1982).

Hexazinone successfully removed white clover from the second year lucerne stand and as a result, seed yield was significantly increased (Askarian, Hampton and Harrington, 1993). Similarly, Waddington (1985) reported that hexazinone could be successfully used for selective weed control in established lucerne seed crops.

Simazine plus paraquat did not significantly increase seed yield, primarily because of the failure of this treatment to control white clover (Askarian et al., 1993). This result agrees with Waddington (1980) who found that simazine plus diuron did not affect lucerne seed production significantly, although both simazine and diuron reduced the weed population. Simazine plus paraquat is commonly used for weed control in lucerne forage crop (Atkinson and Meeklah, 1980),

If white clover is likely to be a problem for lucerne seed production,

the advice of Dunbier et al., (1983) should be followed i.e. sow in rows wide enough to facilitate inter-row cultivation. Any white clover plants not controlled by cultivation could then be removed by hexazinone application in spring of the second year.

In this work seed viability did not differ among treatments, yet both complete and partial removal of weeds significantly reduced hard seed levels (Askarian et al., 1993). The reason is not clear, suggesting that this aspect needs further investigation.

Since the application of 1.0 kg a.i./ha of hexazinone caused slightly yellowing of the leaves, further research might examine whether the use of a lower rate of hexazinone will result in reduced damage while still maintaining weed control until after the seed harvest. The question of whether the chemical could be used for weed removal from lucerne seed crops in the establishment year, also requires investigation.

7.5 Conclusions and recommendations

1. In this environment, to produce seed successfully lucerne plants should be grown at 30-45 cm (particularly 45 cm) row spacings to obtain vigorous plants. Such plants tend to develop more reproductive shoots, flowers, and pods and also appear to be amenable to higher levels of pollination, although this requires confirmation. Closer spacing resulted in a large number of smaller plants with a lower seed yield potential because fewer flowers were produced.
2. There is apparently nothing to^{be} gained in the production of lucerne seed by using high sowing rates (3-12 kg/ha). Maximum seed yield in the

lucerne cultivar Grasslands Oranga, was obtained from a sowing rate of 1 kg/ha, which provided that seed is of high quality should produce a population of around 35 plants/m².

3. Paclobutrazol had a potent but temporary effect as a shoot retardant, and promoted branching when applied at 1.0 kg a.i/ha during active vegetative growth.
4. Because of the effect on branch number, paclobutrazol at 1.0 kg a.i/ha significantly increased seed yield by increasing the numbers of harvestable racemes/m² and pods per raceme.
5. In this study the lucerne plant only responded positively to the application of paclobutrazol at 1.0 kg a.i/ha during active vegetative growth, demonstrating that both plant growth stage at application and rate of chemical applied are important for increasing seed yield.
6. Cycocel did not show a positive effect and/or significantly reduced lucerne seed yield in the present study, despite the fact that other studies, e.g. Skalska (1991) had shown that cycocel applied to *Medicago media* increased seed yield. Why this response was recorded is not known.
7. Row spacing, sowing rate, and plant growth regulators did not affect seed quality, but the presence (or conversely, absence) of weeds affected hard seed percentage.

8. Hand weeding and hexazinone treatment increased lucerne dry matter and seed yield through the control of weeds (particularly white clover). Hexazinone is an effective herbicide for control of white clover in lucerne but is not recommended for use in stands less than twelve months old. It would also be useful however, for further trial work to establish whether damage caused by this chemical applied to a first year lucerne crop would outweigh the loss in seed yield caused by white clover competition.

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Appendix 3.1 Soil description

Soil name	"Manawatu fine sandy loam"
Parent material or rock	Medium textured alluvium
Slope: topographic position	Flat: river levees and flats
Description of representative soil profile	A1 0-23 cm dark greyish brown fine sandy loam to silt loam; friable; strong nut structure, (B) 23-53 cm olive brown fine sandy loam; friable; weak nut structure, C 53-277 cm olive medium to fine sand becoming coarser with depth; loose structure, D1 277-318 cm olive grey coarse sand with stones and gravels, D2 <u>on</u> gravels and stones. Manawatu mottled fine sandy loam (3d) has greyer sub-soil with grey and reddish mottles.

*. Cowie and Kimpton, 1976

Soil map of Palmerston North city and environs, New Zealand

Appendix 3.2: Soil analysis

ANALYSIS								
Sample (cm)	pH	Olsen P	SO4	Exch K	Exch Ca	Exch Mg	Exch Na	CEC
0-10	5.2	26	11	0.30	6.19	1.18	0.07	16
10-20	5.2	26	10	0.24	4.93	1.11	0.07	14
20-30	5.4	15	8	0.17	4.80	0.87	0.07	14

Comment: Phosphate and sulphate values are expressed as micrograms per gram (air-dry). Exchangeable cations and CEC (cation exchange capacity) are expressed as meq/100g (air-dry).

Appendix 3.3 Mean, maximum, and minimum air and soil temperature during the first two weeks after sowing

	Air temperature °C (25 cm)			Soil temperature °C (5 cm)		
	Mean	Max.	Min.	Mean	Max.	Min.
15/3/91	16.5	24.5	12.1	17.0	20.6	14.1
16/3/91	17.3	22.9	11.5	17.0	22.9	12.4
17/3/91	18.9	29.3	9.7	18.7	23.4	14.6
18/3/91	18.3	26.7	7.4	18.7	23.4	14.6
19/3/91	17.4	26.5	12.7	18.4	22.7	15.0
20/3/91	17.8	29.9	7.3	18.4	23.1	13.1
21/3/91	17.5	29.7	9.5	19.5	23.4	15.0
22/3/91	18.3	29.1	11.6	19.4	23.3	15.8
23/3/91	19.1	26.9	15.0	19.5	23.2	17.3
24/3/91	17.1	27.0	11.1	18.8	23.3	15.4
25/3/91	17.3	25.7	13.1	18.2	21.8	15.4
26/3/91	18.5	26.4	14.4	18.7	22.8	16.2
27/3/91	18.4	29.2	12.5	19.1	23.6	16.5
28/3/91	17.1	23.8	14.3	18.5	23.1	17.2

Appendix 3.4 Effect of row spacing on lucerne seed germination and viability in 1991/1992

Row spacing (cm)	GERMINATION				
	Normal	Abnormal	Hard	Dead	Viable
	seedlings (%)	seedlings (%)	seed (%)	seed (%)	seed (%)
15	28.2a	2.6a	68.0a	1.2a	98.8a
30	29.9a	3.1a	66.2a	0.8a	99.2a
45	28.6a	2.7a	67.4a	1.3a	98.7a
60	32.9a	2.2a	63.5a	1.4a	98.6a
Significance	NS	NS	NS	NS	NS
LSD $P<0.05$	4.91	1.42	5.19	0.91	0.73
CV %	21.5	73.0	10.9	92.0	15.0

Means within columns with the same letters are not significantly different at $P<0.05$.

NS - not significant.

Appendix 3.5 Effect of sowing rate on lucerne seed germination and viability in 1991/1992

Sowing rate kg/ha	GERMINATION				
	Normal	Abnormal	Hard	Dead	Viable
	seedlings	seedlings	seed	seed	seed
	(%)	(%)	(%)	(%)	(%)
1.0	31.0a	2.1a	66.1a	0.8a	99.2a
3.0	28.0a	2.7a	68.2a	1.1a	98.9a
6.0	29.6a	3.0a	65.8a	1.6a	98.4a
12.0	31.0a	2.9a	65.1a	1.0a	99.0a
Significance	NS	NS	NS	NS	NS
LSD $P<0.05$	4.9	1.42	5.19	0.91	0.83
CV %	21.5	73.0	10.9	92.0	15.0

Means within columns with the same letters are not significantly different at $P<0.05$.

NS - not significant.

Appendix 3.6 Effect of row spacing on lucerne seed germination and viability in 1992/1993

Row spacing (cm)	Germination				
	Abnormal seedlings	Normal seedlings	Hard seed %	Dead seeds %	Viable seed %
	%	%			
15	28.2a	2.6a	68.0a	0.9a	99.1a
30	29.9a	3.1	66.2a	0.9a	99.1a
45	28.6a	2.7	67.4a	1.2a	98.8a
60	32.9a	2.2	62.5a	1.1a	98.9a
Significance	NS	NS	NS	NS	NS
LSD <0.05	4.81	1.42	5.91	0.91	1.2
CV %	21.5	73.0	10.9	112.0	4.2

Means within columns with the same letters are not significantly different at $P < 0.05$. NS - not significant.

Appendix 3.7 Effect of sowing rate on lucerne seed germination and viability in 1992/1993

Sowing rate kg/ha	Germination				
	Normal	Abnormal	Hard	Dead seed	Viable
	seedling %	seedlings %	seed %	%	seed %
1.0	31.0a	2.1a	66.1a	0.9a	99.1a
3.0	28.0a	2.7a	68.2a	1.0a	99.0a
6.0	29.6a	3.0a	65.6a	1.4a	98.6a
12.0	31.0a	2.9a	64.1	0.9a	99.1a
Significance	NS	NS	NS	NS	NS
LSD<0.05	4.6	1.42	5.19	0.91	1.2
CV %	21.5	73.0	10.9	112.0	4.2

Means within columns with the same letters are no significantly different at $P<0.05$.

NS - not significant

Appendix 3.8 Effect of row spacing and sowing rate on seed yield (kg/ha) in 1991/1992.

Row spacing (cm)	Sowing rate kg/ha				Mean ¹
	1	3	6	12	
15	139.3	98.5	87.8	83.6	102.3
30	145.9	156.6	158.6	109.6	142.7
45	144.8	155.6	145.2	130.6	144.0
60	128.0	138.6	108.3	104.7	120.0
Mean ¹	139.5	137.3	124.9	107.1	

Appendix 3.9 Effect of row spacing and sowing rate on seed yield (kg/ha) in 1992/1993.

Row spacing (cm)	Sowing rate kg/ha				Mean ¹
	1	3	6	12	
15	209.5	180.3	142.8	151.5	171.0
30	233.6	184.8	178.3	161.4	189.5
45	295.7	190.5	191.4	159.9	209.4
60	154.9	173.1	201.7	181.9	177.9
Mean ¹	223.4	182.2	178.5	163.7	

¹for least significant differences of treatment means see Tables 10, 11 and Tables 20, 21.

There were no significant interactions between sowing rate and row spacing in either year.

Appendix 4.1 Soil description

Soil name	Parent: material or rock	Slope: Topographic position	Description of representative soil profile
Ohakea silt loam	Colluvium	Flat: Old fans overlying low terraces	<p>A1 0-23 cm dark brown silt; few reddish brown mottles; friable; moderate nut structure,</p> <p>B1gc 23-41 cm greyish brown heavy silt loam; few to many yellowish brown mottles; abundant black concretions; friable; moderate nut structure,</p> <p>B2g 41-71 cm light grey clay loam; abundant yellowish brown mottles; firm; weak blocky structure;</p> <p>B3g 71-99 cm mottled light grey and yellowish brown heavy silt loam; few light grey vertical veins; very firm; massive,</p> <p>D <u>on</u> iron-stained gravels and stones.</p>

Appendix 4.2 Sixty year average for temperature (minimum and maximum), sunshine hours and rainfall at Palmerston North, and deviations from these average during 1991/1992*

	August		Sept		Oct.		Nov.		Dec.		Jan.		Feb		March	
Temperature(°C)																
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Ave.60yrs	5.0	13.1	6.6	14.7	8.3	16.6	9.8	18.5	11.6	20.6	12.8	21.9	12.8	22.3	11.7	20.9
1991/1992	1.7	1.2	0.7	1.1	-0.2	-0.6	-1.5	-2.3	-0.3	-1.30	0.1	0.0	-0.4	-1.4	-2.2	-2.3
Number of sunshine hours																
Ave.60yrs	132.0		133.0		158.0		177.0		193.0		209.0		186.0		170.0	
1991/1992	-34.4		-7.0		0.9		-42.2		-74.4		-36.6		-18.8		-33.7	
Rainfall (mm)																
Ave.60yrs	89.0		75.0		88.0		78.0		94.0		79.0		67.0		69.0	
1991/1992	9.7		-9.9		-7.1		3.0		-12.8		-1.8		88.2		19.9	

Note: *Data (obtained from AgResearch Grasslands) were recorded at a station 1 km from the trial area.

**Appendix 4.3 Mean minimum and maximum air temperature during
December 1991 and January 1992.**

Day	Mean air temperature (°C)	
	Min.	Max.
<u>Dec.</u>		
1-7	9.7	17.1
8-14	9.5	18.6
15-21	9.1	18.6
22-28	15.4	22.2
29-30	15.5	21.4
<u>Jan.</u>		
1-7	9.1	19.7
8-14	15.9	23.3
15-21	12.5	21.6
22-28	13.7	22.9
29-30	14.2	22.9

Note: Data (obtained from AgResearch Grasslands) were recorded at a station 1 km from the trial site.

Appendix 5.1 Weekly rainfall and temperature during January and February 1993

day	Total weekly rainfall (mm)	Mean daily air temperature (°C)	
		Min.	Max.
<u>Jan.</u>			
1-7	16.7	11.1	18.9
8-14	19.0	13.2	20.4
15-21	10.1	11.4	20.5
22-28	6.6	11.7	20.1
29-31	1.5	8.9	19.2
<u>Feb.</u>			
1-7	16.7	7.7	19.3
8-14	0.0	11.5	21.0
15-21	25.9	12.3	20.4
22-28	1.1	15.6	22.6

Note: Data (obtained from AgResearch Grasslands) were recorded at a station 2 km from the trial site.