SOME FACTORS AFFECTING THE ESTABLISHMENT AND EARLY GROWTH OF LUCERNE (*Medicago sativa* L.) ON MANAWATU SAND COUNTRY

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ABSTRACT.

The thesis reports two experiments carried out during 1973-74.

The field experiment studied the establishment and growth up to one year of two varieties of lucerne (Wairau and College Glutinosa) at three spacings (2.02cm., 9.16cm. and 15.22cm. in 15cm. rows) on two soil types (Puke Puke black sand - plain, and Motuiti sand-dune) and an intergrade near Taikorea in the Manawatu sand country.

From sowing in April, 1973 to December, 1973 soil moisture tension at 10cm. and 30cm. depth was higher in the Motuiti sand than in the Puke Puke black sand with the intergrade being intermediate. From December, 1973 to April, 1974 high soil moisture tension at 90cm. remained low for all three soil types for the duration of the experiment. The water table rose from May, 1973 to September, 1973 and fell from September, 1973 to April, 1974. Both soil moisture tension and water table were controlled by rainfall.

Wairau had a significantly higher percentage establishment than College Glutinosa in the first 110 days after sowing but these differences were not apparent one year after sowing. Plants spaced at 15.22cm. had a significantly higher percentage establishment than plants spaced at 2.02cm. or 9.16cm., 110 days after sowing. This difference appeared to be associated with damping-off by pathogenic fungous species. Plants spaced at 15.22cm. and 9.16cm. had significantly higher nodule dry weights and nodule dry weights per unit plant dry weight than plants spaced at 2.02cm. College Glutinosa plants had significantly higher root weights than Wairau plants. On Motuiti sand, plants had significantly higher nodule dry weights and nodule dry weights per unit plant dry weight than plants on the other two soil types. Lucerne dry matter production was significantly higher at 2.02cm. than at 9.16 or 15.22cm. spacing.

During January, 1974, dessication of many plants occured and these plants exhibited root damage apparently caused by white fringed weevil (Graphognathous leucoloma Boh.) larvae. Subsequent investigations showed that the number of dessicated plants per unit area was greater in Motuiti sand than in the intergrade than in Puke Puke black sand. A similar trend was observed in the number of white fringed weevil larvae per unit area.

A glasshouse experiment was set up to investigate the mortality of lucerne seedlings (Variety: Wairau) from 8 to 14 weeks after sowing in Motuiti sand under two moisture regimes (10% and 20% of dry soil weight) with three populations of white fringed weevil larvae (22, 44 and 88 larvae/m^2). It was shown that there was a significantly greater plant mortality at 10% M.C. than at 20% M.C. Furthermore at 10% M.C., surviving plants in plots with a popula-

tion of 22 larvae/m^2 had significantly higher root dry weights than plants in plots with population of 44 and 88 larvae/m^2. It was concluded that at high soil moisture tensions, damage by white fringed weevil larvae was more critical to the survival of the lucerne plants.

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INTRODUCTION.

This study was undertaken to examine some of the factors affecting the establishment of lucerne in the Manawatu sand country. Lucerne has proved a valuable summer crop in the sand country, yielding four times the dry matter production of pasture from November to mid-January at Flock House. However, difficulities have been experienced in establishing lucerne stands in this area.

The major limiting factors to the establishment and growth of lucerne in the sand country are generally considered to be the lack of soil structure resulting in wind blow, the low moisture holding capacity of the soil, and the high surface temperatures which can be experienced due to the thermal properties of the sand. Brown (1973) has recently studied the temperature factor and found that lucerne stands sown in the summer months are liable to high seedling mortality because of high soil temperatures.

The factors under investigation in the present study were the effects of different varieties and plant spacings on the establishment and early growth of lucerne on two soil types and an intergrade. From previous work (Cowie et al, 1967) it was expected that the soil types chosen would demonstrate differences in soil moisture status. The field experiment was designed to study how the three varieties with contrasting root systems would respond to these differences in soil moisture status at different plant spacings.

During the course of the field experiment, it became apparent that plant mortality attributable, at least in part, to the activity of white fringed weevil larvae was a major factor affecting the establishment of lucerne in this area. A further experiment under controlled conditions in a glasshouse was therefore designed to study the effect of white fringed weevil larvae and soil moisture status on the establishment of lucerne.

Chapter I: Literature Review.

(A) INTRODUCTION.

This literature review gives a general account of the factors affecting lucerne establishment but emphasis is placed on those factors which are considered in this study. The first two sections give a general description of lucerne as a crop plant and the Manawatu sand country. In the remaining six sections, most references are specific to lucerne establishment and growth in the first year after sowing. Unless otherwise stated the literature quoted refers to lucerne.

(B) GENERAL DESCRIPTION OF LUCERNE.

1. Types and Varieties of Lucerne.

According to Iversen and Meijer (1967), there are two main species of lucerne; Medicago sativa L., native of a temperate climates, and the Siberian Medicago falcata L.

M. sativa L. is considered to be native to the area south of the Black Sea and Caspian Sea, a district with a pronounced arid continental climate with cold winters and hot, dry summers. Low humidity, intense sunshine, high day temperatures, cool nights, absence of competitive plants, and soils high in pH, rich in bases and with moisture at deep levels are other characteristics of the area. Under these conditions there has developed an erect, highly productive plant, of great speed of recovery after cutting, with a deep, almost unbranched tap root and a variable degree of winter hardiness based on dormancy. Diseases are rare so that very little resistance has been developed. The flowers are purple, the pod forms two to three spirals, the leaves are long and few, while stems are coarse and mainly unbranched.

The native home of M. 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 is found a prostrate plant of low productivity, late in spring, slow in recovery, with a much-branched root and a deep crown, giving it excellent resistance to cold; disease resistant forms have been evolved. The flowers are yellow, pods do not form a complete spiral, leaves are small and dark in colour and stems are fine and branched.

Hybridisation between M. 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. However intermediate forms which have been given specific rank as the species M. media Per. do occur. Cultivated varieties of this species have a mixture of variegated, purple, green, white and yellow flowers; considerable resistance to disease and frost is found; stems are fine numerous and branched, and leaves small and numerous. In the western world M. sativa L. and M. media Per. are the only species to be cultivated, but in Siberia and China strains of M. falcata L. are in use.

Iversen and Meijer (1967) recognize that lucerne has tremendous plasticity due to the more or less hybrid nature of all cultivated forms, to the fact that it is cross-pollinated and to the heavy mortality in all sowings. Various classifications of lucerne strains have been made by different workers. Criteria used include winter hardiness, growth form, disease resistance, time of flowering, type of tillering, spring earliness and the type of parental stock.

2. Lucerne Varieties used in Experiment.

2.1 Origin and Characteristics.

Palmer (1967) claims that Wairau lucerne (originally called strain B and then New Zealand Certified lucerne, and always popularly known as Certified Marlborough) was released in 1950. This was produced from 20 foundation plants of Marlborough and two of Grimm, two of Ontario variegated and two of American commercial. Hadfield and Calder (1936) suggest that Marlborough lucerne originated from the Argentine but give no authority for this. Palmer (1967) suggests that Marlborough lucerne may have arisen by natural selection from Hunter River or Provence lucerne in New Zealand with Grimm or some other hybrid lucerne contributing genes to give some degree of winter dormancy to the local New Zealand population. Zaleski (1954) classifies Marlborough lucerne as a Medicago sativa L. type with a trace of Medicago falcata L. with a semi-erect growth form.

Iversen and Meijer (1967) claim that Grimm lucerne originated from hybridisation of Provence lucerne with wild M. falcata L. in Bavaria and was introduced to North America in 1857 from whence it spread to New Zealand from Canada as Canadian Grimm, Canadian variegated or Ontario variegated. Zaleski (1954) classifies Grimm lucerne as a M. sativa L. hybrid with a small amount of M. falcata L., namely a M. media Per. type (Palmer, 1967) which is semi-prostrate in growth form. Iversen and Meijer claim that Ontario variegated lucerne was introduced to Ontario from Germany in 1875 and according to Bolton (1962) it is semi-erect in growth habit.

Thus Iversen and Meijer (1967) classify Wairau lucerne as a Medicago

media Per. type with mainly Medicago sativa L. characteristics with a semi-erect growth habit. Wairau lucerne is slightly more winter dormant than most lines of uncertified Marlborough (Palmer, unpublished), is high producing, produces good quality hay, and persists well when used for either hay or grazing (Palmer, 1967).

College Glutinosa is a lucerne variety derived from Glutinosa, a natural strain of rhizomatous lucerne which was improved by selection at Lincoln College by Iversen. (Palmer, 1967). Iversen and Meijer (1967) classify the natural strain Glutinosa as a M. falcata L. hybrid with variegated purple and yellow flowers. Palmer (1967) reports that Glutinosa is a variety that reputedly withstands grazing well though comparative trials have not demonstrated any advantage in this repect over Wairau. However Janson and Knight (1972) consider that although Glutinosa did not outyield Wairau under grazing trials, the more prostrate nature of Glutinosa and its tendency to spread under favourable conditions may give it more persistence than Wairau under farm-scale grazing. However in hay trials Glutinosa has generally produced about 20% less than Wairau (Palmer, unpublished) although Janson and Knight (1972) found that both varieties performed equally in an all-hay situation. Palmer (1967) reports that the advantages of College Glutinosa have yet to be demonstrated in comparative trials.

The seed of C.R.D. Suckering lucerne comes from 800 crosses between (((Saladina X Swift Current) X Spanish) X Spanish) and Rambler varieties. In each generation plants have been selected for their suckering ability. All 800 parents produce suckers in varying degrees and it is expected that 20 to 50% of their progeny will have this ability (Palmer, unpublished). Iversen and Meijer (1967) classify Saladina and Spanish lucerne as M. sativa L. types which are both fairly winter active. Palmer (1967) reports that Rambler lucerne, released by Heinrichs in Canada in 1955, is a suckering or creeping rooted lucerne variety which is very winter hardy and drought resistant. Palmer (1967) expects lucerne with this character to be much more resistant to mismanagement than non-suckering lucernes, in that they could regenerate a full stand from remaining plants and they could be very useful for sowing in difficult situations where establishment is likely to be poor, as they could produce a fullstand from a few initial plants. Palmer (1967) states that this variety was bred to incorporate root-suckering ability and high winter and total production in one variety, but although considerable progress has been made, none of the material with a high degree of suckering is as productive as the best non-suckering lines. Palmer (1967) found that plants of this type of variety are equal to standard varieties such as Wairau in winter yield but below the best winter growing selections while their summer

yield is about 10% below standard varieties of Chanticleer, Du Puits and Wairau.

2.2 Root Systems.

Heinrichs (1963) states that most of the cultivated lucerne varieties have a tap root system which is characteristic of varieties originating from M. sativa L. A tap rooted plant has a rather narrow protruding crown, the tap root penetrating vertically into the ground with branch roots arising at intervals from it. Such plants are unable to spread sideways except to a limited degree by crown expansion as the plant ages.

Heinrichs (1963) identifies branch-rooted lucerne varieties and those with a proportion of both branch and tap roots which are of more recent origin. A branch-rooted plant differs from a tap-rooted plant in that a number of primary roots arise from the crown instead of only one, and the crown is inclined to be wider. The primary lucerne root emerges near the hilium of the seed and penetrates the soil as an unbranched tap root initially although lateral roots later originate from it (Grove and Carlson, 1972). Smith (1950) found that adventitious roots developed on root segments of Ladak lucerne and an M. falcata L. strain. However Heinrichs (1963) considers that although the branched root system in lucerne can be considered to result in a slight tendency for the plant to spread horizontally, the spread is restricted to the above-surface crown.

Heinrichs (1963) identifies two types of root system in lucerne which enable the plant to spread horizontally, generally referred to as rhizomatous and creeping rooted.

Graumann (1955) defines rhizomatous lucerne varieties with regard to crown development and spreading ability as wide low crowned types which have the inherent ability to produce underground stems or rhizomes. A rhizome can be defined as a more or less horizontal underground stem, bearing buds in axils of reduced-scale like leaves serving as a means of perennation and vegetative propogation (Abercrombie et al, 1960). Heinrichs (1963) reports that these rhizomes expand laterally for varying distances, eventually root over part of their length and emerge from the soil as vegetative stems. Rooting may occur not only from underground stems, but also from prostrate stems lying on the soil surface. Both Heinrichs (1954) and Hanson et al (1960) make the observation that rhizomatous varieties such as Rhizoma and Nomad will tend to spread only if climatic conditions are moist and the surface soil is moist for prolonged periods, particularly in the autumn. Smith (1955) found a direct relationship between the quantity of rhizomes and the amount of M. falcata L. which figured in the parentage of the varieties.

Graumann (1955) defines creeping-rooted lucernes as those with low

crowns which spread by means of creeping roots. These creeping horizontal roots arise from the primary root (Graumann, 1955) and are anatomically true root structures resembling the primary roots (Murray, 1957) Graumann (1955) reports that these horizontal or creeping roots are usually found 10 to 20cm. below the soil surface and develop buds at irregular intervals which later emerge and develop as normal shoots or stems, each of which is capable of developing eventually into an independent crown and plant. Murray (1957) found that creeping roots have the ability to produce these adventitious stems on a much greater range of roots than branch roots. Heinrich (1954) found that creeping rooted plants resulting from intercrosses between M. falcata L. and plants of the varieties Ladak and Rhizoma expressed the spreading habit to a much greater extent than any M. falcata L. parent which appeared to be due to complementary gene effects rather than to hybrid vigour.

However Graumann (1955, 1958) makes it clear that any one lucerne strain or variety may have in one population a variety of crown and root types.

3. Historical Development.

Bolton et al (1972) claim that the history of lucerne or alfalfa is a story of the worlds most important forage crop. Being the first forage crop to be domesticated, it was obviously recognized by early 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 Turkey and Persia. 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 century.

However it was in the 18th century that lucerne became distributed worldwide when it was taken from Europe to the Americas by the Spanish and Portugese and to Australasia and South Africa by colonists in the 19th century.

4. Lucerne in New Zealand.

Bolton et al (1972) state 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). Marlborough is the principal strain evolved in the South Island and is particularly well adapted to New Zealand. It is thought to have resulted from natural selection of the Provence or Hunter River types

over a long period of time. Some stands in the Maniototo region reputed to be up to 50 years old contain a number of variegated and yellow-flowered plants, so Grimm or some other hybrid lucernes may have contributed genes and some degree of winter dormancy to the local New Zealand population (Palmer, 1963).

In 1950 Wairau lucerne was released and it is still the main variety grown. Other varieties used include Hunter River, Rhizoma, College Glutinosa, a selected strain of Glutinosa and Chanticleer, a selection of Provence which is also available as a certified variety.

Official statistics for the year 1967-68 quoted by Bolton et al (1972) show the area of lucerne in New Zealand to be approximately 121,400ha. of which the estimated utilisation is 50% hay, 40% pasture, 5% silage, 4% seed and 1% devoted to the production of lucerne meal.

According to Duder and Scott (1970), lucerne is mainly grown in New Zealand in areas where it can substantially out-produce pasture either in total or in summer yield. Unless substantial yield increases are obtained, lucerne growing is not warranted because of the extra costs involved in establishment, maintenance and handling, except where the area available for haymaking is limited and/or where higher quality feed is required.

Generally lucerne is most useful on free draining, drought-prone soils in areas with less than 750mm rainfall per annum and with low summer precipitation. Thus in 1967-68, over 50% of the lucerne grown in New Zealand was concentrated in the Canterbury region and over 80% in the South Island (Bolton et al, 1972). Despite this generalisation, Duber and Scott (1970) concede that increasing quantities of lucerne are grown with success on soils such as the clay pans of South Canterbury and North Otago. In suitable areas such as parts of the North Island pumice country, and on light and medium-light soils of Canterbury, North Otago and Marlborough, lucerne under good management produces 50 to 100% more total dry matter than pastures with less, annual variation in yield.

Bolton et al (1972) note that recently, farmers in areas of uncertain rainfall in the North Island have been advised to expand lucerne production.

5. Agronomy of Lucerne.

Jung and Larson (1972) claim that lucerne especially M. falcata L. grows naturally under more diverse conditions than most perennial species. Environmental conditions for lucerne range from those of high latitude with low temperatures, wide annual range of photoperiod and relatively low light intensity, to subtropical environments where temperature fluctuations will depend largely upon altitudinal differences, photoperiod will have small range, and light intensity will be high, while superimposed upon this

variation will be the range of precipitation (Leach, 1967).

Aamodt (1941) found that 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 25cm. or less. Jung and Larson (1972) state that low temperature survival of lucerne is dependent on air and soil cooling rates, minimum temperature reached, warming rate and cold tolerance of the lucerne involved. In turn, the cooling rate of soil is essentially related to soil moisture percentage. Peltier and Tysdal (1932) exposed an unspecified soil type at 12, 17, and 27% moisture content to an air temperature of -19°C. They found that soil temperature decreased to -4°C within 3, 4 and 11 hours respectively at the three lower moisture levels but only to -2°C after 16 hours for soil at 33% moisture content.

Heat tolerance of lucerne has been difficult to assess because high temperatures are generally associated with low moisture (Jung and Larson, 1972). However, Wilsie (1962) found that high temperatures may be just as limiting as low temperatures in lucerne production while it is well recognized that plant growth ceases at high temperatures that are not immediately lethal. (Levitt, 1969).

Several workers (Kiesselbach et al, 1929; Fredrickson, 1938) ascribe the drought tolerance of lucerne to its deep penetrating root system which can obtain moisture from relatively great depths in the soil. Leach (1967) suggests that the morphology and physiology of the crown may also have an important function to perform. New buds are protected from very high temperatures at the soil surface by being developed below soil level and often below the mass of older stubbles, and most of the buds will remain dormant until adequate moisture available for growth. After summer rains a flush of new shoots is produced and after a long dry summer period the plants will usually then have their highest shoot numbers.

Lucerne has a unique pattern of growth which has been recognized for many years, but surprisingly, little is known about the control or about the extent of variation between cultivars (Leach, 1967). The normal pattern of lucerne growth has been described by several workers (Leach, 1967; Langer, 1968; Mitchell and Denne, 1967). In contrast to the grasses, in which only the leaf blades are removed at cutting or grazing and the growing points or tiller meristems are left intact during most of the year, in lucerne the apical meristems are removed when the plant is cut, so that recovery growth depends on the availability of sites from which new shoots can arise. These sites are buds situated either in the axils of stubble leaves or on the so-called crown of the plant. Langer (1968) states that the crown is a very complex and ill-defined part of the plant which is initially made up of the first few branches

of the seedling, those arising in the axil of the two cotyledons, the simple leaf, and the first few trifoliate leaves and it is on nodes on those branches that buds may appear.

The normal pattern of growth appears to be that in the spring a number of buds grow up to form shoots. When these shoots have reached a certain stage which normally appears to coincide with the appearance of young flowers a new crop of buds appears on the crown and is ready to take over when the older shoots have been cut. This process is repeated until these new shoots reach the flowering stage. The number of generations of buds that will appear depend on the variety and the environment. Smith (1962) found that Vernal lucerne in Wisconsin produced three generations per season when left uncut.

(C) DESCRIPTION OF THE MANAWATU/RANGITIKEI SAND COUNTRY.

1. Topography.

The Manawatu/Rangitikei sand country covers an area of 110,000ha. on the West Coast of the lower North Island (Cowie et al, 1967). According to Cowie et al (1967) the sand country slopes gently inland from sea level. This low overall relief of the sand country is obscured by the alternation of dunes and sand plains which affects the drainage and plays an important part in the formation of the different soils. Basically each dune consists of two parallel east to south-east-trending wings up to 3.2km in length united at their eastern end to form an apex, which is generally the highest part of the dune. The land enclosed by the dune is a flattish sand plain, which slopes up eastwards towards the apex. Near the apex the water table is some distance from the surface, but westward as the surface of the sand plain becomes lower, the water table is closer to the surface. At the extreme west of the sand plain and at the foot of the next dune the water table is usually at or near the surface depending on the season. Where the flow of water away from the sand plain is restricted by encircling dunes, peaty swamps, ponds, or lakes are formed.

Although examples of this basic unit of dune, sand plain and peaty swamp can be found, in many places the pattern is usually more complex.

2. Climate.

The Manawatu/Rangitikei sand country lies within the western Wellington climatic district, which is characterised by warm summers and mild winters, a reliable rainfall evenly distributed throughout the year, and prevalent

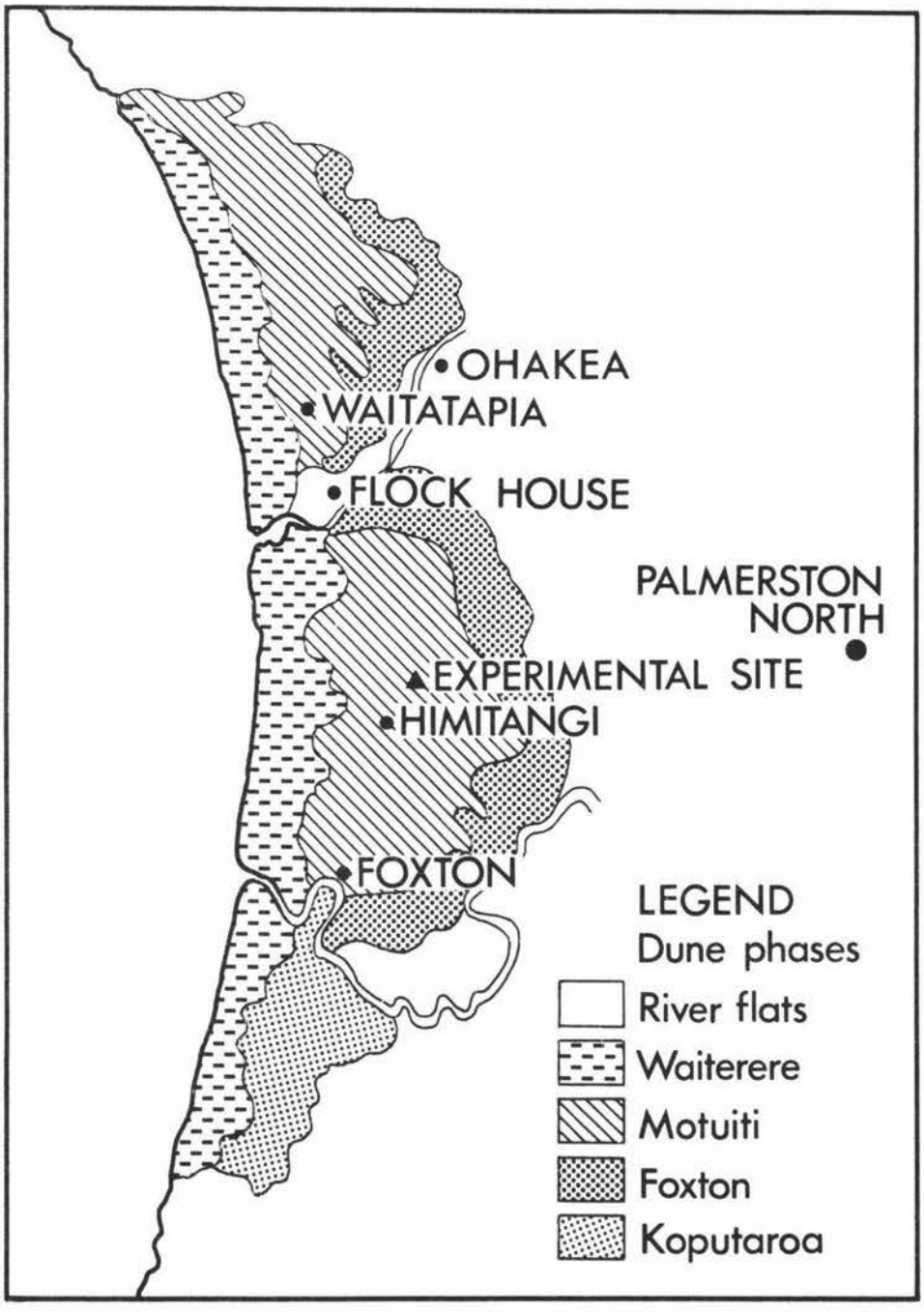


FIGURE I.1 PHYSIOGRAPHIC MAP OF THE MANAWATU/RANGITIKEI SAND COUNTRY SHOWING DUNE PHASES (COWIE *ET AL.*, 1967)

west to north-west winds with relatively frequent gales (Robertson, 1959). Conditions are however, drier than in the more inland parts in this district (Garnier, 1950). Cowie et al (1967) give an account of the climate of the Manawatu/Rangitikei sand country.

2.1 Rainfall.

Most of the rain in this district is brought by westerly winds, and the rainfall pattern is largely controlled by the position of higher country to the east which causes precipitation of the moisture carried by these winds. Thus rainfall is lowest in the Himitangi-Foxton area where westerlies have little obstruction to their passage. Annual rainfall in the area in any one year ranges from 800 to 1100mm. Seasonal variations in rainfall are remarkably consistent throughout the area with a well defined increase in rainfall from March, the driest month to June, the wettest month followed by a decrease to September and marked increase during October and a decrease over the summer months. Monthly rainfall figures taken at Foxton from 1912 to 1954 show a mean annual rainfall of 826mm, and extreme annual rainfall of 1100mm, an average number of raindays of 119 and a largest number of annual rain days on record of 162.

Rainfall data taken at other sites throughout the area do not differ markedly from the Foxton data.

2.2 Temperature.

Temperature data recorded at Flock House Research Area near Bulls over a six year period (1948-54) show that there is no great extreme in temperature range. Air temperatures are highest in February when the mean monthly temperature is 17.3°C and lowest in July when the mean monthly temperature is 8.0°C. This is the time of the greatest number of ground frosts, which increase in frequency from late autumn and decline in early spring. Mean 10cm. soil temperatures measured at 9am. are at a maximum of 18.8°C in January and a minimum of 6.1°C in July. However these soil temperature measurements are taken from an alluvial sandy loam and a wider range of temperatures would be expected in freely drained sand soils.

2.3 Wind.

The dominant winds are from the west and north-west and these have controlled the oreintation of the dunes. During spring and early summer strong north-west and westerly winds frequently reaching gale force are common. These winds decrease in frequency and strength during late summer and autumn when easterlies become more frequent. From late autumn to spring light winds prevail and calm spells are common.

3. Soils.

Most of this section is based on a survey carried out by Cowie et al (1967). The parent material of most of the soils of the Manawatu/Rangitikei Sand Country is wind-blown sand, derived chiefly from greywacke of the central ranges, tertiary sandstones and mudstones flanking these ranges, and volcanic material from the Taupo and Taranaki districts. As a result of sorting during transport down rivers, along beaches and inland by wind these sands are of a fairly uniform size grade with negligible amounts of silt and clay. Thus as the sand accumulates on the beaches, and is built into dunes by the wind, the shore line advances seaward so that the youngest dunes and their accompanying sand plains are nearest the coast. Dune building has not been continuous, however and four distinct phases can be recognized.

The dunes of the Waitarere Phase form a coastal belt from 0.4 to 3.22km wide and also occur as small patches where previously stabilised sand plains and dunes of the Motuiti Phase have been wind eroded and their sand transported inland. These dunes are believed to be less than 120 years old.

The advance of the Waitarere dunes is attributed partly to overgrazing and burning of the original vegetation on previously stabilised dunes, and partly to accelerated erosion inland due to clearing and burning causing increased accumulation of sand along the beaches.

The dunes and sand plains of the Motuiti Phase form a belt up to 9.65km wide inland of the Waitarere dunes. According to radiocarbon dating of a totara stump, the advance of the Motuiti dunes took place about 750 years ago and from the degree of soil-profile development it is thought that the Motuiti dunes became stabilised about 500 years ago.

The dunes of the Foxton Phase form a 3.22 to 6.44km wide belt inland of the Motuiti Phase and are believed to have formed 2000 to 4000 years ago. The dunes of the Koputaroa Phase, the oldest phase recognised are only preserved in the northern and southern parts of the Manawatu district and are inland of the Foxton dunes.

On these four dune phases, different soil associations have been formed. Cowie et al (1967) state that the landscape of the sand country is made up of the repetition of a basic unit of dune ridge, sand plain and peaty swamp. Over this unit, differences in drainage determined by relief have produced a sequence of soils in which each soil is confined to one segment of the landscape. Hence in the sand country, the soils form a repeated and predictable pattern related to drainage and relief. These different patterns of soils are mapped as soil associations (Taylor and Pohlen, 1962).

Individual soil types and phases within an association are called

members, principal members being those that individually occupy roughly from 10 to 70% of the area of the association, minor members are those that individually occupy less than 10% of the area. Each association is named after its two most extensive members, the name of the dominant member appearing first. Separation of associations is based on the degree of weathering or age of the principal members; the kind of melanisation (i.e. whether due to forest or scrub) of the dominant member and the proportion of the various drainage classes within the dune unit.

Because the sand country soils are coarse textured and are in a district with a fairly low summer rainfall, their suitability for pastures or crops is largely dependent on the amount of soil moisture available during the growing season and also on their erodibility. Consequently, differences in soil characteristics such as drainage, content of organic matter, texture, structure and consistence-features that determine the moisture status and erodibility of the soil - are used as the main criteria in identifying soil types and phases.

The Waitarere Dune Phase is represented by Waitarere sand formed on the unconsolidated dunes. Here soil forming processes such as weathering, leaching and melanisation have had little time to affect the sand, and profile development is limited to a darkening of the top 2cm. or so by decomposing plant remains. Below this the sand retains the grey colour and loose consistence of beach sands. Soils on the sand plains corresponding to Waitarere sand are mapped in the Hokio series. Hokio sand is an imperfectly drained soil formed on the low-lying sand plains. Profiles show up to 7.5cm. of very dark brown sand changing abruptly to a dark grey slightly compact sand with few reddish mottles. These two soils form the Hokio-Waitarere Association, successful farming of which depends on permanent stabilisation of the dunes and a sufficient area of imperfectly and poorly drained members on which high-producing pastures can be maintained.

Foxton dark grey sand or Motuiti sand as it is now termed (J. Pollock, pers. comm.) is formed on the dunes of the Motuiti Dune Phase. The topsoil consists of 7.5 to 15cm. of very dark grey to black sand, and this overlies 5 to 12.5cm. of brown, loose sand which grades down into grey, loose sand. Associated with this dune soil are soils of the Himitangi series formed on the higher sand plains and the Puke Puke series formed on the low lying swampy sand plains. Himitangi sand occurs on the sand plain where the water table rises to the lower part of the subsoil in winter. Thus profiles show 15 to 25cm. of a black sand overlying 15cm. of yellowish grey loose sand with few yellowish-brown mottles grading down to a grey firm sand with many yellowish-brown mottles grading down to a grey firm sand with many yellowish-brown mottles. Puke Puke black sand is an imperfectly drained soil where the water

table rises to the surface for short periods in winter. The topsoil consists of 15 to 25cm. of a black sand overlying a dark grey compact sand with abundant reddish mottles which decrease in number with depth. Cowie and Smith (1958) state that mottles and concretions are found in the horizon in which the water table fluctuates and can owe their formation to the alternate reduction and oxidation of iron as the water-table rises or falls, and prevents or allows the access of oxygen.

These three soil types are part of the two major soil associations of the Motuiti Dune Phase. Pastures on the soils of the Himitangi-Foxton association dry off in summer while attempts to establish good pastures on Motuiti sand have been hampered by excessive drainage, difficulty of cultivation, rapid growth of weed grasses, scrub and bracken fern and breaching of the shallow topsoil by grazing stock. Soils of the Puke Puke-Foxton soil association are more suitable for farming because pastures on the imperfectly and poorly drained sand plain soils provide feed throughout the summer. Drainage of surface water is sometimes necessary to farm these wetter soils.

Foxton black sand, the oldest dune soil occurs on the dunes of the Foxton Dune Phase Profiles show a top soil of 25 to 30cm. of black sand overlying a very slightly firm, yellowish brown sand which grades down into a loose grey sand. On the sand plains of the Foxton Dune Phase, Awahou series are mapped on the drier sand plains, the Carnarvon series on the wetter, low-lying sand plains, and Puke Puke brown sands which were formed under forests on the higher parts of the and plains. Soils of the Awahou-Foxton association do not dry off as severely as those on the Himatangi-Foxton association, for the soils contain more organic matter and clay to hold moisture. Soils of the Carnarvon black-Foxton association are ideal for dairying but poor drainage on the Carnarvon black soils is often a limiting factor.

(D) REQUIREMENTS FOR ESTABLISHMENT OF LUCERNE.

1. Introduction.

Since in the first season of growth, lucerne roots may reach a depth of 150 to 180cm. and 270 to 370cm. root depths have been measured in plants two years old (Langer, 1968) the exact time span of lucerne establishment can not be strictly defined. In this experiment establishment will include the entire first year of growth of the lucerne plants.

Management practices in the establishment period can be critical to seed germination, seedling emergence, early seedling survival and growth and

nodulation. As seedling emergence is usually the first evidence in the field that germination has occured, seed germination and seedling emergence will be considered together as the first phase of establishment followed by early seedling survival and growth which will be considered as the second phase of lucerne establishment. Although nodulation and resulting nitrogen fixation can probably be better defined as a process, in this case it will be considered as a third phase in lucerne establishment.

2. Requirements for Germination and Emergence.

Germination is defined as the processes starting with the imbibition of the dispersal unit and ending with the protrusion of the embryonic root which take place inside the dispersal unit and prepare the embryo for normal growth (Evenari, 1961).

Seedling emergence can be regarded as the first appearance of parts of a seedling above the soil surface.

Bula and Massengale (1972) list factors such as temperature, available moisture, age and osmotic concentration of the media surrounding the seed as being known to influence the germination of lucerne seed and thus seedling emergence.

2.1 Soil Moisture.

Mayer and Poljakoff-Mayber (1963) state that the first process which occurs during germinationis the uptake of water by the seed due to the process of imbibition. During imbibition molecules of water enter the seed causing swelling of the colloid components which results in imbibition pressure which breaks the seed coat and also to some extent makes room in the soil for the developing seedling. The extent to which imbibition occurs is determined by three factors, the composition of the seed, the permeability of the seed coat to water and the availability of water in liquid or gaseous form in the environment.

Collis-George and Sands (1959, 1962) studied the control of seed germination, which was taken to be the first emergence of the radicle, by moisture as a soil physical property. They found that for three different Medicago species, an increase in soil moisture tension produced a decrease in rate of germination until at 10 atmospheres, germination practically ceased. However, the moisture condition of the soil controlled the germination rate not only by means of this suction effect, but also in terms of hydraulic conductivity or permeability. A drier soil has less ability to transmit water than a wetter soil, reducing the rate at which water can reach the seed, with a consequent decline in germination rate.

Both matric and osmotic potential strongly influence the emergence

percentage and the rate of emergence (Peters and Runkles, 1967). Triplett and Tesar (1960) found that no lucerne seedling emergence occured when the soil moisture tension one day after planting was greater than 10 atmospheres on a silt loam or 11 atmospheres on a sandy loam. Under conditions favouring high evaporation within 24 hours after a short-duration rain, the soil often dried below the wilting percentage in the top 0.85cm. in treatments with no compaction, resulting in a very low percentage of emergence. The critical period in this case was the time required for the seeds to initiate germination and for the radicles of the seedlings to extend into a zone of soil with ample moisture for the development of the seedlings. When this occured, the moisture content in the original location of the seed was no longer critical.

Ayers (1952) believes that germination may be affected by increasing osmotic concentrations of the media surrounding the seed through either decreasing the rate and total amount of water absorbed or by increasing the entry of ions in quantities sufficient to be toxic. Generally, the percentage of seeds germinating decreases as osmotic concentration increases (Bula and Massengale, 1972) but seeds of various cultivars differ in their ability to tolerate salinity and/or other osmotic gradients during germination. Certain salts are known to be more toxic to lucerne seeds than others. (Bula and Massengale, 1972). Uhvits (1949) found a greater reduction in germination of lucerne seed from sodium chloride than from mannitol at the same osmotic concentrations.

2.2 Soil Temperature.

Shaw (1952) claims that germination and emergence are intimately related to soil temperature. Bula and Massengale (1972) state that temperature regulates speed of germination primarily through its role in regulating the metabolism of the germinating seed, generally an increase in temperature, within limits, will increase the rate of germination and emergence.

Larsen (1965), using a thermogradient plate found that after six days, lucerne (Variety: Ranger) germination had occured within a soil temperature range of 12 to 38°C with maximum germination occuring at 25°C.

Dubetz et al (1962) found that the percentage of emergence of lucerne (Variety: Vernal) was significantly higher at 18°C than at 6°C or 24°C but there was no significant difference in percentage of emergence between the lowest and highest soil temperature.

These differences in results may be due to differences in seed treatment or condition both of which may affect germination response as a function of temperature (Larsen, 1965) or to varietal differences.

Heinrichs (1967) studied the rate of germination of twenty lucerne

varieties at 5, 10, 15 and 20°C and found significant differences in rate of germination between varieties at each temperature although for each variety the rate of germination increased with increasing temperature.

Williams (1963) considered that the emergence force of the seedling was critical where soil crusts, soil compaction, rough seedbeds or excessive depth of planting occured and found the maximum emergence force at 30°C with a significant positive correlation between emergence force and seed size.

2.3 Seed Viability and Vigour.

Mayer and Poljakoff-Mayber (1963) claim that seeds are fairly resistant to extreme external conditions, provided they are in a state of dessication. As a result seeds can retain their viability for considerable periods. The length of time for which seeds can remain viable is extremely variable and depends both on the storage conditions and on the type of seed.

Viability can be retained for very long periods of time, especially in seeds having a hard seed coat. Mayer and Poljakoff-Mayber (1963) state that a hard seed coat may be impermeable to water, impermeable to gases or it may mechanically constrain the embryo. The impermeability of seed coats to water is most widespread in the Leguminosae. Graber (1922) demonstrated the effectiveness of scarification for the improvement of immediate germination but notes its deleterious effect on the longevity of lucerne seed. Using hard seed, Graber (1922) found a reduction in germination of lucerne seed from 94.5% to 47% after storage in a cool place for ten to twelve years.

Blair (1971) quotes data from 79 germination tests of lucerne conducted in New Zealand that show that the occurence of hard seeds in individual samples is variable, averaging 15-25% but with a range from single figures up to 40%. Thus Blair (1971) regards delayed germination derived from hard seeds as a factor in the disparity of plant vigour within a lucerne seedling population.

Zaleski (1957) claims that hard seed is variable and can produce seedlings by the end of the first growth season but only a very small percentage of hard seed could normally be established under field conditions owing to competition from plants already established from normal seed.

Thus apart from seed viability, the speed of seed germination or seed vigour is an important factor in establishment under field conditions. Seed vigour will depend on several factors such as seed size, storage and disease effects. 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, thus giving greater nourishment to the young plants. Walter and Jensen (1970) also found a relationship between seed

size and seedling vigour.

2.4 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 soil texture, soil moisture and degree of compaction. Triplett and Tesar (1960) found that when emergence was dependent on moisture present in the soil at the time of sowing (no irrigation), increasing compaction from 0 to 12 psi (84 kPa) and depth of sowing from 0 to 2.5cm. improved moisture conditions around the seed and resulted in a progressive increase in initial emergence except at maximum levels of seed depth and soil compaction on the sandy loam which crusted easily.

When plants were irrigated with 12.5mm of water after sowing, initial emergence was highest when seed was planted 0.625cm. deep on the sandy loam and 1.25cm. deep on the silt loam. Increasing the degree of compaction improved emergence at all sowing depths on the silt loam and at the 0 to 0.625cm. depth on the sandy loam.

Optimal sowing depth for both soils was 1.25cm. which agrees with the findings of other workers (Nel and Burgers, 1968; Beveridge and Wilsie, 1959).

3. Requirements for Seedling Survival and Growth.

Bula and Massengale (1972) list temperature, light, available soil moisture and nutrients, seed size and environmental conditions under which seeds matured as factors affecting lucerne seedling vigour and growth.

Walter and Jensen (1970) found that air temperature and soil moisture during the period of seed production not only influenced seed weight and percent germination but also influenced the growth of seedlings grown from that seed.

3.1 Soil Moisture.

Bula and Massengale (1972) state that available soil moisture greatly influences growth of lucerne seedlings. A readily available soil moisture supply during the seedling stage is important but excess moisture reduces soil aeration and may result in a shallow root system and plants with small crowns. In addition excessive soil moisture may induce seedling damage or loss by "damping-off" pathogens.

The effect of water stress on growth is most pronounced in tissues that are developed rapidly (Bula and Massengale, 1972) and such tissues comprise the major part of the plant during germination, emergence, and initial growth.

Cowett and Sprague (1962) consider soil moisture to be one of the

factors affecting the occurence of basal shoots on the crown of the lucerne plant.

TABLE I.1. Growth of Lucerne Seedlings as Influenced by Soil Moisture (harvested at 8 weeks of age). (Cowett and Sprague, 1962)

Moisture.	Characteristics of Growth.				
	Stems/ Plant	Buds/ Plant	Plant Height (cm.)	Root Weight/ Pot(g.)	Top Weight/ Pot(g.)
Low (10 atmospheres)	2.58	1.22	18.0	2.74	2.19
Medium (3 atmospheres)	3.33	1.54	36.4	4.74	5.13
High (0.5 atmospheres)	3.56	1.78	42.5	4.41	6.71

Thus soil moisture expressed itself as a factor controlling over-all growth as all characteristics varied similarly. Plants with the greatest yields of either tops or roots and those with the greatest height possessed the largest number of stems and buds per plant. However when plants from the low moisture treatment were cut and subjected to higher moisture levels, comparable yields and stem numbers were obtained to those from plants which had been subjected to a high moisture treatment for both growth periods. Thus soil moisture during a previous growth period had no significant effect on plant growth measured at a later harvest. The number of stems was greater where soil moisture was high during the recovery period regardless of the size of crowns or root system at the previous harvest. Apparently, an accumulation of carbohydrates in the roots and crowns under the low-moisture conditions (Willard et al, 1934) was such that plants following this treatment produced more stems and buds per unit of crown than plants not subjected to moisture stress, thus compensating for smaller crowns.

Gist and Mott (1957) also reported that growth of both tops and roots of lucerne seedlings was reduced by increasing the moisture stress. They found important interactions between the effects of light intensity and soil moisture on seedling development such that at low light intensities the large root growth which is characteristic of lucerne and attributes largely to its drought tolerance, did not occur.

Leach (1967) believes that the lucerne plant has a buffer against short term changes in transpiration losses in its distribution of roots through a large volume of soil, although little is known about where the active roots are. Houston (1955) found that established lucerne plants obtain 46% of their moisture from the top 6.1dm. of their root zone in irrigated soil. However

these percentages can vary, depending on climatic conditions, depth and amount of roots within the soil profile, soil texture and perhaps other factors (Jung and Larson, 1972). Therefore an extensive and deep root system, is important for survival in semi-arid areas because plants with shallow roots are unable to secure moisture from lower depths.

Differences in water requirement between varieties of lucerne were reported by Briggs and Shantz (1914) and Shantz and Piemeisel (1927). Water requirement is influenced by external environmental factors, such as temperature, evaporation, soil texture, soil salinity, depth and extent of root penetration, and sources of water (Bolton, 1962).

Taylor (1952) found a highly significant linear decrease in yield of second year lucerne with soil moisture tension as measured with gypsum blocks and tensiometers.

3.2 Light.

Bula and Massengale (1972) state that intensity, duration and quality of light are influenced by latitude, time of year, atmospheric conditions, and elevation. Bula et al (1959), using light intensities up to 32,000 lux, observed that total plant dry-weight accumulation was essentially proportional to intensity of light.

Gist and Mott (1957, 1958) grew legume seedlings in light intensities ranging from 2200 to 17,200 lux for 12 hours per day and reported a curvilinear growth response. Growth reponses to different intensities of light varied with stage of seedling development.

Matches et al (1962) reported that lucerne seedlings were not tolerant of low light intensities. Low light intensities reduced total plant dry weight, and weight of aerial parts. These results further confirm that root production is affected more than shoot production as light intensities decrease

3.3 Soil Temperature.

Garza et al (1965) reported that growth of lucerne (Varieties: Culver and Tanverde) seedlings up to 4 weeks of age was better at 30°C than at 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. These temperatures resulted in an 18 and 40% increase in dry matter accumulation during 4 weeks period over constant temperatures of 15 and 30°C respectively. This was attributed to the increasing amount of non-photosynthetic tissue with advancing age resulting in high temperatures increasing respiration more than photosynthesis, especially when such temperatures prevail at night when photosynthesis ceases.

Ueno and Smith (1970) found that highest weights of all lucerne (Varieties: Vernal, Cody and Florida 66) plant parts at 35 days growth were obtained in a warm (27°C day/21°C night) air temperature regime compared with

a hot (32°C day/27°C night) and cool (21°C day/15°C night) air temperature regime.

Jensen et al (1967) reported that lucerne (Variety: Moapa) plants grown in a warm regime (33°C day/17°C night) grew faster and reached 10% bloom in about half the time as plants grown in a cool regime (2 °C/4°C). Further, dry matter yields were significantly lower when root temperatures were maintained at 9°C than when root temperatures were 16, 24 or 32°C but there were no significant differences in forage yield among plants grown at the three highest root temperatures.

McElgunn and Heinrichs (1970) found improved growth of lucerne (Varieties: Rambler and Alfa) roots and tops at 20°C than at 10°C or 15°C soil temperature.

Brown (1973) found that high soil temperatures near the surface of a Himitangi sand in the Manawatu sand country caused substantial seedling mortality with a temperature of 45°C shown to be lethal.

3.4 Light Temperature Interactions.

Top and root growth reponses to temperature and light intensity are interrelated as shown by Gist and Mott (1957) for lucerne (Variety: Ranger) seedlings.

TABLE I.2. Top Dry Weight of Lucerne Seedlings (g/pot) Grown at Four Air Temperatures and Three Light Intensities for 45 days. (Gist and Mott, 1957)

Light Intensity (f.c.)	Temperatures			
	16°C	21.3°C	26.6°C	32°C
1200	1.655	1.521	1.079	0.688
600	0.942	0.991	0.887	0.449
200	0.152	0.135	0.127	0.125

TABLE I.3. Root Dry Weight of Lucerne Seedlings (g/pot) Grown at Four Air Temperatures and Three Light Intensities for 45 days. (Gist and Mott, 1957)

Light Intensity (f.c.)	Temperatures			
	16°C	21.3°C	26.6°C	32°C
1200	0.969	0.907	0.642	0.249
600	0.419	0.432	0.290	0.119
200	0.039	0.021	0.018	0.020

These interactions were further examined by Steinke (1963) who found that high light intensities (3500 ft.c) increased lucerne (Variety: Wairau) root dry weights significantly at either a 18°C day/5°C night or 18°C day/ 10°C night air temperature regime.

3.5 Soil Fertility.

Bolton (1962) lists phosphorous, calcium, potassium, magnesium, sulphur, boron, iron, manganese, zinc, molybdenum, copper and chlorine as mineral elements essential for lucerne growth, the last seven of which are required only in trace amounts.

Tesar and Jackobs (1972) claim that in addition to calcium which is supplied by lime, phosphorous and potassium are elements most likely needed for stand establishment. Lathwell (1966) claims that phosphorous is particularly important because of its role in root development. When a soil is deficient in potassium, this element must be applied in adequate quantities for high forage yields and winter survival.

Cowett and Sprague (1962) grew lucerne seedlings under two levels of nitrogen, phosphorous and potassium with all minor elements provided in abundance to all treatments.

TABLE I.4. Effect of Nitrogen, Phosphorous and Potassium Levels on Growth of Lucerne Seedlings in a Sand Culture. (Cowett and Sprague, 1962)

N P K Levels.	Characteristics of Growth.				
	Stems per plant.	Buds per plant.	Top weight per pot(g.)	Crown weight per pot(g.)	Root weight per pot(g.)
H H H	7.2	2.5	23.25	3.17	29.07
H H L	5.9	1.8	16.18	1.56	14.76
H L H	1.6	0.4	1.14	0.22	1.32
L H H	3.0	1.1	1.58	0.22	2.46
L L H	1.3	0.4	0.87	0.15	1.54
L H L	2.8	1.4	1.65	0.26	2.40
H L L	1.4	0.2	0.85	0.23	1.49
L L L	4.6	1.1	4.46	0.49	5.33

Nutrient balance was revealed to be more important for growth and basal shoot development of lucerne seedlings than nutrient levels and it is suggested by the authors that a balanced supply of nutrients may have an effect on efficiency of photosynthesis.

Of the elements previously listed, only six have given worthwhile responses in lucerne in New Zealand. These are phosphorous, potassium, sulphur,

molybdenum, copper and boron (Dale, 1967). In addition lime reponses due at least in part to altered soil pH are important especially on acid soils. More calcium is needed for nodulation than for plant growth (Loneragan and Dowling, 1958; Andrew and Norris, 1961) and even greater amounts are required for nitrogen fixation (Loneragan, 1959).

Acid soil conditions are known to adversely affect lucerne root development (McLeod and Jackson, 1965; White, 1960, 1965a, 1965b) and marked effects of lime in improving root development have been reported. Liming the lower layers of the soil markedly affected root distribution of the lucerne (Schmel et al, 1952) and encouraged normal tap root development (White, 1965a). White (1965a) found that lucerne developed short brown branched roots where only 500 kg/ha. of lime was applied in the drill row but developed long strainght white taproots where 2500 kg/ha. was broadcast and rotary hoed to 10cm. depth.

White (1970) in a sod seeding trial with lime pelleted lucerne on an acid soil (pH 5.5) in the tussock grasslands of the South Island, found that increasing rates of lime from zero application to 5022 kg/ha. increased dry matter production which was associated with the production of more and larger nodules. A heavy rate of lime broadcast on the surface of the plot generally proved superior to a smaller amount of fine lime in the drill row, apparently by stimulating more widespread nodulation. No significant effects on taproot development were measured, although taproots were present on more plants where lime was broadcast than in other treatments.

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 (Schmel et al, 1950) or aluminium (McLeod and Jackson, 1965) in the soil.

3.6 Wind.

Susceptibility of the sand-country soils to wind erosion is greatest for the soils with low amounts of organic matter and excessive drainage, and it decreases as drainage becomes poorer and the organic matter content of the soil increases. (Cowie et al, 1967)

Wind erosion is initiated when the pressure of wind against the surface grains overcomes the force of gravity holding the grains. The grains of sand move in series of jumps and bounces (saltation) and this movement is accompanied by surface creep of larger and denser particles and suspension of the smallest and lightest particles (Chepil and Woodruff, 1963; Williams, 1972).

As the wind erosion on bare or sparsely-covered soil depends on wind velocity at the soil surface, methods of overcoming wind erosion usually

involve methods of reducing surface windspeeds or of increasing cohesion of the particles on the soil surface. Vegetation covers effectively reduce surface wind speeds (Chepil and Woodruff, 1963) and may bind surface particles and suspension of the smallest and lightest particles (Chepil and Woodruff, 1963; Williams, 1972).

Apart from wind erosion, resulting in the burial of seeds and seedlings under blown sand, other harmful effects of wind on crops include wind rocking of plants, causing cracking and twisting of stems and in prolonged high velocity wind, transporation losses can be harmful (Williams, 1972).

However Kramer (1969) reports that most of the effect of wind on transpiration occurs at low wind velocity (0 to 5km/hr.). Wind acts directly to increase transpiration by reducing the resistance of air to water movement. It acts indirectly to decrease transpiration by cooling leaves and therefore reducing the water potential gradient from leaf to air. Knoerr (1966) reports that at low levels of radiation a breeze should increase transpiration while at high levels (when the leaf is warmer than the air) a breeze should reduce transpiration.

3.7 Time of Sowing.

The common sowing times for lucerne in New Zealand are the late spring and early summer when soil temperatures are high enough to give rapid germination and the plants will be established before the first winter.

However Peters and Peters (1972) consider that weeds are often more of a problem in spring planted lucerne than in lucerne planted at other times because abundant moisture and favourable temperature in the spring cause large numbers of weed seeds to germinate. Also as the daylength shortens in late summer, most summer annual weeds go into the reproductive stage in a shorter time than those germinating in spring and consequently offer less competition to new seedlings.

Furthermore, the only reliable period adequate moisture is available for lucerne establishment in areas such as the Manawatu Sand Country is the cool part of the year from autumn/early winter until the early spring (Flock House Report, 1972). The cooler weather and shorter days at this time of the year reduce soil moisture losses to a minimum and the seedlings are not so dependent on subsequent rain for successful establishment.

Cowie et al (1967) state that from late autumn to spring light winds prevail and calm spells are common in the Manawatu sand country reducing the possibility of wind erosion. This could be another advantage in selecting an autumn sowing time especially on more exposed areas nearer the coast.

4. Requirements for Nodulation.

4.1 Nodulation Process.

The nodule is the focal point of reaction between rhizobia and leguminous plant. Burton (1972) briefly reviews the fundamental features of rhizobium nodulation in lucerne. Rhizobia proliferation and root-hair curling precede infection, but the mechanism of entry of the rhizobia remains obscure. Curling may be induced by either homologous or heterologous rhizobia. The first evidence of specicifity occurs with entry of the rhizobia and infection thread initiation that is induced only by homologous strains of bacteria.

Development of a visible functional nodule depends upon many factors after infection occurs as evidenced by the small number of infected root hairs (1 to 5%) that actually develop into nodules. The infection thread must penetrate the root cortex, locate tetraploid cells, stimulate rapid cell division, and release the bacteria. The rhizobia following release must multiply infect other plant cells and change to bacteriods. The resulting bacteriod tissue may still fail to fix gaseous N or may function for only a short time.

4.2 Rhizobium Specicifity.

The three legume genera Trifolium, Medicago and Lotus not only form nodules with three separate cross-innoculation groups of rhizobia with no effective cross-nodulation between them but within each of these groups there is also a wide range of strains of bacteria which show variation in temperature and pH limits for growth and a large variation in the ability to form an effective symbiosis with host plants of their particular cross-innoculation group. (Parle, 1967) This variation in effectiveness is related to genetic factors in both plant and bacterium as shown by Nutman (1958) and Gibson (1962).

Several workers in New Zealand and Australia (Blair and Bennett, 1960; Purchase et al, 1951; Brockwell and Hely, 1961) have demonstrated the differential reponses of lucerne varieties to specific strains of Rh. meliloti. However in practice, Blair and Bennett (1960) note that the use of multi-strain cultures seems to cope with the differential responses of the lucerne varieties at present used in New Zealand.

4.3 Level of Inoculum.

All the species of Trifolium, Medicago and Lotus now in New Zealand have been introduced from overseas, and are not closely related to any native leguminous plant. Thus it is very probable that their associated rhizobia are also not native but were originally introduced by chance during the early days of settlement in the country. Since then they have been spread widely by a number of agencies - for example as contaminants on seed, the feet of

animals, agricultural implements and in dust, flood water and agricultural lime (Greenwood, 1964).

However, except in very few places where large areas of lucerne or other Medicago species have been grown for many years, innoculation of lucerne is necessary to ensure adequate nodulation (Greenwood, 1964). The reason for the poorer spread of Rhizobium meliloti probably lies in its lower tolerance to soil pH below 5 (Vincent, 1958). Jensen (1942) showed that in nutrient solution the optimum pH for Rhizobium meliloti growth is between 7 and 8.

Commercial innoculants used at present in New Zealand supply over 1000 rhizobia per seed and this is usually sufficient for effective nodulation provided the soil pH has been raised to 6 or higher. In certain problem soils, however there may be improved nodulation of very high levels of inoculum are used. On acid soils, both the percentage nodulation and the numbers of nodules per plant increased with increasing level of inoculum on the seed (White, 1865a, 1966) where seed had been drilled. White (1970) found that increasing level of inoculum gave a highly significant improvement in percentage nodulation and number of surviving nodulated plants when seed was broadcast on to a South Island steepland Y. G. E. (pH 6.1) probably due to the higher mortality of rhizobium on the surface exposed seed by dessication from the sun and wind.

4.4 Rhizobium Toxicity.

Parle (1964) at Wither Hill first demonstrated a material toxic to lucerne rhizobia occured in the rhizosphere of danthonia roots. Both Parle (1964) and later workers (White, 1970; Janson and White, 1971b) found that destruction of the danthonia using a herbicide such as paraquat some six weeks before sowing would stop the production of toxin and allow ample opportunity for a decrease in its concentration before sowing by leaching (Parle, 1964) and adsorption (Rice, 1964) and greatly enhance subsequent nodulation.

Thompson (1960) and Bowen (1961) have demonstrated the presence of a toxic material in the coat of a number of legume seeds and it has been suggested that the initial rapid death of innoculated rhizobia could be due to this material.

4.5 Seed Pelleting.

White (1966) comments that if the full value is to be obtained from innoculation, the seed must be sown under conditions which favour survival of the applied bacteria. Once the rhizobia are innoculated on to the seed coat, death can be fairly rapid (Vincent, 1958) and in order to obtain a reasonable level of viable rhizobia on seed at sowing, precautions need to be taken if seed is to be stored after innoculation. Several workers

(Vincent, 1958; Brockwell and Phillips, 1965a; Burton and Gurley, 1965) have shown the use of peat as a carrier improves the storage life and aids survival of organisms on seed after innoculation. However Blair (1971) found a very sharp decline in Rhizobium numbers when coated or peat cultured innoculated seed had been stored in cool conditions. The decline in numbers of viable rhizobia on the seed surface depends on several factors including temperature and humidity. (Parle, 1967)

Hastings and Drake (1960) developed a method of pelleting innoculated seed which involved protecting the rhizobia on seed by applying them in a bonding agent, methyl cellulose and then covering them with a layer of finely powdered non acid materials. Improved nodulation and establishment of lucerne has been obtained on acid soils from the pelleting of innoculated lucerne seed with lime and certain other materials. (Lobb, 1958; Blair and Bennett, 1960; Hayman, 1964). White (1966) compared the effect of several types of pellets on seed sown on an upland yellow-brown earth (pH 5.5) in the South Island and concluded that finely divided lime was the best material to use.

TABLE I.5. Effects of Pelleting on Nodulation of Lucerne. (White, 1966)

Pelleting Treatment	Percentage of plants effectively nodulated after 11 weeks.
Lime alone	60.4
Lime/Gasfa phosphate	48.2
Lime/dolomite	37.4
Dolomite	34.4
Gasfa phosphate/dolomite	21.6
Innoculated seed	0.8
Uninnoculated seed	Nil

Pellets perform several functions (Hastings et al, 1966) but in lucerne the main effect of the lime pellet is the raising of soil pH immediately adjacent to the seed thus permitting better survival and/or multiplication of the rhizobia (White, 1967). However the calcium requirement for growth of rhizobia bacteria is low (Loneragan and Dowling, 1958; Vincent, 1962) although Blair and Bennett (1960) suggest that calcium may render magnesium available through cation exchange for the rhizobium which have a greater requirement for magnesium than for calcium (Norris, 1958). The pellet also protects the rhizobia against dessication during storage or when seed is

surface sown, and against possible damage from contact with fertilisers (Adams, 1964).

Both White (1966) and Hayman (1964) have conducted pot trials which show that lime pelleting of seed can result in nodulation equal to that obtained from heavy liming.

TABLE I.6. Effects of Lime and Seed Pelleting on Nodulation of Lucerne. (White, 1966)

Treatment	Percentage of plants effectively nodulated after 11 weeks.
Unpelleted	6.1
Phosphate/Dolomite-pelleted	21.8
Lime-pelleted	90.9
Unpelleted + 1 ton/acre (2460 kg/ha.)	90.6
Phos/Dol-pelleted + 1 ton/acre lime (2460 kg/ha.)	89.8
Lime-pelleted + 1 ton/acre lime (2460 kg/ha.)	92.7

These results suggest that in some moderately acid soils effective nodulation of lucerne can be obtained by lime-pelleting of innoculated seed alone. However White (1967) comments that good nodulation of lucerne does not necessarily mean good establishment and growth. Recent work in tussock country of the South Island (Hayman, 1964; Lowther, 1965; White, 1966) has shown that lucerne can become nodulated in acid soils through lime-pelleting of seed, and yet still not grow well in the field unless lime is also applied, although in pots it may grow as well as limed treatments.

Loneragan and Dowling (1958) suggested that the effect of liming on nodulation was through its influence on the level of calcium in the plant. The effects of hydrogen and calcium ions may be partly on root hair length and density (White, 1965; White and Powrie, 1967). White and Powrie (1967) showed that in nutrient solution the effects of calcium and pH on root hair development were closely related, suggesting that one of the main effects of calcium and pH was through effects on root hair development. For example, at pH 5.0 no root hairs or nodules were present on lucerne at any of the calcium levels used.

Rhizobia normally invade legume roots via curled root hairs and as

little curling occurs where lucerne root hairs are less than 150u in length (Thornton, 1936), the length and density of root hairs may largely determine the percentage of root hairs that curl and the nodules which form, so long as rhizobial numbers are non-limiting (White, 1967). However as White (1967) points out, it is difficult to separate the effects of calcium and pH on nodulation in the field owing to interactions with the rhizobial population and the infection process itself.

(E) TYPES OF ESTABLISHMENT PROCEDURES.

The three major sowing methods used in the establishment of lucerne are oversowing or broadcasting, overdrilling and drilling into cultivated ground. Various sward treatments, including chemical treatment and burning can be used in association with all of these sowing methods.

Several workers (Janson and White, 1971; White, 1966) have shown the different effects of method of sowing on aspects of lucerne establishment which include total germination, time of germination, early seedling survival and nodulation. In addition much work, relevant to lucerne has been carried out on other legumes (Cullen, 1966, 1969, 1970; Campbell, 1968; Warboys, 1966; Watkin and Vickery, 1970).

Janson and White (1971) compared two sowing methods (broadcasting and overdrilling) and three sward treatments (burning, paraquat, dalapon/amitrole) for introduction of lucerne into uncultivated country at two sites in the South Island, differing in rainfall and vegetation but representative of large areas of country on which lucerne may have agronomic advantage over other legumes.

Overdrilling was much superior to broadcasting at both sites, as sowing of the seed into moist soil resulted in high and rapid germination and excellent early seedling survival, irrespective of rainfall, vegetative cover or sward treatment. Germination and survival of broadcast seed was very dependent on rainfall after sowing, and on cover. At both the wetter Mesopotamia and drier Waikari sites, total germination after broadcasting was considerably lower on burnt than on control, paraquat or dalapon/amitrole plots. At Mesopotamia, the method of sward preparation had no effect on the time of germination when the seed was broadcast but at Waikari, early germination on burnt plots comprised a very small proportion of total germination compared with the other sward treatments.

The number of seedlings that reached the unifoliate leaf stage at Mesopotamia when seed was broadcast was equally high on control, paraquat and dalapon/amitrole plots but was reduced on burnt plots. However at the

Waikari site, early seedling survival was poor when seed was broadcast although it was improved by the paraquat and dalapon/amitrole treatments.

From these results it is obvious that conditions for lucerne seed establishing on the surface of the soil are much more severe than those for buried seed. However, germination and early seedling survival on broadcast sowings were greatly improved by the presence of cover, the importance of cover being greater at the drier Waikari site than at Mesopotamia. This has also been observed in similiar studies (Cullen and During, 1965; Cullen, 1966; McWilliam and Dowling, 1970). Under controlled conditions, McWilliam and Dowling (1970) found that the effects of cover was due to the greater retention of moisture and higher humidity at ground level rather than to a temperature effect.

Although there was no improvement in germination resulting from herbicide application with broadcasting as noted at other sites by Cullen (1966, 1969, 1970), Warboys (1966) and Campbell (1968), Janson and White (1971) found that early seedling survival was markedly improved at the drier Waikari site where the vegetation was treated with dalapon/amitrole in comparison to that of the untreated vegetation. Unlike the other sward treatment plots, the surface soil under the dalapon/amitrole treated vegetation did not crust but remained moist and friable, a condition which appeared excellent for easy penetration of the radicle. This process is also aided by anything that places a restraint on the upward movement of surface-sown seed during germination.

Whereas at Mesopotamia there was complete nodulation failure due to an insufficient number of rhizobia on the seed at the time of sowing, at Waikari reasonable nodulation occured only on the dalapon/amitrole treatment. Here, decreasing nodulation with lateness of germination was attributed to a decrease in the number of viable lucerne rhizobia during the interval from sowing until infection of the young seedling.

The higher nodulation achieved when seed was overdrilled rather than broadcast on dalapon/amitrole plots was attributed to an expression of the better conditions for rapid germination and rhizobial survival when seed is buried rather than placed on the soil surface. This confirms the results of White (1966) and Watkin and Vickery (1970).

Clare (1971) compared four methods of lucerne establishment; cultivation alone; chemical treatment prior to cultivation; chemical treatment prior to cultivation plus soil incorporated benfluralin and chemical treatment plus direct drilling on pumice country. By the end of the first growing season, total dry matter yields were comparable although the percentage of weeds was lowest on the benfluralin plots and the lucerne component was

lowest on the direct-drilled plots.

Several trials have been conducted at Flock House F.R.A. on different seed bed preparations to establish lucerne on the yellow brown sands of the Manawatu Sand Country. Methods of seed bed preparation and sowing that have been tried include cultivation both with and without cover crops, direct drilling following chemical pretreatment of the existing sward, chemically killing of the existing sward followed by a shallow cultivation and over-drilling and direct drilling into a dessicated greenfeed cover crop. (Flock House F.R.A. Report, 1972)

The major conclusions to be drawn from these trials (Allbrook, pers. comm.) were:

(i) Chemical fallowing followed by a light discing gave better lucerne establishment and weed control than the use of a cover crop on Himitangi sand.

(ii) When direct drilling was tried in comparison to normal cultivation, germination suffered due to the restriction of the root to the slit cut by the coulter. However a chisel shaped coulter which cuts a very narrow groove at the surface but an enlarged shattered area below has been developed at Massey University (Baker, 1973). In this way, the soil/seed contact is improved, drying is inhibited and root growth is encouraged.

(iii) Where a cover crop is used, the relative times of sowing of the cover crop and the lucerne is very important. If the cover crop is sown too long before the lucerne is directly drilled into the crop, the plants of the cover crop compete strongly with the lucerne seedlings for light and moisture resulting in early wilting of the lucerne in a dry period and complete dessication of many seedlings. If the cover crop is drilled with the lucerne seed, it was found that it is too slow in establishing to give the lucerne seedlings adequate protection from wind and drifting sand.

(iv) For lucerne establishment on sand dunes of the Waitarere Dune Phase, a cover crop is essential. Lucerne is difficult to establish on these sand dunes due to the extreme coarseness of texture of the soils which causes low moisture retention, low nutrient status, susceptibility to erosion and very high soil temperatures due to the low specific heat of sand.

(F) PLANT POPULATION AND YIELD.

1. General Theory.

Holliday (1960b) suggested that there were essentially two basic biological relationships that can be described by different yield/density equations: an asymptotic one where, with increase in plant density, yield

rises to a maximum and is then relatively constant at high densities and a parabolic one where yield rises to a maximum but then declines at high densities.

Holliday (1960b) suggested that total crop dry matter conformed to an asymptotic relationship as shown for perennial ryegrass (Holliday, 1953), rape (Holliday, 1960a); and barley and white persicaria (Aspinall and Milthorpe, 1959). Holliday (1960b) further points out that this relationship applies to all components of vegetative yield including for example yield of potato tubers.

Conversely, Holliday (1960b) suggested that reproductive forms of yield (i.e. grains and seeds) conformed to a parabolic relationship as shown for grain yield of maize (Lang et al, 1956).

2. Lucerne Yield/Population Studies.

Willey and Heath (1969) stress that yield per unit area is dependent not only on the number of plants per unit area (plant density) but also on the spatial arrangement of those plants (plant rectangularity). Plant rectangularity can be most easily visualised in a row crop where it can be defined as the ratio of the distance between plants within the rows to the distance between the rows. Rectangularity is an important consideration because of the unevenness of competition which it produces; competition being more intense between some plants and less intense between others. Although the extent to which rectangularity may effect the yield of a crop is clearly dependent on the plasticity of the individual plant, generally as rectangularity increased, yield per unit area gradually declines as shown by Wiggans (1939) for soybeans, Reynolds (1950) for peas, Pendleton and Seif (1961) for maize, Harvey et al (1958) for wheat, and Weber et al (1966) for soybeans.

Lucerne yield population studies have been conducted where the effect of both plant density and plant retangularity or spacing on yield have been examined.

Palmer (1971) sowed viable Wairau lucerne seed at rates ranging from 2.8 to 16.8 kg/ha. in six field trials and recorded no differences in herbage yields from plant densities varying from 46 to 240 plants/m^2 up to five years after sowing. Death rates of established plants were similar over a range of plant densities and continued until a low plant density was reached.

Cowett and Sprague (1962) recorded yields of 2600, 5300 and 6400 kg/ha. of dry matter in the first harvest from populations of 10, 40 and 80 transplanted plants/m^2.

Zaleski (1959) sowed lucerne at 5.6, 11.2 and 16.8 kg/ha. and found a significantly lower yield at 5.6 kg/ha. than at the other two densities in the first year but in the second and third year when plants were fully developed the differences in total yields were insignificant between seed rates. Death rates over this period were 58%, 66% and 73% respectively.

Donald (1956) stated that stands with 40 plants/m^2 gave higher yields than stands with 100-150 plants/m^2. He found that in the first year maximum lucerne yields are given at medium or high densities but in succeeding years the population undergoes adjustment to the environment, thinning to an equilibrium value. However Donald (1956) found that despite the thinning of dense initial stands they do not thin to densities giving the maximum production. The relative productiveness of swards of different densities changes as the stand matures. In the first year the densest stand is the most productive, but in the subsequent years less dense stands give the greatest production. This is apparently a consequence of increasing plant size and greater root penetration in less dense stands.

Jarvis (1962) planted lucerne at square spacings of 2.5 x 2.5, 5 x 5, 7.5 x 7.5, 15 x 15, 22.5 x 22.5, 30 x 30, 60 x 60 and 90 x 90cm. which represent establishment from 35g. to 40kg of seed per hectare. During the first three years, yields from the four closest spacings were not significantly different. However the wider spacings gave significantly lower yields. It is suggested that since the yield of lucerne per acre did not decline at high populations, a high rate of seeding may be justified as an insurance against poor germination or subsequent loss of plants. However over the three year period death rate were higher in the denser populations.

Rumbaugh (1963) planted lucerne at 13 x 13, 27 x 27, 54 x 54 and 107 x 107cm. and obtained higher yields from denser populations in the first two harvest years. Moreover, as plant density increased so individual plant yield, crown width, stem length and the number of stems per plant decreased.

Takasaki *et al* (1970) grew lucerne at spacings ranging from 2cm. to 16.7cm. between plants. In the first year, higher densities gave significantly higher yields than lower densities but in the second and third years there were no differences in yield. Death rates of the plants over the three years were density dependent.

(G) COMPETITION.

Competition only begins when the immediate supply of a single necessary factor falls below the combined demand of the plants in a population (Clements *et al*, 1929). Competition in an establishing lucerne stand is of two types;

intraspecific competition between the lucerne plants and interspecific competition between the lucerne plants and other species present.

1. Intraspecific Competition.

The nature and degree of intraspecific competition depends on intrinsic plant factors such as seed size, relative time of emergence, initial growth rate and proximity of neighbouring plants (Black, 1957; Black and Wilkinson, 1963; Zaleski, 1957; Ross and Harper, 1972) together with extrinsic environmental factors such as water, nutrients, light, oxygen and carbon dioxide (Donald, 1963).

2. Interspecific Competition.

At sowing rates normally used by farmers in New Zealand, it would appear that interspecific competition is more severe than intraspecific competition during lucerne establishment.

Allen (1967) states that weeds in seedling lucerne are of importance because of their effect on the first season's production and their possible effect on future production either through excessive reduction of initial plant numbers, or the establishment from seed of perennial weeds within the stand.

According to Allen (1967), the weed problem itself and the method of dealing with it are largely determined by the ecological principles governing inter-plant competition. The seedling lucerne plant is an erect sparsely leafed axis for the first few months of its life and as such offers little competition to weeds which have germinated at the same time. Seedling lucerne is susceptible to competition for light with the result that erect or scrambling fast growing annual weeds can severely retard development or even kill seedlings (Allen, 1967).

In a glasshouse experiment, Pritchett and Nelson (1951) found that shading depressed the weight of roots more than that of the tops as shown by declining root to top ratios with increasing shade. Langer (1967) claims that restriction of root growth in weak light is probably of more ecological significance in lucerne which relies on depth of root penetration more than in other species.

O'Connor (1967) found that lucerne seedlings which may suffer competition for moisture especially in shallow soils can also suffer acute competition for phosphate but this may not necessarily persist.

Peters and Peters (1972) list weed control methods in establishing

lucerne stands as use of clean seed and implements, planting when weed infestations are low and conditions are most advantageous to the lucerne, the use of tillage practices and cropping sequences that will deplete the supply of weed seeds or vegetative parts in the soil, the use of selective herbicides, banding of fertiliser under the seed during planting and sowing lucerne with a companion crop.

(H) INSECT PESTS.

Pottinger and MacFarlane (1967) consider the two major lucerne insect pests in New Zealand to be the larvae of grass grub (Costelytra zealandica White.) and lucerne stem nematode (Ditylenchus dipsaci Kuhn.). Other insect pests reported to affect lucerne establishment include white fringed weevil (Grapognathous leucoloma Boh.), red legged earth mite (Halotydeus destructor Tuck.), lucerne flea (Sminthurus viridis L.) and sand dune weevil (Cecyropa discors Brown.).

1. Grass Grub.

Although mature lucerne stands are tolerant to grass grub larvae attack (Flay and Garrett, 1942), lucerne stands up to six months of age are highly susceptible to root damage, especially on lighter soils (Pottinger and MacFarlane, 1967).

2. Lucerne Stem Nematode.

Stem nematode damage to lucerne varies from year to year but, if present, curtails production. The most obvious effect of light infestations is the production of fewer stems than normal, whereas severe infestations often cause death of the plant (Pottinger and MacFarlane, 1967). In lucerne seedlings, susceptible plants react by swelling of the meristematic tissues and eventually growth of the primary shoot is inhibited (Grundbacher, 1962).

3. White Fringed Weevil.

In New Zealand, white fringed weevil larvae exhibit a very wide host range including lucerne, peas, tomatoes, potatoes, pumpkin, barley, wheat, choumoellier, exotic forest seedlings and pasture species. White fringed weevil has been reported as a lucerne pest in many parts of New Zealand (Perrot, 1964; Eyles, 1961; Todd, 1964; May, 1966) and in Australia (Wallace,

1941; Wright, 1961).

(a) Life Cycle.

Todd (1964) reports that in New Zealand, the white fringed weevil has a two year life cycle, but because of overlapping generations, larvae at various stages of development may be found throughout the whole year. Adult weevils are present from about December until April with peak numbers occuring during the January to February period. During their life span which is apparently several months, they may lay hundreds of eggs which are cemented in small masses to the base of plant stems, to sticks, stones, and other objects on or near ground level. Larval development extends over a period of about 17 months from May until October of the following year and during this stage the larvae pass through four, or possibly five instars before pupating.

(b) Habit.

Todd (1964) reports that the larval stages of the insect are responsible for most of the damage. Within a particular crop, damage may vary from complete destruction in one portion to just a trace in other parts, thus indicating a patchy larval distribution within the crop.

The larvae feed on the root system of the host plant, destroying parts of the cortex and epidermis and may sometimes sever the main tap root. When this occurs the affected plant wilts and may eventually die. When only a small portion of the cambium is destroyed, the plant usually survives but yield may be reduced.

The adults are parthenogenetic, flightless and foliage feeders and unless present in large numbers cause little crop damage.

(c) Dispersal.

Todd (1964) claims that dispersal of white fringed weevil may occur in a number of ways. Although the adult cannot fly, the eggs are deposited on many plants that are moved in commerce, the larvae and pupae may be transported in small quantities of soil, and the adults readily cling to objects being transported. Since all adults are females, each potentially able to start a new generation, it means that infestation can result from movement of a single egg, larva, pupa or adult.

(d) Control.

(i) Chemical Control.

Todd (1964) tested an extensive range of chemicals against the white fringed weevil larvae, and, although a number of materials proved moderately effective namely "Telodrin" and aldrin, none gave the desired level of control at dosages up to economic field rates. In U.S.A., Young (1960) has had some success with single applications of a range of organo-chlorine insecticides lightly worked into the cultivated land where they were effective for more

than three years.

Wright (1961) suggests the surface application of similar insecticides to kill adults as they emerge in crops. Gross et al (1972) found that dates when larvae of white fringed weevil were introduced into the soil directly influenced the rate of larval development and therefore the capacity of larvae to reduce stands of soybeans and rye. Since the capacity of most immature phytophagous insects increases proportionally with the size of the developing larvae, Gross et al (1972) claim that this data suggests the need to evaluate preventive treatments against adults during critical ovipositional periods to reduce the establishment of larval populations. However to be effective insecticides would have to be applied as sprays which are prohibited in New Zealand due to possible contamination of pastoral produce.

(ii) Cultural Control.

Observations indicate that intensive cultivation of infested land prior to crop establishment may be a practical method of reducing larval populations below the damaging level. Todd (1964) found that following a heavily infested Hawkes Bay pea crop which was thoroughly re-cultivated, a further pea crop sown suffered little or no damage. However it was not possible to decide whether the mechanical and dessicating effect of intense cultivation was responsible for the reduction in larvae numbers or whether birds reduced the population of exposed larvae sufficiently to prevent serious damage.

Gross et al (1972) report that soybean seedlings had minimum vigour under dry conditions and thus were more susceptible to damage by white fringed weevil larvae. Anonymous (1956) reports that a heavy rainfall which saturates the soil for about a week kills many young larvae, also the larvae are more abundant and damage is greater in well drained sandy loams than in heavy clay soils.

Berry (1947) describes a method used to combat white fringed weevil in South American areas where beans are grown under irrigation. This method consists of cultivating the bean fields in such a way as to mound the soil around the bean plants and then irrigate immediately. Berry (1947) reports that although this method does not kill the larvae that damage the crop, it enables the beans to grow more vigorously and thus reduces damage to the bean crop. In addition, when plants begin to die, irrigation alone is used in order that the plants may be revived. Often many apparently dead lucerne plants damaged by white fringed weevil larvae can be found in fields that have been dry for several weeks but following irrigation there is a decided recuperation and infestations cannot be detected among the dead or wilted plants.

4. Lucerne Flea.

The nymphs and adults of lucerne flea, a member of the springtail family, chew the leaf tissues of lucerne so that only the lower cuticles and leaf veins remain to give badly infested stands a white or bleached appearance (Pottinger and MacFarlane, 1967). Damage is usually confined to the autumn, winter and spring and Davidson (1934) predicted correctly that it would not be a major pest problem in New Zealand apart from Hawkes Bay since the remainder of the North Island is too wet and winter temperatures too low in the South Island for epidemic lucerne flea populations.

5. Red Legged Earth Mite.

This mite occurs through the east coast districts of the North Island (Dumbleton, 1947). Erlich (1962) reports that the mites preferably feed on young growth, lacerating the leaf tissues and sucking the liberated sap such that plants may appear scorched, become stunted and even die. Erlich (1962) notes that lucerne seedlings are often killed. However Wallace (1960, 1961) has shown that seedling crops can be protected by treating seed with organophosphate compounds.

6. Sand Dune Weevil.

Hudson (1950) reports that adult sand dune weevil have been found to defoliate lucerne seedling crops in dune development areas in coastal Manawatu.

(I) LUCERNE DISEASES.

1. Introduction.

In new Zealand, 12 diseases have been recorded on lucerne (Close, 1967). Diseases can affect lucerne at all stages in its development and so influence establishment, herbage yields, seed quantity and quality and lucerne stand deterioration (Close, 1967).

Diseases that affect lucerne establishment in New Zealand are the fungous diseases associated with Pythium species, Fusarium species and Common leaf spot (Pseudopeziza medicaginis (Lib.) Sacc.).

2. Pythium Species.

Close (1967) reports that seed-rotting, pre-emergence blight and post-emergent damping-off by Pythium species all affect the initial establishment of lucerne stands. The disease complex is one mainly of young seedlings, although rotting of rootlets and stems of established plants can occur especially in wet areas.

Barton (1958) found that the activity of Pythium mamillatum increased as soil moisture content increased in a cultivated soil of pH 5.4 and reports that the presence of this fungi in soils is correlated with slightly acid or neutral conditions. The presence of host plants was also found to be an important factor in the establishment of inocula of Pythium mamillatum in soils.

MacKenzie et al (1972) found that lucerne survival up to ten weeks was largely determined by the incidence of fungal attack by Pythium irregulare, damping-off being evident within a week of emergence. Jacks (1956) showed that Pythium ultimum Trow. was responsible for the damping-off patches in lucerne fields in New Zealand.

The disease is soil-borne and Close (1967) suggests that the best control measures are the use of high quality seed, a well prepared seed bed, a balanced fertility (including liming of acid soils) and seed treatment with protective fungicides.

3. Fusarium Species.

Blair (1971) reports the pathogenicity of Fusarium species. These species can be readily isolated from young lucerne seedlings and Blair showed that cultures of Fusarium avenaceum produced 70% mortality of seedlings which had been innoculated with the cultures. Blair (1971) concluded that Fusarium species not only cause substantial failures of lucerne seedlings to emerge but can also impair the vigour of established seedlings through various degrees of root injury.

Stover (1955) reports that under aerobic conditions, multiplication of Fusarium species was more rapid in dry than in moist soil.

4. Common Leaf Spot.

Close (1967) reports that Common leaf spot occurs in lucerne stands throughout New Zealand as small, circular, brown to black spots on leaflets. It is usually of no great economic importance since infection is generally

moderate but when spots are abundant, yellowing and shedding of leaflets does take place and severe infections, do at times occur.

Chapter II: Materials and Methods.

(A) FIELD EXPERIMENT.

1. Objective.

The objective of the field experiment was to determine the effects of different varieties and plant spacings on the establishment of lucerne on two soil types and an intergrade in the Manawatu sand country.

2. Site Selection and Description.

The selection criteria for an area on which to site the experiment were:-

1. A sand dune and sand plain soil type adjacent to one another.
2. An easy and uniform slope so that gradation from the sand dune to the sand plain is gradual.
3. No large variations in microtopography.
4. Reasonable accessability.

The following procedure was used to locate and then identify such an area. Two farms on which lucerne was being grown were inspected and an area which satisfied the above criteria selected as an experimental site. Consultation of the New Zealand Soil Bureau Soil Map of the Manawatu-Rangitikei Sand Country (Cowie et al, 1967) showed that the site was part of a Puke-Puke Motuiti Soil Association of the Older Dune Comples or Motuiti Dune Phase.

The boundaries of the soil types on the site were established by examining soil profiles in collabaration with Mr J. Pollok, Soil Science Department, Massey University. The dune soil type was identified as Motuiti sand while the soil type on the lower part of the site was identified as Puke Puke black sand. Between these two soil types, the area consisting of the upper sand plain and lower sand dune could not be strictly classified as either of these two soil types and was considered an intergrade between the two soil types.

The experiment site selected was an area of 0.23ha. situated within a paddock of approximately 5ha. which was part of a farm owned by Mr. W. Kernohan. The site consisted of a low sand dune and a sloping sand plain (see Plate I) and had a roadside plantation of Pinus radiata situated 15m from its western side.

PLATE 1 General view of experimental site and surrounds (19.8.73)

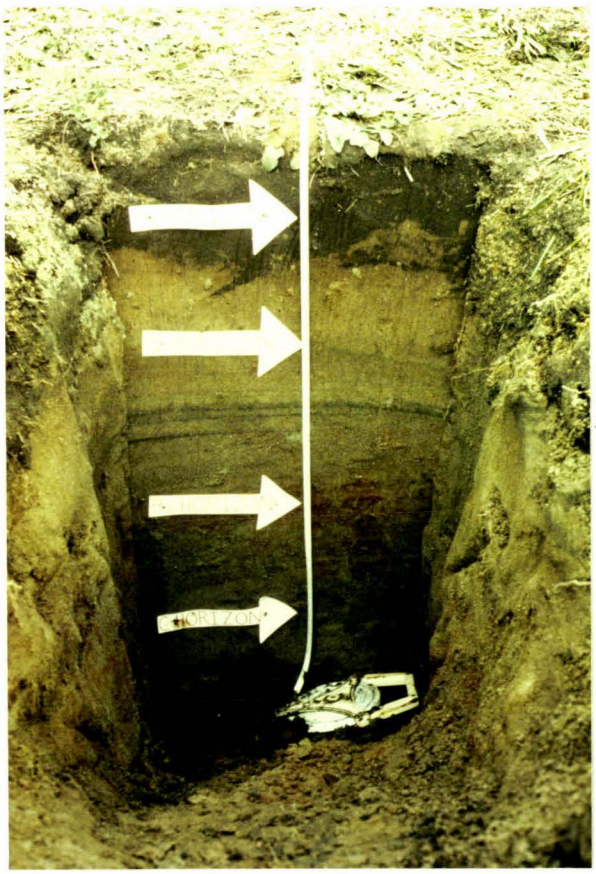


PLATE 2 Soil profile - Puke
Puke black sand

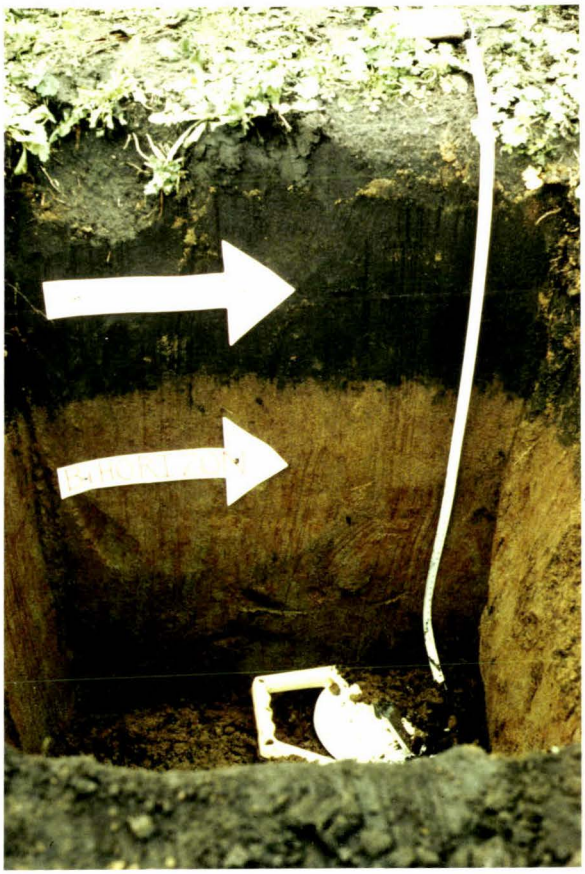


PLATE 3 Soil profile - Intergrade

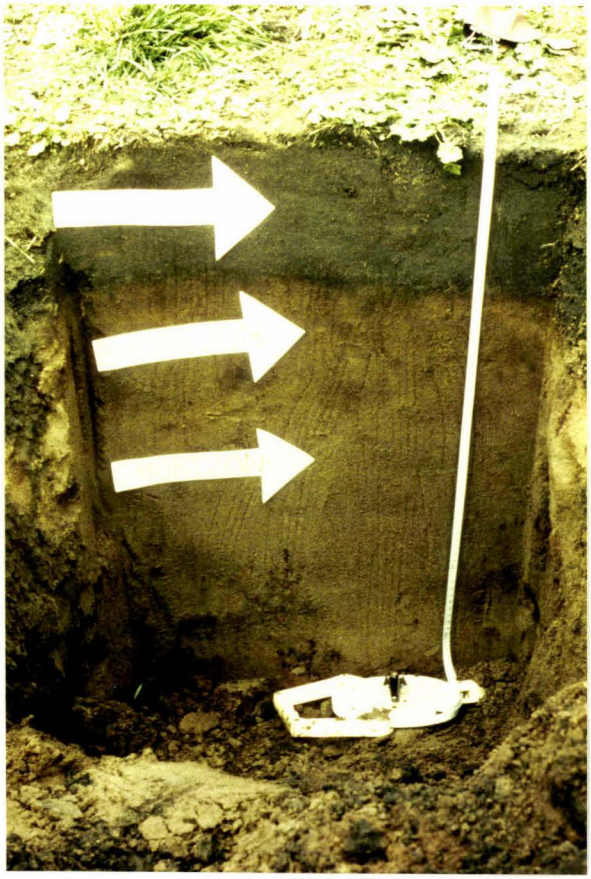


PLATE 4 Soil profile - Motuiti sand

3. Experimental Design.

Each of the two soil types and intergrade were designated as positions within the experimental site. Thus the area of Puke Puke black sand was termed Position I, the area of intergrade was termed Position II and the area of Motuiti sand termed Position III. It was not possible to include equal areas of each position within the experimental site because of the limited areas of the two soil types available. From the experimental layout (see Appendix 1), it can be seen that the experiment was designed as a split plot experiment with positions as a systematic arrangement. The treatments, variety and plant spacing were arranged randomly as nine strips within each of the three replicates. Each strip consisted of only one combination of treatments. The division of each strip into three portions, each covering one position was termed a plot and hereafter will be referred to as such. Thus the effect of wind from the west or north west, as influenced by the shelter belt, will be similar on each plot within a strip but will differ between replicates.

An alternative experimental design was to have all treatments randomised in blocks within each position but this would have entailed headlands between each position. It was decided that the statistical advantages of the alternative were outweighed by the convenience of laying down the trial inherent in the first design and this design was adopted.

4. Site Preparation.

(a) Cultivation.

Cultivation consisted of two rotary hoeing operations to a depth of 5cm. on March 8 followed by two further rotary hoeing operations on April 9. The rotary hoe was used in preference to other cultivation techniques because it allowed a seed bed to be prepared so that the lucerne could be sown before the end of April and the advent of winter. After the second operation, levelling and consolidation of the seed bed was carried out using chain harrows and a Cambridge roller.

(b) Fertiliser.

The fertiliser history of the paddock in which the experimental site was situated consisted of an annual topdressing of 250kg/ha. of superphosphate with no application of lime in recent years. Ministry of Agriculture and Fisheries "quick test results" indicated a pH of 5.7, Ca of 5, K of 5 and P of 13 for Puke Puke black sand and a pH of 5.7, Ca of 7, K of 6 and P of 26 for the Motuiti sand. Thus according to During (1972) the phosphate status of the soils ranged from high to very high while the potassium status

of the soils was medium. In order to raise the potassium status of the soil and to ensure that adequate soil phosphate would be available for the duration of the experiment, 740kg/ha. of 30% potassic superphosphate was applied. Since a pH of 6.0 - 6.5 is considered essential for lucerne establishment (Duder and Scott, 1970), 2460kg/ha. of lime was also applied. During (1972) claims that on most sandy soils, 2460kg/ha. of average quality lime shifts the soil pH by 0.6 to 1.0 units in the top 7.5cm. Both dressings were applied with a Vikon spreader on April 9 and incorporated into the soil with a rotary hoeing operation.

(c) Weed Control.

On April 9, Treflan was sprayed on to the experimental site at a rate of 2.8 litre/ha. active ingredient in 500 litres of water for pre-emergent weed control. This was incorporated into the soil with a rotary hoeing operation.

(d) Insect Control.

On May 24, leaf damage believed to be due to the actions of Spring-tail (Sminthurus viridis L.) was noticed and the crop sprayed with Dyzol 80 at a rate of 142ml of active ingredient in 54 litres of water.

5. Seed Preparation.

(a) Source.

The Wairau and College Glutinosa lucerne seed was commercial lucerne seed supplied by Hodder and Tolley, Ltd. The C.R.D. Suckering lucerne seed was supplied by Crop Research Division, DSIR, Lincoln. These three varieties were selected because of their contrasting root system and growth forms.

(b) Germination Tests.

Germination tests of the supplied seed were carried out by placing 100 seeds of each variety on moist filter paper and counting the number of seeds that had germinated after the seeds had been in growth room conditions for a week. However, as the C.R.D. Suckering lucerne seed only arrived two days before the date of sowing, the results of these tests were not available until after sowing.

(c) Innoculation and Pelleting.

The seed was all 'Rhizocote' innoculated and 'Prillcote' pelleted to give a true pellet which is spherical in shape and 1.5mm in diameter. Tests carried out by the N.Z. Institute of Agricultural Engineering at Lincoln showed that when true pelleted lucerne seed was checked through Stanhay test equipment, there were 95% successful single drops, 4% doubles and only 1% misses.

6. Sowing of Seed.

(a) Sowing Method.

The seed was sown on April 30 using a Stanhay Precision Drill. A trial conducted by Fletchers' Lucerne Research Division at Winslow compared similarly pelleted and innoculated seed sown both with a Stanhay Precision Drill and with a conventional Duncan Seedliner at seven times the sowing rate used for the Precision Drill. Results showed both stronger root and foliar devlopment and a 17.02% increase in dry matter prodcution after four months growth when lucerne seeds were spaced to advantage using a Precision Drill as opposed to random distribution using a conventional drill in good working order.

(b) Seed Spacing.

The three varieties were sown at three different intra-row seed spacing; 2.02cm, 9.16cm. and 15.22cm. with a constant 15cm. inter-row spacing which corresponded to sowing rates of 6.88, 1.52 and 0.90kg/ha. seed respectively. The highest seed spacing was selected so as to give a square planting pattern. Although the sowing rate of seed at the lowest seed spacing is below the sowing rate of 10 - 12kg/ha. generally recommended for drilling lucerne (Duder and Scott, 1971), it is still sufficient to give a productive lucerne stand (Palmer, 1971). Furthermore any attempt to increase this sowing rate at the constant row width, would have resulted in overcrowding of plants within the row. The 9.16cm. seed spacing was selected to give an intermediate seed spacing between the two extreme seed spacings.

7. Lucerne Growth Measurements.

(a) Establishment.

On May 31, 1973 initial seedling establishment was determined by counting the number of live lucerne seedlings in a randomly sited one metre square quadrat in each plot. Since Position II (intergrade) was twice the area of either Position I (plain) or Position III (dune), plots in this position were divided into two sub plots of equal area. One quadrat in each sub plot was then measured and the results averaged to give a value for the complete plot. This procedure was continued with all other lucerne growth measurements. All quadrats were marked and plant counts repeated on July 3 and August 16. Recorded numbers of live plants were compared with the number of seeds sown per unit area and percentage establishment data derived. On May 23, 1974 a final plant population count was made using the same method as above but with different randomly sited quadrats.

(b) Nodulation.

Two different types of measurement were used to determine the effectiveness of nodulation of the lucerne plants. On Jun 19, five lucerne seedlings from Position I (plain) and Position III (dune) and ten lucerne seedlings from Position II (intergrade) selected at random from the middle two rows of each plot were carefully lifted from the soil and the number of nodules per seedling counted.

However as effectiveness of nodulation is not necessarily correlated with nodule number o average nodule size but is correlated with nodule weight (Masterton and Sherwood, 1970), the same numbers of lucerne plants were carefully lifted from the soil on September 11 and total dry weights of nodules, roots and tops measured.

(c) Dry Matter Production.

Dry matter production cuts were carried out when young shoots appeared from the crowns of the lucerne plants. These took place on December 5, 1973; February 21, 1974 and April 9, 1974. As a rotary-cut mower was used to cut the sward resulting in maceration of the clippings, separate hand cut herbage samples were required to determine the botanical composition of the sward. This was done by taking five 0.1 m^2 quadrats at random from the middle two rows of each plot. The samples were cut with a shearing handpiece at a height of 5cm. above ground level. The lucerne and weed components were then separated, oven dried at 80°C for 24 hours and weighed.

Total dry matter production was assessed by harvesting a 45cm. wide strip out of the centre of each plot using a rotary-cut mower set at 5cm. cutting height. The green herbage was weighed in the field and one 0.45kg. dry matter sample per plot taken by randomly selecting four subsamples of mown herbage. These samples were weighed, oven dried at 80°C for 24 hours and reweighed dry. After each production cut, the remainder of the sward was mowed to an even height of 5cm. and the herbage discarded off the plots.

(d) Plant Component Measurements.

The roots and tops of five plants in each plot were weighed on September 11, the plants used being those harvested for the nodulation measurements. On February 7, the number of shoots per plant were counted for five plants in each of the 2.02cm. and 15.22cm. plant spacing, Wairau plots in Positions I (plain) and III (dune) and for ten plants in Position II (intergrade).

(e) Effect of White fringed Weevil Larvae on Plant Survival.

During the growth period after the first production cut, substantial plant mortality occured. On inspection this appeared to be due to root damage by white fringed weevil larvae. The nature and extent of this damage was

measured using the following methods.

Firstly, on February 4, lucerne plants in a square metre quadrat placed at random in the centre of each 2.02cm. plant spacing, Wairau and Glutinosa plot were examined and categorised. The categories used were dessicated, partially dessicated and green plants (apparently unaffected).

Secondly, an attempt was made to determine what happened to the above categories of plants over a period of time. Thus five plants of each category in the 2.02cm. plant spacing, Wairau and College Glutinosa plots; the 9.16cm. plant spacing, Wairau and College Glutinosa plots and the 15.22cm. plant spacing Wairau plots were marked with different coloured wires on February 20. It was decided that measurement of this number of plants would give sufficient information on this aspect, without measuring all the plots. On March 6, after the second production cut, these markers were relocated and the plants recategorised according to their condition at that time.

(f) White fringed Weevil Larval Distribution.

From previous reports of the presence of white fringed weevil larvae in the district, it was suspected that larvae may have been present in the experimental site. Thus a survey was carried out on March 14, 1974 to indicate the numbers of larvae in the experimental site before the lucerne was sown. The site was divided into four equal sectors and ten locations within each sector randomly selected. At each location, an iron frame quadrat of area $30.5cm^2$ was placed and the soil within the quadrat excavated to a depth of 20cm. The numbers of larvae present in this volume of soil were recorded in the field.

On March 19, 1973 another larval count was conducted to determine the effects of experimental treatments on larval distribution. This more systematic measurement method consisted of extracting soil cores of 9cm. diameter to a depth of 15cm. sieving the soil in the cores and counting the numbers of larvae in each core. These cores were extracted from the 2.02 cm. and 15.22cm. plant spacing, Wairau plots. Only one variety was included in the measurement because differences between varieties were expected to be small compared with differences between positions and plant spacings. Ten cores were extracted from each plot in Position I (plain) and Position III (dune) and twenty cores extracted from Position II (intergrade). In each plot half the cores were extracted from site where the lucerne plants were severely dessicated. The remainder of the cores were extracted from sites where the plants were apparently unaffected.

8. Climate and Soil Measurements.

8.1 Wind-Speed.

Wind-run was measured using one Casella three-cup W1204/1 anemometer located at the top of the dune on the eastern side of the site at a height of 1.5m above the ground. The anemometer, which recorded culmulative miles of wind-run was read ither once or twice weekly and average wind-speeds in units of kilometres per hour derived from the readings for each period.

8.2 Rainfall.

Rainfall was collected at the same site as wind-run and was measured by a perspex 'Maquis 1000' raingauge and read at the same times as the anemometer. The collection surface was horizontal and 0.5m vertically above ground level.

8.3 Water Table Depth.

Holes were drilled into the water table with a Dutch auger at six positions along the western side of the site and lengths of 3.75cm. diameter drainpipe inserted into the holes. Water table depth was measured by lowering a graduated measuring stick down the pipes and reading the water level weekly from May, 1973 to September, 1973 and twice weekly from September, 1973, to April, 1974. (see Appendix 2 for location of pipes).

8.4 Soil Moisture.

(a) Available Methods of Measurement.

The available methods of soil moisture measurement were limited to gravimetric moisture sampling, tensiometer or gypsum block installation or a combination of these.

(i) Gravimetric Sampling.

Gravimetric sampling would have necessitated a large number of soil samples being taken at regular intervals and thus would have been time consuming especially since it was desirable to measure soil moisture status at depths to where the lucerne roots were expected to grow. Moreover the measurement obtained is not a direct measure of the amount of moisture available to the plant.

(ii) Tensiometers.

Aitchison and Butler, (1951) report that tensiometers only operate satisfactorily in relatively wet soils and they cease to function at pressure deficiencies approaching 1 atmosphere.

(iii) Gypsum Blocks.

Gypsum blocks, although unreliable below approximately 0.7 atmospheres soil moisture tension measure soil moisture status in terms of moisture tension which is directly related to moisture availability to plants. Aitchison

and Butler (1951) report that gypsum blocks operate throughout the tension range in which water is available to plants namely pF 2.4 to 4.2.

(b) Measurement Methods Used.

1. From May 8 to August 27, soil moisture content was measured by taking weekly gravimetric samples at 5cm. soil depths at 36 sites situated so that each plant population and variety were included in the sampling (see Appendix 2). This limited number of samples was considered adequate since over this period the lucerne roots were not expected to have grown below the A horizon of the soils.

2. Gypsum blocks were used to measure soil moisture status from September 10, 1973 to February 21, 1974.

(c) Description.

The blocks used were cylindrical in shape and consisted of two tinned lengths of bared flex set parallel in a matrix of dental plaster. The blocks were 7cm. in length and 2cm. in diameter and were manufactured according to the procedure outlined by Aitchison et al (1951) (see Appendix 8 for details).

(d) Measuring Sites.

Three gypsum blocks were installed at each of the twenty-four measuring sites; the blocks being buried at 10, 30 and 90cm. (measured perpendicular to the ground surface). As can be seen from Appendix 2, there were eight measuring sites in each replicate. Each set of eight sites was in a strip of three plots of Wairau lucerne at a different inter-plant spacing. The two sites within each plot were selected at random. The three soil depths were selected as giving reasonably full coverage of the moisture conditions in the rooting zone of lucerne of one years growth, also giving a measurement in each horizon of the soil profile.

(e) Installation.

All blocks were lowered down one 8.8cm. diameter hole made by a Dutch Auger at each site and the soil cores taken from the holes carefully replaced. The leads from the three blocks at each measurement site were buried in the soil and the free ends connected to a socket board located on the top of the site.

(f) Block Measurement.

The electrical resistance of each block was measured using a portable meter on each measuring day. The meter was a battery powered, A.C. operated Wheatstone bridge with a capacitance balance and a microammeter for visual null-point determination. The instrument was constructed from the circuit diagram for the 'type B' meter described by Aitchison et al (1951). Two leads with terminal banana plugs were attached to the meter and these were plugged into the socket board mentioned above when reading the resistance of the

gypsum blocks.

(g) Block Calibration.

(i) Available Methods.

Aitchison et al (1951) suggest that block resistances can be calibrated in the laboratory or in the field.

(ii) Field Calibration.

Field calibration consists of simultaneous resistance and moisture measurements with sufficient replication of each determination to provide the necessary degree of accuracy. As most soils are vaiable either in texture or structure, a large number of random moisture samples is required for accuracy.

(iii) Laboratory Calibration.

Bouyoucos and Mick (1940) suggested that block resistances could be calibrated in the laboratory in terms of the water content of the soil. Kelley (1944) proposed a rapid method of measuring block resistances in small blocks of soil contained in perforated metal boxes. Such a technique appears to be limited to soils which do not possess a well defined structure which may deteriorate with handling or wetting. Although poor results are obtained with many clay soils, in lighter textured soils with water structure, Aitchison et al (1951) considered that Kelley's method is satisfactory if care is taken to ensure that equilibrium resistances only are accepted.

The other method of laboratory calibration is that carried out in the pressure membrance apparatus. Gypsum blocks are embedded in the soil and electrical connections through the walls of the chamber permit simultaneous determinations of resistance, water content and effective tension in the soil water. Aitchison et al (1951) found that the laboratory calibration curve determined with this technique is a reasonable representation of the resistance-water content relation existing in the natural soil. However in order to ensure that a suitable number of replicate blocks is properly embedded in a sufficient mass of soil, it is necessary to have such a large soil mass that the time taken to attain resistance and water content equilibria at each successive increment of tension may be as great as 30 days. Thus one series of observations covering the whole available moisture range may extend over a period of from 2 to 6 months.

(iv) Calibration Method Chosen.

Due to the limited time available for calibrating the blocks and the light texture and weakly developed structure of the soils involved it was decided to calibrate the block resistances in the glasshouse in terms of the moisture content of the soil.

Representative soil samples were taken from the three depths where the blocks were sited from each of the two soil types and the intergrade, that is the three positions in the experimental site as defined previously. Nine wooden boxes (45cm. x 30cm. x 9cm.) were weighed empty and each filled with 13.5kg of the samples. Several gravimetric sub samples were taken from each sample to determine the dry weight of the dry weight of the representative samples. The appropriate blocks as situated in the field were weighed dry and buried in their respective box. The soil in each box was then completely saturated and allowed to drain overnight.

Subsequently, at regular intervals, block resistances and soil weights were measured simultaneously as the soils lost moisture through evaporation from the surface. As gypsum blocks are unreliable below soil moisture tensions of 0.7 atmospheres, (Aitchison and Butler, 1951), block resistance readings fluctuated for a period of a week until a steady increase in block resistance with loss of soil weight was recorded. This point was taken to represent the extreme at the wet end of the scale where reliable block readings could be taken.

To give an indication of the block resistance range over which plant wilting occured cauliflower plants were transplanted into each box and used as indicator plants.

The moisture status of the soils was taken from field capacity to a point that was well past wilting point. Lamber (1973) demonstrated the size of errors which may arise from hysteresis effects when using a calibration curve derived in the laboratory during the drying phase of a soil, to interpret measurements made in the field during both wetting and drying phases. However, calibrating the blocks during a soil wetting-up phase was considered of very limited use because in the field it is difficult to judge whether the soil and blocks are wetting up or drying out at any one instant without intensive investigations. Furthermore, the soil moisture characteristic curves used (see below) were derived during a drying phase only.

(v) Interpretation.

As it is desirable to measure soil water status in terms of soil moisture tension, soil moisture content/soil moisture tension data was obtained from M.W. Gradwell, Soil Bureau, DSIR, Lower Hutt for Puke Puke black sand, one of the soiltypes on the experimental site and Foxton black sand which is closely related to Motuiti Sand in its soil physical properties as given by Cowie et al (1967) and soil moisture characteristics curves plotted (see Appendices 5 and 6).

It should be noted that these soil moisture characteristic curves are only for representative soil profiles of the two soil types and would only

approximate the relationship on the experimental site. For interpretation purposes, the intergrade site position was split in two, the upper half being regarded as similar to the dune soil and the lower half similar to the plain soil.

(vi) Calibration Drift.

Aitchison and Butler (1951) report that where blocks of the same type are considered, differences in block resistance persist in the same order throughout the sensitive range of the units. As a block resistance/soil moisture content relationship was derived for each block and used for each reading in the field no correction for individual block differences was considered necessary.

However in order to determine whether any calibration drift had occured all of the blocks that were used in the field were oven dried at 40°C for twenty-four hours, soaked in water for the same period and following a five minute drip period, block resistances were measured. This procedure was carried out at both the beginning and end of the experimental period. This calibration check showed that drift in tension values measured for the blocks ranged from +0.2 to +0.8 atmospheres with an average of +0.5 atmospheres but no attempt was made to correct for this drift.

(vii) Temperature Correction.

Due to lack of any reliable soil temperature data, no temperature correction of the resistance blocks could be carried out and thus the data presented include error from this source. It was considered that the major soil temperature differences would be between soil depths rather than measuring sites within the experimental site.

8.5 Soil Temperature.

It was originally intended to measure soil temperatures using the method of measurement used by Lambert (1973). Since mains electric power could not be supplied to the site due to the high cost involved, an attempt was made to run the recording system used by Lambert (1973) with an invertor and two 12V batteries. However the batteries could not supply sufficient power to run the recorder for more than a short period. A more modern transistorised recorder was adapted for the system but the same problems recurred and this aspect of the experiment was finally abandoned.

8.6 Soil Organic Matter.

On April 29, 1974, soil samples were taken at each soil moisture measuring site at 10cm. and 30cm. soil depths. Since the organic matter content at 90cm. soil depth was expected to be negligible and would not vary greatly within the experimental site, only two samples were taken at this depth. Soil organic matter content was determined using the following pro-

cedure. Water was first driven off at 110°C for 12 hours and 10g. of dry soil heated in a furnace for eight hours at a temperature of 400°C (Hesse, 1971). The sample was then reweighed and the loss in weight taken as equivalent to the soil organic matter. Ball (1964) claims that this ignition method gives an estimate, sufficiently accurate for most purposes, of organic matter in non-calcareous soils.

8.7 Soil Nutrient and pH Tests.

On May 30, 1973 ten soil samples were taken to a depth of 7.5cm. from each half of the experimental site and analysed by the Research Division, Ministry of Agriculture and Fisheries, Ruakura. This was repeated on May 6, 1974.

(B) GLASSHOUSE EXPERIMENT.

1. Objective.

The objective of this experiment was to further investigate differences in the effect of white fringed weevil larvae on lucerne plants within the experimental site. This was done by growing lucerne in the glasshouse under different soil moisture and larval population conditions.

2. Soil Preparation.

On March 10, 1974, a quantity of topsoil of Motuiti sand was collected from an area adjacent to the experimental site. The soil was sieved to remove any white fringed weevil larvae present and thoroughly mixed. Thirty-eight wooden boxes (30 x 30 x 12cm.) were weighed empty and each filled with 30kg of soil. Several gravimetric soil samples were taken to determine soil moisture content of the soil at that point and thus derive the dry weight of the soil.

3. Lucerne Growth.

On March 13, 1974, mini-pelleted Wairau lucerne was hand sown to a depth of 1cm. in two rows in each box. The seed was sown at 2cm. spacings with a spacing of 15cm. between rows, that is similar to the lowest inter-plant spacing used in the field experiment. The seed was found to have a 70% germination capacity. To give complete rows, lucerne seedlings of similar age were transplanted into sites where seeds had not germinated. For the first two months until the experimental treatments were imposed, the lucerne was grown at a 25°C day/20°C night air temperature regime and watered every

second day. All boxes were hand weeded and sprayed with malthion at regular intervals to control insect pests such as slaters which were damaging the plant leaves. The two rows in each box were partitioned by sheet metal to provide two 'plots' per box (see below).

4. Experimental Design.

The boxes were arraned in the glasshouse in six blocks of six boxes (see Appendix 15 for experimental layout). Each block consisted of two split plots on the basis of soil moisture level. Within each split plot, the three white fringed weevil larval populations were arranged systematically. As each box was divided into two 'plots' of equal initial larval population, the treatments were replicated within each block. Two boxes were used to carry out a parallel study of plant growth under the two soil moisture levels in the absence of larvae.

The soil used in the experiment was relatively homogenous due to thorough mixing, the lucerne plants were similar in size since they had been grown from common seed and the environmental conditions in the recently constucted climate controlled glasshouse could be assumed to be uniform over all the boxes. Thus any statistical advantages in arranging treatments at random within the split plots were considered to be outweighed by the ease of conducting the experiment under the experimental design used.

5. Larval Population.

Three different white fringed weevil larval populations; 1 larva, 2 larvae and 4 larvae per plot were used. These particular populations were chosen because the larval survey carried out on 14.3.73 showed this range of larvae numbers within a similar volume of soil. The larvae used in the experiment were collected from the experimental site. Due to the time that would have been involved in collecting larvae of the same individual weight, the initial weights of larvae used in the experiment covered a range of 40 to 110mg. It has bee reported (Steven, pers. comm., Gross et al, 1972) that larval body weight may be an important factor in the feeding activity of the larvae. Thus the larvae were individually weighed and allocated as shown in Table III.11 so that valid comparisons could be made between wet and dry soil moisture treatments both at one initial larval population and totally over the three initial larval populations. However there are differences in individual larva weight range between different initial larval populations within one soil moisture level. This method of allocation of

larvae thus introduces a complicating factor in comparisons between certain treatments. However this could not have been completely avoided no matter which method of allocation was used. After weighing, the larvae were placed just beneath the soil surface at regular intervals alongside the lucerne plants.

6. Soil Moisture.

Two different soil moisture levels; 20% and 10% of dry soil weight were used in the experiment. Rumball (pers. comm.) found that field capacity in the top 12.5cm. of Motuiti sand was at 27% of dry soil weight. The soil moisture characteristic curves supplied by the DSIR Soil Bureau showed that wilting point (assumed to be at 15 atmospheres soil moisture tension) at 12.5cm. soil depth in a similar soil was at 8.0% of dry soil weight. Thus the 10% soil moisture level was chosen to impose a soil moisture stress on the plants without mortality of plants and the 20% soil moisture level chosen as being unlikely to stress plants significantly. Each box was weighed on platform scales every second day and the necessary weight of the box and its contents to give the appropriate soil moisture level made up by the addition of water uniformly over the soil surface. Gravimetric samples taken from each box halfway through the experiment showed that this method gave soil moisture levels very close to the desired levels.

7. Experimental Measurements.

(a) Interim Measurements.

During the course of the experiment, the plants were individually inspected every second day. The location of any plant which was dessicated so severely as to be assumed dead was recorded.

(b) Final Measurements.

In order to have some plants remaining in all plots at the end of the experiment the experiment was terminated on June 24 and final measurements made over the next four days. These included:-

1. Individual top and root fresh weights of all surviving plants.

2. Bulking roots and tops for each plot and determining a mean dry weight.

3. Numbers and individual weights of surviving larvae in each plot.

4. Total dry weight of root material present in the soil in each plot after the plants had been extracted.

(C) STATISTICAL METHODS.

1. Field Experiment.

1.1 Climatic and Soil Measurements.

The climatic and soil measurements were not statistically analysed. This was for two reasons:

(i) Much of the measured data did not involve sufficient replication to enable satisfactory statistical analysis.

(ii) It was judged that graphical or tabular presentation adequately expressed the differences noted.

1.2 Lucerne Growth Measurements.

Establishment and dry matter production measurements were all analysed by regression using the BAR III computer programme on the Massey University I.B.M. 1620 computer. The computer was used in preference to a programmable calculator because of the shorter time involved especially since missing data was due to an error at sowing such that the observations for one entire strip of three plots had to be disregarded when establishment and dry matter production data was considered.

The field experiment was of a split-plot design with positions arranged systematically and treatments arranged in strips across each replicate (see Appendix 1) as described by Cochran and Cox (1966) on page 305. The schematic analysis of variance for this design is given below:

	d.f.
Replicates (R)	2
Positions (P)	2
Error (a) (RxP)	4
Treatments (T)	5
Error (b) (TxR)	10
T X P	10
Error (c) (TxRxP)	20

Error mean square (b) is appropriate for testing hypotheses about treatment differences and error mean square (c) is appropriate for testing hypotheses about (TxP) interactions. Since positions can not be randomised, it is not possible to perform strictly valid statistical tests of significance relating to the effect of positions. However, where differences between position effects are large, tests of hypotheses about position differences may be attempted using error (a) but the estimate of probability for position effects will be biased.

The absence of data for the three plots resulted in a loss of one

degree of freedom in the estimate of error (b) and two degrees of freedom in the estimate of error (c). When the data was processed through the computer using single precision arithmetic, large rounding-off errors occured. The analysis was then attempted using double precision arithmetic but it was found than an excessive amount of computer time was required. Missing values were then estimated by successive approximation. The values for missing data in two of the plots were approximated and the standard missing value procedure used by the computer to calculate the value for the missing data in the third plot. Using this calculated value, the standard missing value procedure was used to estimate a value for the missing data in one of the other two plots. Both calculated values were then used to estimate a value for missing data in the remaining plot. Thereafter, the standard missing value procedure was then applied to the calculated values until they all remained relatively constant.

Using these values for missing data, tests of significance were then performed for some selected dependent variables using both error (b) and error (c) but the procedure was found to be time consuming. Errors (b) and (c) were then combined and this analysis was compared with the analysis using separate estimates of error. It was found that combining the errors tended to reduce the F values slightly but not enough to change the level of significance of treatment differences. Thus this method of analysis was used for all establishment and dry matter production data.

Although they did not involve any missing data, nodulation and plant component measurements were also analysed using the computer.

The percentage establishment data and all measurement ratios were analysed using an arc sine root proportion transformation as described by Winer (1971) on page 397 but this gave similar results to those derived when untransformed data was analysed. Since it is simpler to translate, this data is all presented in the untransformed form.

Other lucerne growth measurements which did not involve all plots were analysed using analysis of variance for a split-plot design as in Snedecor and Cochran (1967) on page 371.

2. Glasshouse Experiments.

This experiment was also analysed using the analysis of variance for a split-plot design as in Snedecor and Cochran (1967) on page 371.

3. General.

In all results, when the F test indicated that the null hypothesis was

rejected at the 1% or 5% level of significance, least significant differences (L.S.D.) for comparisons between treatment means are shown in each table. Least significant differences for comparisons between position means are shown in Table III.5. Levels of significance are indicated in tables with * for significance at the 5% level and ** for significance at the 1% level.

Chapter III: Results.

(A) FIELD EXPERIMENT.

1. Climate and Soil Measurements.

(a) Wind-Speed.

Wind speed over the period 8.5.73 to 4.4.74 is shown in Figure III.1.

(b) Rainfall.

Rainfall over the period 1.5.73 to 4.4.74 is shown in Figures III.4, III.5 and III.6, in conjunction with soil moisture tension.

(c) Water Table Depth.

Mean monthly water table depths are shown for June, 1973 to September, 1973 when the water table was rising in Figure III.2 and for October, 1973 to March, 1974 when the water table was falling in Figure III.3. A full table of measurements is given in Appendix 3 to show the fluctuations in water table depth that occured within months.

(d) Soil Moisture Tension.

Soil moisture tension at 0-5cm. soil depth fo the period 1.5.73 to 3.9.73 is shown in Figure III.4. Soil moisture tension at 10cm. and at 30cm. soil depths for the period 3.9.73 to 21.2.74 are shown in Figures III.5 and III.6. Soil moisture tension measurements from 21.2.74 to 15.3.74 are not presented due to the resistance meter being out of operation during this period.

As there was little variation in soil moisture tension at 90cm. soil depth between the three positions these measurements are not graphed but shown in tabular form in Appendix 4. No attempt was made to show differences in soil moisture tension between plots at different interplant spacings because no clear pattern was evident. This would be due to the differences in the numbers of both lucerne and weed plants in the vicinity of each measurement site and the insufficient number of measuring sites available in each plant population.

(e) Soil Nutrient and pH Tests.

Soil test results for soil samples taken on 30.2.73, 30.5.73 and 6.5.74 shown in Table III.1.

(f) Soil Organic Matter.

Soil organic matter results are summarised in Table III.2, as mean values for each position. The soil organic matter content at each measurement site is shown in Appendix 7 which is drawn to scale.

FIGURE III.1. WIND–SPEED: WEEKLY AVERAGES MAY, 1973 TO APRIL, 1974

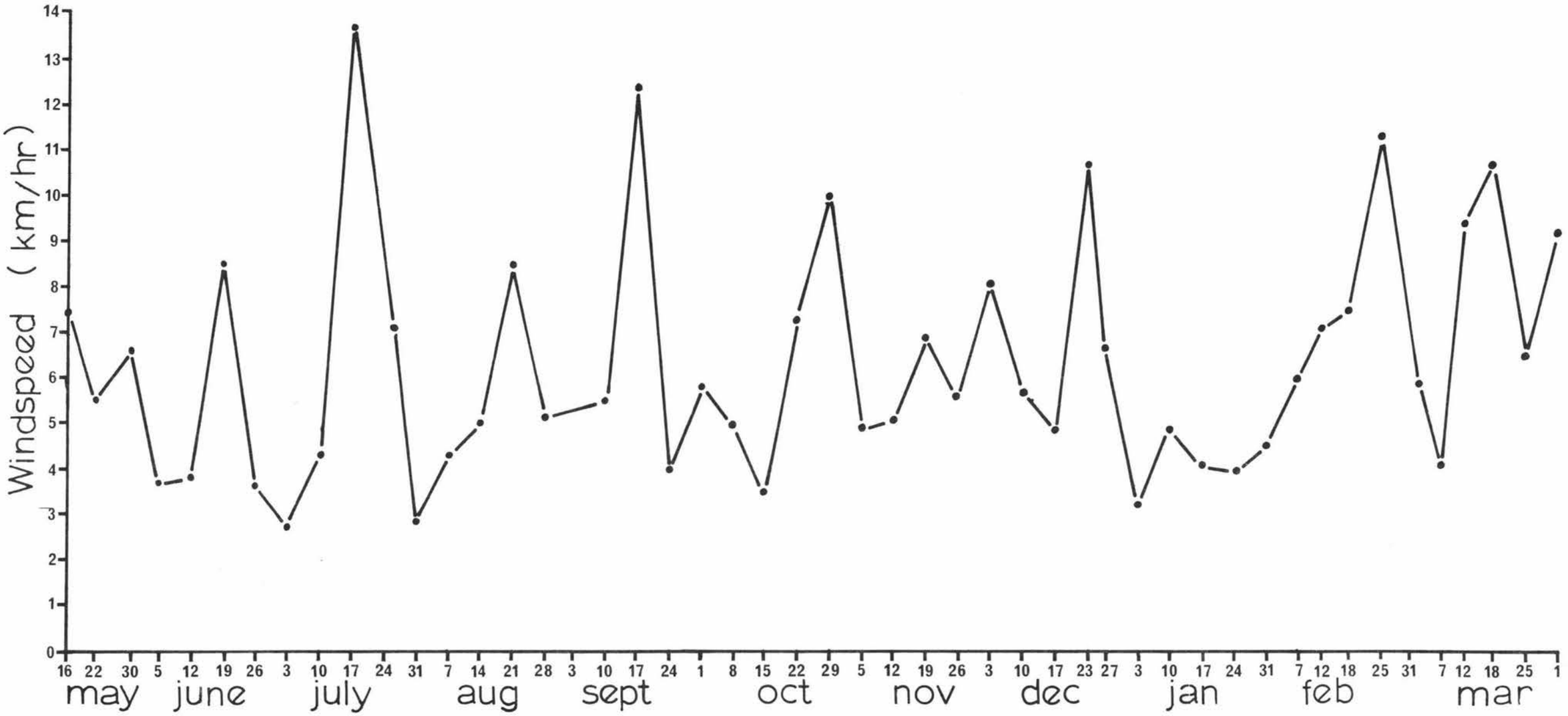


FIGURE III.2. MEAN MONTHLY WATER TABLE DEPTHS (cm BELOW SOIL SURFACE) : MAY, 1973 TO SEPTEMBER, 1973

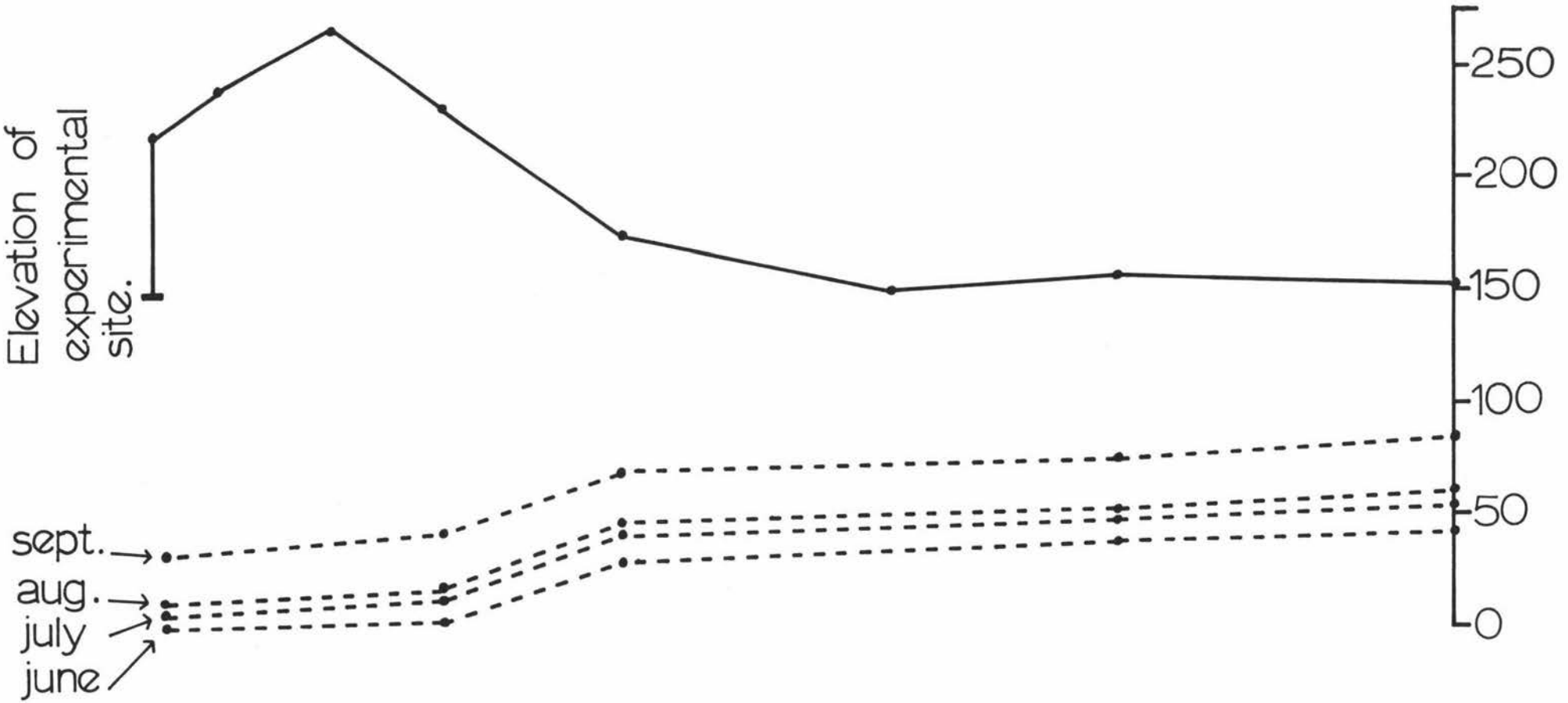


FIGURE III.3. MEAN MONTHLY WATER TABLE DEPTHS (cm BELOW SOIL SURFACE) : OCTOBER, 1973 TO MARCH, 1974

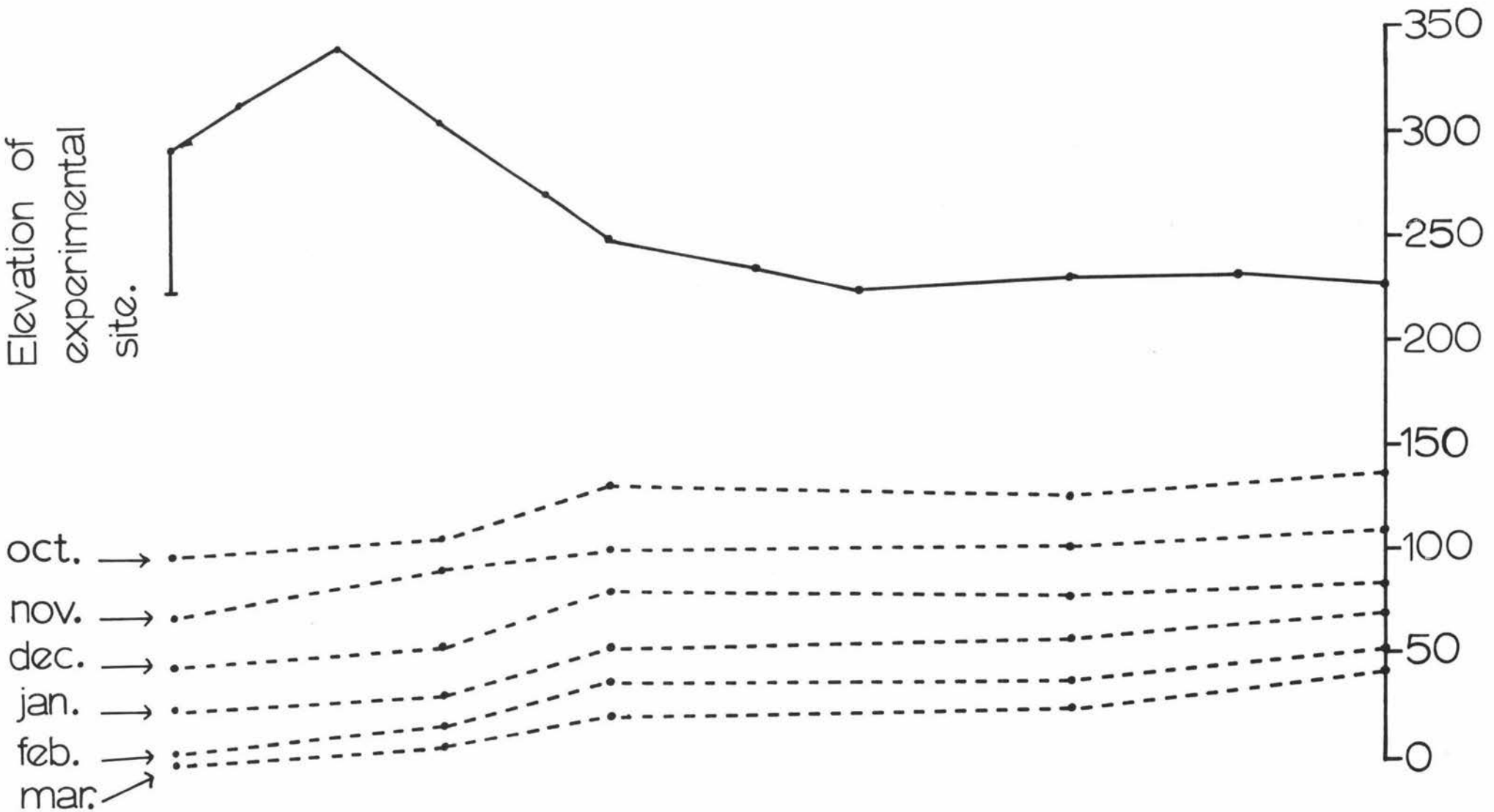


FIGURE III.4. SOIL MOISTURE TENSION AT 5cm. DEPTH: MAY, 1973 TO AUGUST, 1973

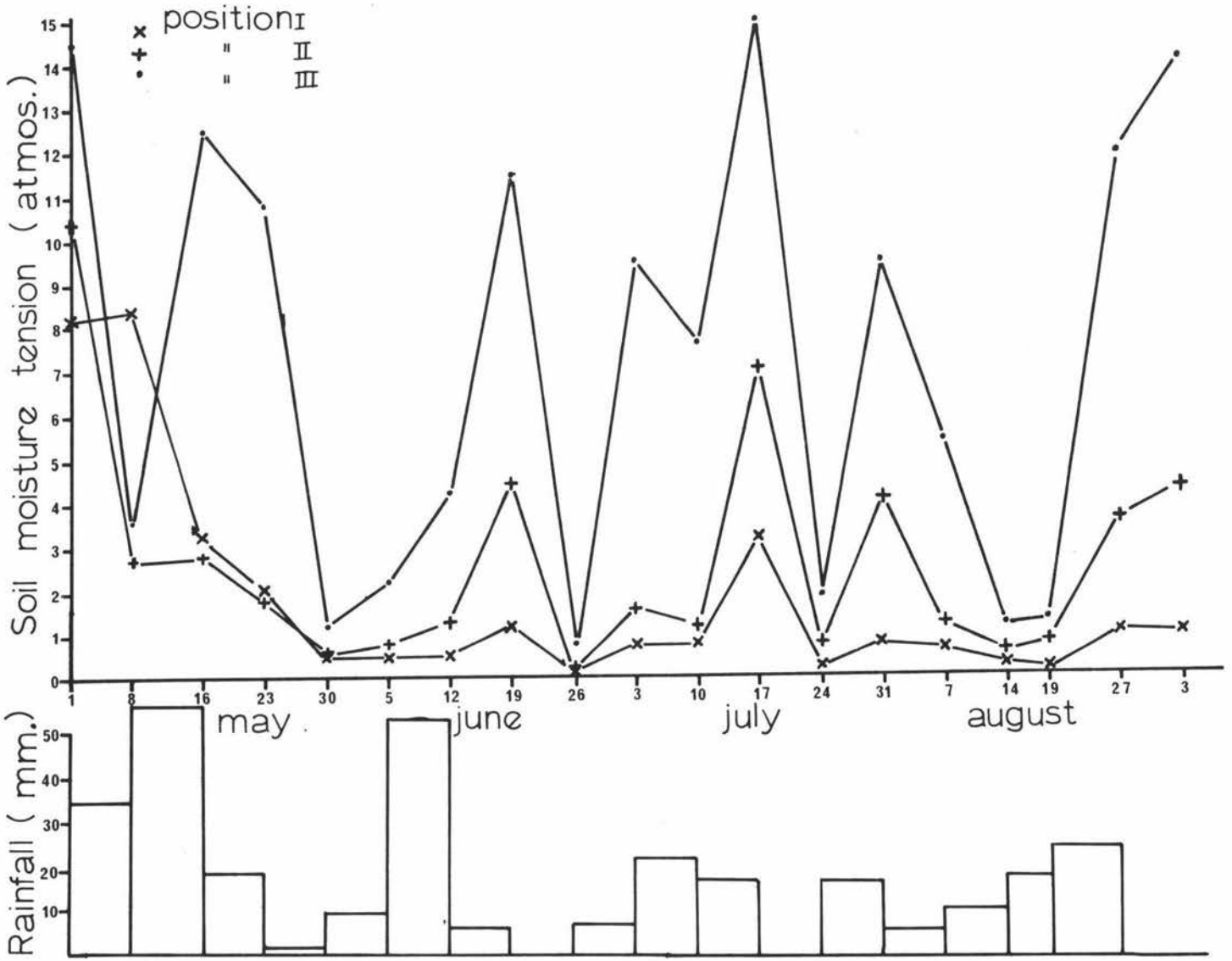


FIGURE III.5 SOIL MOISTURE TENSION AT 10cm. DEPTH : SEPTEMBER, 1973 TO APRIL, 1974

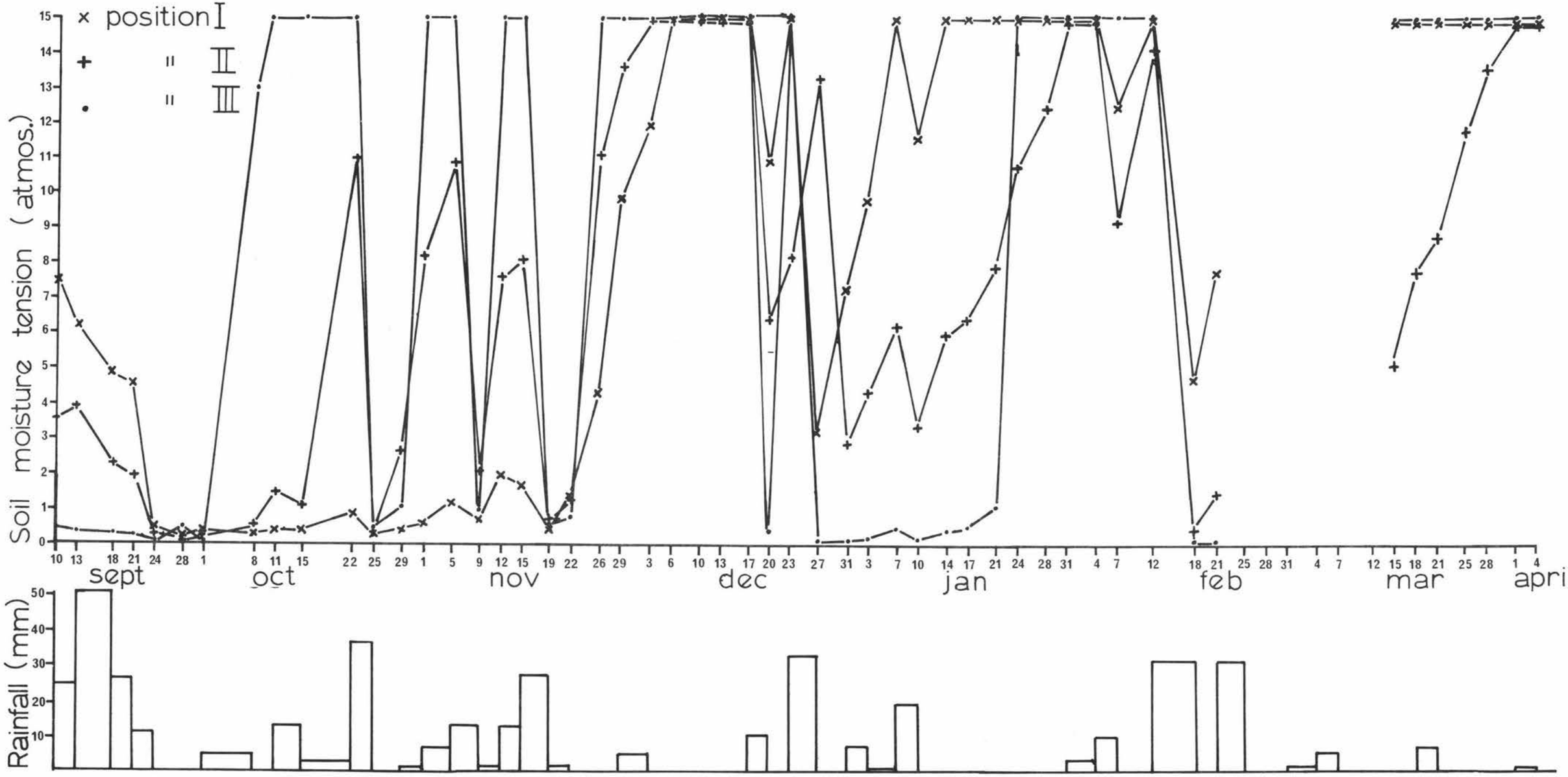
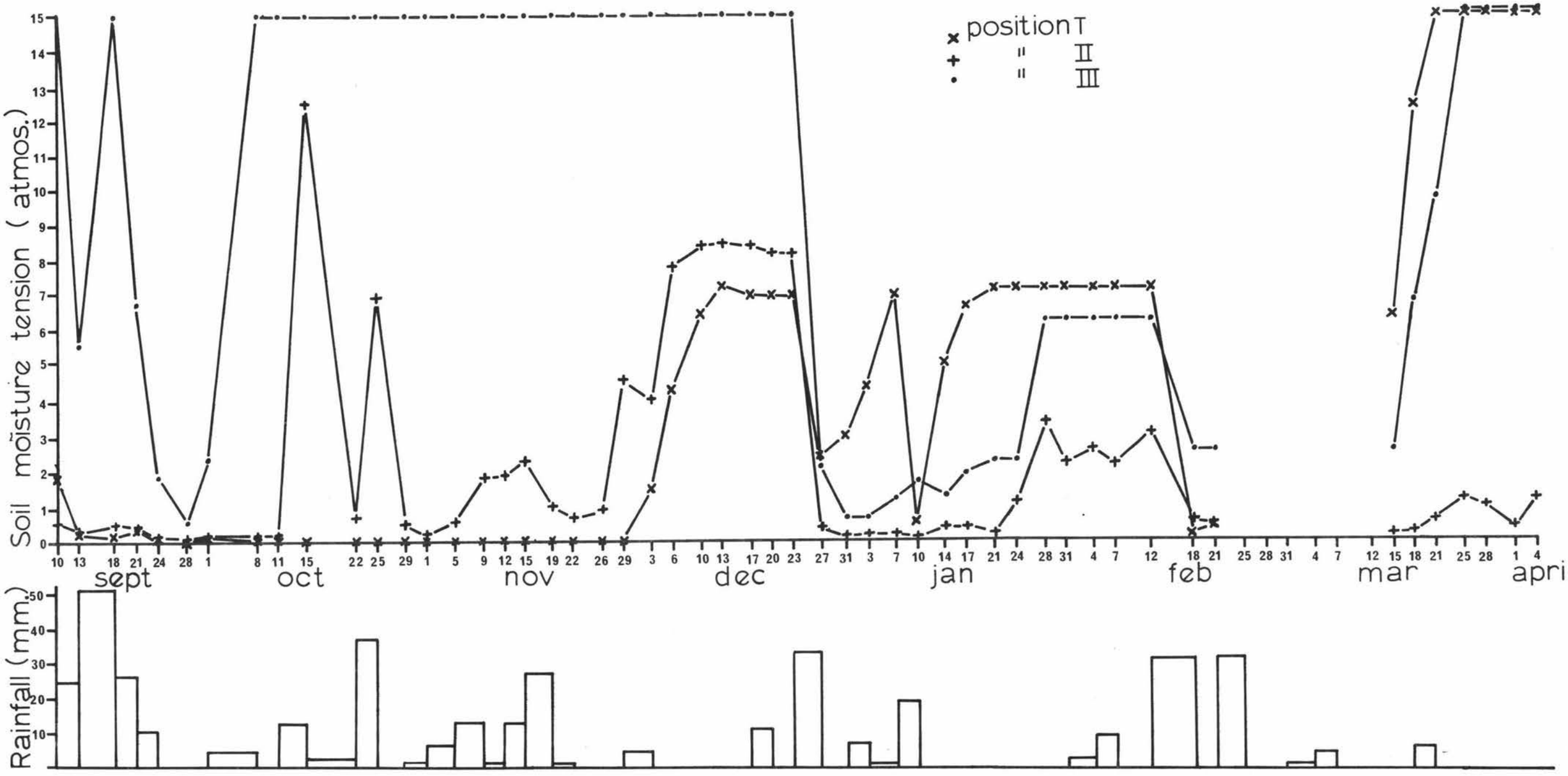


FIGURE III.6 SOIL MOISTURE TENSION AT 30cm. DEPTH : SEPTEMBER, 1973 TO APRIL 1974



2. Lucerne Growth Measurements.

(a) Seed Germination.

Seed germination percentages determined in the laboratory for each variety are shown in Table III.3.

(b) Establishment.

Since the Wairau and College Glutinosa seed used in the experiment had very similar high laboratory germination percentages, percentage establishment was derived from expressing the number of lucerne plants counted as a percentage of the number of seeds sown. Due to the low germination percentage of the C.R.D. Suckering seed used in the experiment, percentage establishment measured at 31.5.73 was very low compared with the other two varieties. As the large differences in the number of plants established at one inter-plant spacing made comparisons between C.R.D. Suckering and the other two varieties unrealistic, no further lucerne growth measurements for this variety were taken.

In Table III.4, the significance levels at which differences between means occur are shown for the four establishment measurement dates. Since there were no significant differences between interactions (treatment x position and variety x plant spacing), the position and treatment means for each measurement are shown in Tables III.5, III.6 and III.7. Least significant differences are also shown in each Table where significant differences between position and treatment means occur. The percentage establishment of lucerne plants in each plot at the four measurement dates is shown in Appendix 19. The change in plant number per square metre with time after sowing is shown at each plant spacing in Figure III.7 and for each position in Figure III.8.

(c) Plant Component Measurements.

The shoot, root and plant dry weight and shoot/root ratio for a total of five plants in each plot is shown in Tables III.5, III.6 and III.7 and Appendix 10. The mean number of shoots per plant measured for a total of five plants in each plot is shown in Tables III.5 and III.6.

(d) Nodulation.

The nodule number, nodule dry weight and the nodule dry weight as a ratio with shoot, root and plant dry weight for a total of five plants in each plot is shown in Tables III.5, III.6 and III.7.

Measurements of nodule number and nodule dry weight for a total of five plants in each plot is shown in Appendix 10.

(e) Dry Matter Production.

The production cut which was scheduled for the end of October was lost

when cattle broke into the experimental site on October 18 and grazed the stand.

Dung was removed from the experimental site without damaging the lucerne and the area mowed to a constant height of 5cm. with a rotary mower. However urine patches still remained and this could have introduced an error into later dry matter production results. Lucerne dry matter, weed dry matter and total dry matter production at each production cut is shown in Appendix 11.

(f) Effect of White fringed Weevil Larvae on Lucerne Survival.

The percentage of dessicated plants per square metre measured at 4.2.74 for 2.02cm. inter-plant spacing Wairau and College Glutinosa lucerne is shown in Tables III.5 and III.7.

The recovery of the three categories of lucerne plants after the second production cut is shown in Table III.8.

The effect of position on the recovery of the lucerne plants categorised as partially dessicated is shown in Table III.9.

(g) Distribution of White fringed Weevil Larvae.

The distribution of larvae as measured at random sites within the experimental site at 14.3.73 is shown in Appendix 14. The numbers of larvae at each apparent level of infestation in the 2.02cm. and 15.22cm. inter-plant spacing Wairau plots are shown in Table III.10.

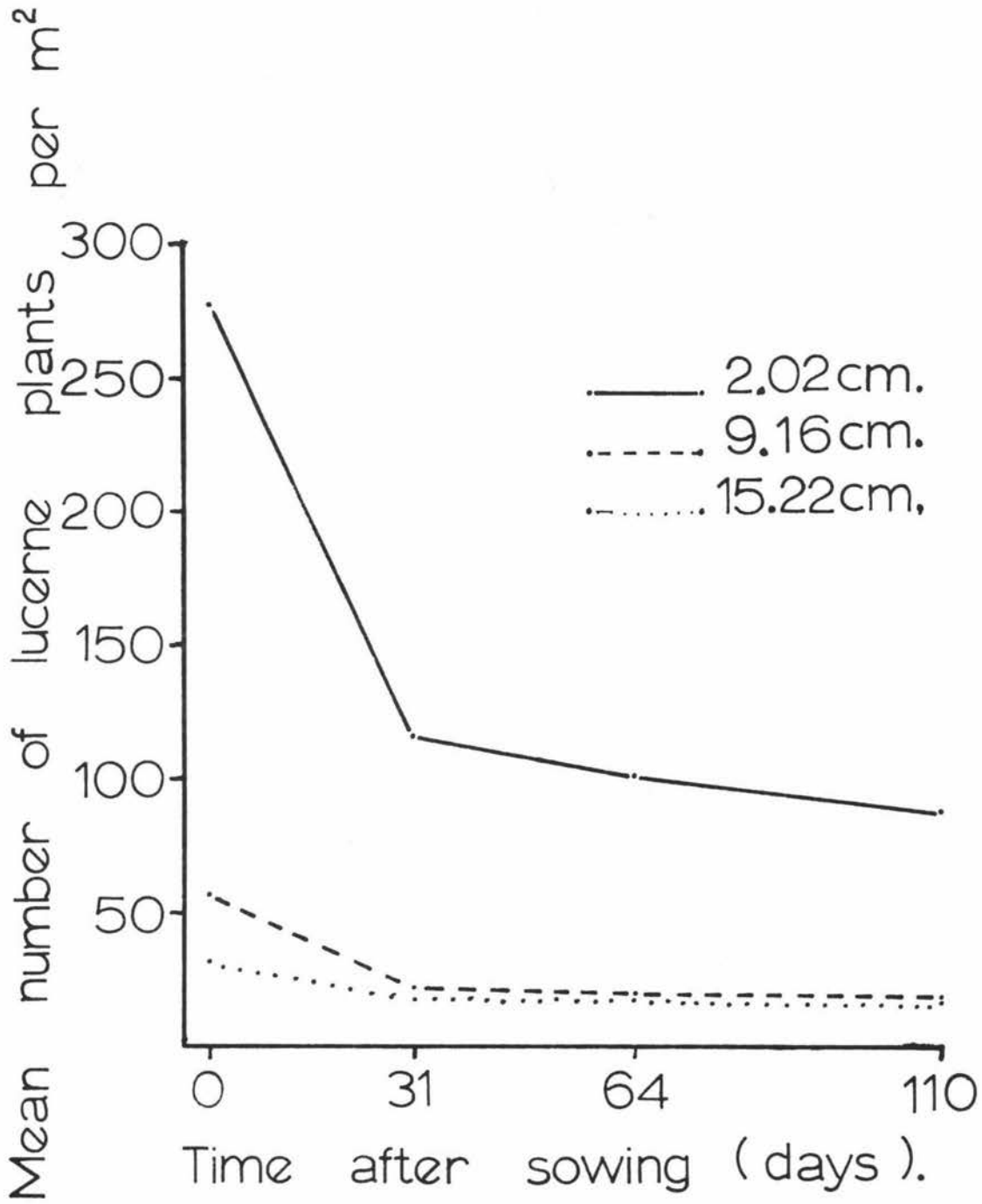


FIGURE III.7 MEAN NUMBER OF LUCERNE PLANTS PER SQUARE METRE AT EACH SPACING PLOTTED AGAINST TIME AFTER SOWING

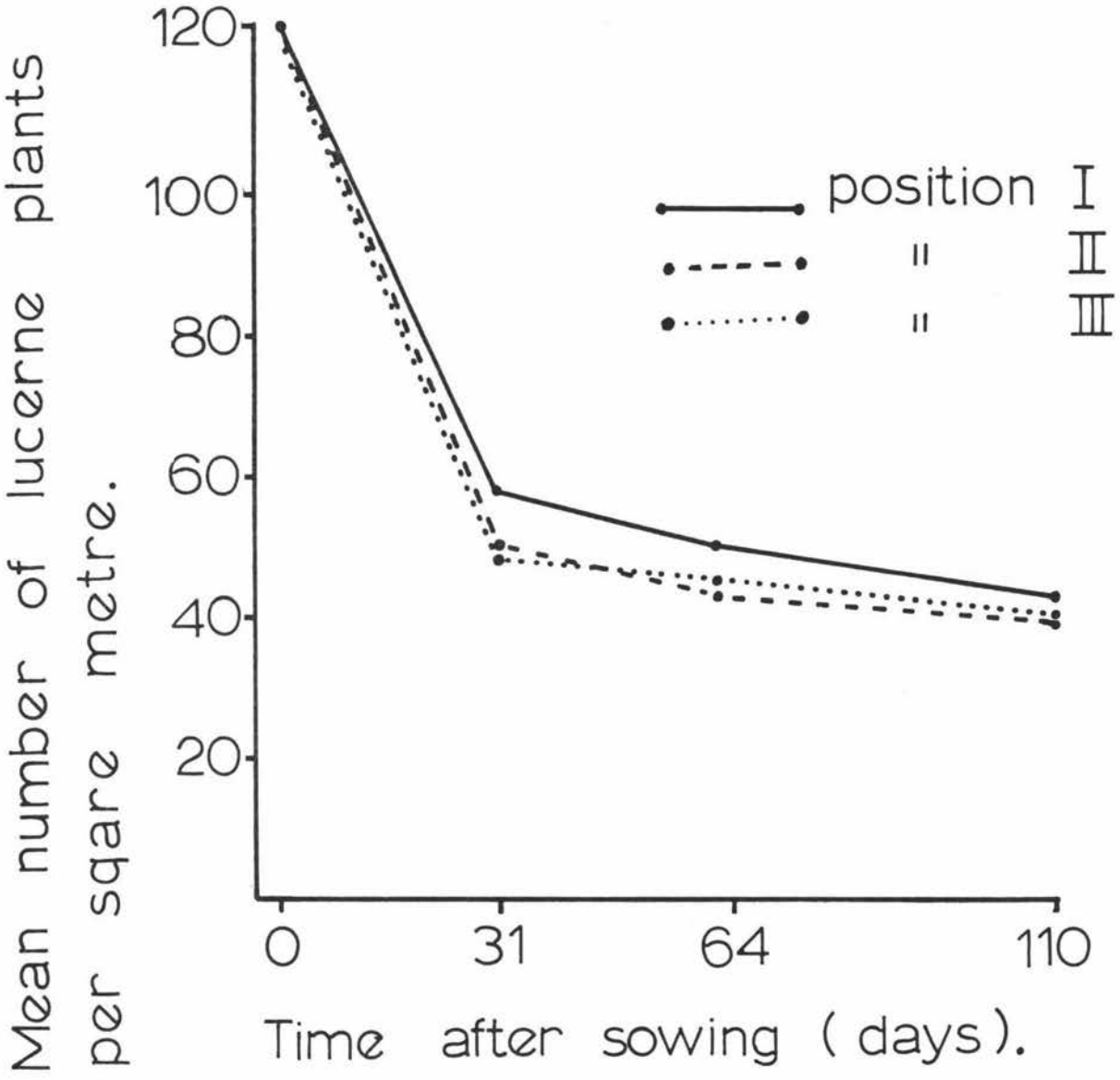


FIGURE III.8. MEAN NUMBER OF LUCERNE PLANTS PER SQUARE METRE IN EACH POSITION PLOTTED AGAINST TIME AFTER SOWING

TABLE III.1. Soil Nutrient and pH Tests.

Date	Soil Type.	Quick Test Analyses. pH	Ca	K	P
30.2.73	Puke Puke black sand	5.7	5	5	13
	Motuiti sand	5.7	7	6	26
30.5.73	Puke Puke black sand	6.1	7	8	22
	Motuiti sand	6.2	7	8	27
6.5.74	Puke Puke black sand	6.1	9	7	15
	Motuiti sand	6.3	10	9	24

TABLE III.2. Mean Percentage Soil Organic Matter Content.

Position	Soil Depth	
	10cm.	30cm.
I	5.86	2.45
II	5.77	3.65
III	3.58	2.35

TABLE III.3. Laboratory Seed Germination Percentage.

Variety	Germination Percentage
Wairau	93
College Glutinosa	92
C.R.D. Suckering	14

TABLE III.4. Significance Levels of Differences between Means.

	Position	Treatment			Treatment
		Spacing	Variety	Spacing X Variety	X Position
Percentage establishment (31.5.73)	N.S.	**	**	N.S.	N.S.
Percentage establishment (3.7.73)	N.S.	**	**	N.S.	N.S.
Percentage establishment (16.8.73)	N.S.	**	**	N.S.	N.S.
Percentage establishment (23.4.74)	*	**	N.S.	N.S.	N.S.
Nodule number	N.S.	*	N.S.	N.S.	N.S.
Nodule dry weight	*	*	N.S.	N.S.	N.S.
Top dry weight	N.S.	N.S.	N.S.	N.S.	N.S.
Root dry weight	**	N.S.	N.S.	N.S.	N.S.
Plant dry weight	N.S.	N.S.	N.S.	N.S.	N.S.
Top /root ratio	*	N.S.	*	N.S.	N.S.
Nodule d.wt./shoot d.wt.	*	*	N.S.	N.S.	N.S.
Nodule d.wt./root d.wt.	N.S.	**	*	N.S.	N.S.
Nodule d.wt./plant d.wt.	*	**	N.S.	N.S.	N.S.
Total D.M. production (5.12.73)	N.S.	N.S.	*	N.S.	N.S.
Lucerne D.M. production (5.12.73)	N.S.	**	N.S.	N.S.	N.S.
Weed D.M. production (5.12.73)	N.S.	N.S.	*	N.S.	N.S.
Total D.M. production (21.2.74)	N.S.	N.S.	N.S.	N.S.	N.S.
Lucerne D.M. production (21.2.74)	N.S.	**	N.S.	N.S.	N.S.
Weed D.M. production (21.2.74)	**	*	N.S.	N.S.	N.S.
Total D.M.production (9.4.74)	N.S.	N.S.	N.S.	N.S.	N.S.
Lucerne D.M. production (9.4.74)	N.S.	**	N.S.	N.S.	N.S.
Weed D.M. production (9.4.74)	N.S.	N.S.	N.S.	N.S.	N.S.
Total D.M. production (3 cuts)	N.S.	N.S.	*	N.S.	N.S.
Lucerne D.M. production (3 cuts)	N.S.	**	N.S.	N.S.	N.S.
Weed D.M. production (3 cuts)	N.S.	N.S.	*	N.S.	N.S.
Shoot number/five plants	N.S.	**			
Percentage dessicated plants (4.2.74)	**		N.S.		

TABLE III.5. Position Means and Least Significant Differences. (dry matter production in kg/ha.)

	Position			L.S.D.	L.S.D.
	I	II	III	(P<0.01)	(P<0.05)
Percentage establishment (31.5.73)	47.0	39.6	39.2		
Percentage establishment (3.7.73)	40.6	34.9	38.1		
Percentage establishment (16.8.73)	36.5	31.8	35.6		
Percentage establishment (23.4.74)	15.1	8.3	5.3		6.87
Nodule number	10.9	12.8	14.8		
Nodule dry weight (mg.)	39	63	96		27
Top dry weight (g.)	2.72	2.94	3.06		
Root dry weight (g.)	1.24	1.47	2.10	0.17	
Plant dry weight (g.)	3.96	4.41	5.16		
Top /root ratio	2.19	2.00	1.46		0.18
Nodule d.wt./shoot d.wt.	15	22	32		9.6
Nodule d.wt./root d.wt.	32	45	47		
Nodule d.wt./plant d.wt.	10	14	19	5	4
Total D.M. production (5.12.73)	910	668	601		
Lucerne D.M. production (5.12.73)	130	140	194		
Weed D.M. production (5.12.73)	780	528	407		
Total D.M. production (21.2.74)	253	384	295		
Lucerne D.M. production (21.2.74)	123	216	203		
Weed D.M. production (21.2.74)	130	168	92	69	
Total D.M. production (9.4.74)	193	207	228		
Lucerne D.M. production (9.4.74)	99	117	114		
Weed D.M. production (9.4.74)	94	90	114		
Total D.M. production (3 cuts)	1366	1264	1104		
Lucerne D.M. production (3 cuts)	399	427	417		
Weed D.M. production (3 cuts)	967	837	687		
Shoot number/five plants	20.66	22.57	25.33		
Percentage dessicated plants/m^2 (4.2.74)	24.70	38.62	60.70	33.09	19.95
Larvae/m^2	19	25	34		

TABLE III.6. Plant Spacing Means and Least Significant Differences.
(dry matter production in kg/ha.)

	Plant Spacing			L.S.D.	L.S.D.
	2.02cm.	9.16cm.	15.22cm.	(P<0.01)	(P<0.05)
Percentage establishment (31.5.73)	38.7	36.3	51.2	5.79	
Percentage establishment (3.7.73)	33.6	32.6	47.5	5.59	
Percentage establishment (16.8.73)	29.4	30.0	44.5	5.84	
Percentage establishment (23.4.74)	5.2	9.2	14.3	5.14	
Nodule number	13.0	14.5	10.0		2.84
Nodule dry weight (mg.)	49	71	78		21
Top dry weight (g.)	2.66	3.03	3.01		
Root dry weight (g.)	1.57	1.65	1.59		
Plant dry weight (g.)	4.24	4.54	4.60		
Top/root ratio	1.84	1.90	2.09		
Top d.wt./nodule d.wt.	20	24	27		2
Root d.wt./nodule d.wt.	29	44	52	17	
Plant d.wt./nodule d.wt.	11	15	18	5	4
Total D.M. production (5.12.73)	787	600	795		
Lucerne D.M. production (5.12.73)	254	116	95	40	
Weed D.M. production (5.12.73)	533	484	700		
Total D.M. production (21.2.74)	339	300	294		
Lucerne D.M. production (21.2.74)	242	131	174	23	
Weed D.M. production (21.2.74)	98	169	169		13.6
Total D.M. production (9.4.74)	220	199	209		
Lucerne D.M. production (9.4.74)	146	94	90	14	
Weed D.M. production (9.4.74)	74	105	119		
Total D.M. production (3 cuts)	1326	1098	1297		
Lucerne D.M. production (3 cuts)	641	341	359	51	
Weed D.M. production (3 cuts)	705	758	939		
Shoot number/five plants	19.33		26.37	4.16	

TABLE III.7. Lucerne Variety Means and Least Significant Differences. (dry matter production in kg/ha.)

	Variety		L.S.D.	L.S.D.
	College Glutinosa	Wairau	(P<0.01)	(P<0.05)
Percentage establishment (31.5.73)	35.7	48.3	4.73	
Percentage establishment (3.7.73)	32.6	43.1	4.57	
Percentage establishment (16.8.73)	19.8	39.4	8.92	
Percentage establishment (23.4.74)	8.2	10.9		
Nodule number	12.6	12.6		
Nodule dry weight (mg.)	71	62		
Top dry weight (g.)	2.96	2.84		
Root dry weight (g.)	1.48	1.72		
Plant dry weight (g.)	4.44	4.56		
Top/root ratio	2.12	1.77		0.09
Top d.wt./nodule d.wt.	25	22		
Root d.wt./nodule d.wt.	46	36		10
Plant d.wt./nodule d.wt.	15	14		
Total D.M. production (5.12.73)	857	597		65
Lucerne D.M. production (5.12.73)	167	142		
Weed D.M. production (5.12.73)	690	455		198
Total D.M. production (21.2.74)	305	317		
Lucerne D.M. production (21.2.74)	173	176		
Weed D.M. production (21.2.74)	165	126		
Total D.M. production (9.4.74)	197	221		
Lucerne D.M. production (9.4.74)	108	112		
Weed D.M. production (9.4.74)	89	110		
Total D.M. production (3 cuts)	1358	1135		69
Lucerne D.M. production (3 cuts)	448	445		
Weed D.M. production (3 cuts)	910	690		65
Percentage dessicated plants/m^2 (4.2.74)	40.65	42.02		

TABLE III.8. Percentage Recovery of Different Categories of Lucerne Plants after the Second Production Cut.

Category before Production Cut.	Category after Production Cut.		
	Dessicated	Partially dessicated	Green
Dessicated	92.7	2.6	4.7
Partially dessicated	21.0	6.8	72.7
Green	3.5	4.4	92.1

TABLE III.9. Effect of Position on Percentage Recovery of Plants Categorised as Partially Dessicated.

Position	Category after Production Cut.		
	Dessicated	Partially dessicated	Green
I	16.5	8.2	75.3
II	21.2	11.8	67.0
III	24.7	27.0	48.3

TABLE III.10. White fringed Weevil Larval Distribution (larvae/m^2) at 19.3.74.

Apparent level of infestation	Variety	Spacing (cm.)	Position			Level means
			I	II	III	
High	Wairau	2.02	38	38	67	
		15.22	33	33	29	40
Low	Wairau	2.02	0	10	25	
		15.22	5	20	15	12.50
Position means			19	25	34	

L.S.D. Level ($P<0.01$) = 9.42

L.S.D. Level x spacing x position ($P<0.05$) = 9.75

(B) GLASSHOUSE EXPERIMENT.

(a) Initial Allocation of Larvae.

The numbers of larvae in each 10mg. weight range that were initially introduced to each treatment are shown in Table III.11.

(b) Significance Levels.

The significance levels at which differences between treatment means occur are shown in Table III.13. for each measurement.

(c) Larval Mortality.

The numbers and weight range of the larvae surviving at the end of the experiment are shown in Table III.12. The percentage survival of larvae in each treatment is shown in Table III.14. Analysis of variance of these results showed no significant differences in percentage survival of larvae between treatments at either the 1% or 5% level of significance.

(d) Larval Weight Gain.

The percentage total weight gain of larvae in each treatment is shown in Table III.15. This was calculated by multiplying the initial total larvae weight per treatment by the percentage survival of larvae in each treatment, subtracting this value from the total larval weight per treatment and expressing the difference as a percentage of the corrected initial total larval weight per treatment.

(e) Parallel Plant Study In The Absence of Larvae.

Measurements of mean root dry weight, mean top dry weight, mean top/root ratio and mean root residue dry weight for plants in both the dry and wet soil moisture treatments are shown in Table III.16. These measurements are not included in later tables because there are only two plots per soil moisture level compared with thirty-six treatment plots per moisture level.

(f) Lucerne Plant Mortality.

The number of plants in each treatment that had their main root severed by the larvae and consequently withered and died is shown in Table III.17. As in all the other tables in this section, the least significant difference (L.S.D.) at the indicated level of significance is shown at the foot of the table where the F test showed significant differences between main treatment effects and/or treatment interactions.

(g) Root Weight.

The mean root dry weight of lucerne plants in each treatment surviving at the end of the experiment is shown in Table III.18.

(h) Top Weight.

The mean top dry weight of lucerne plants in each treatment surviving at the end of the experiment is shown in Table III.19. The analysis of

variance of these results showed no significant differences between treatment means at the 1% or 5% level of significance.

(i) Top /Root Ratio.

The mean top /root ratios of lucerne plants in each treatment surviving at the end of the experiment is shown in Table III.20.

(j) Mean Life Span of Lucerne Plants.

The mean life span of lucerne plants in each treatment is shown in Table III.21. The analysis of variance of these results showed no significant differences between treatment means at the 1% or 5% level of significance.

(k) Root Residue.

The mean root residue dry weight in each treatment is shown in Table III.22.

TABLE III.11. Numbers of Larvae in each Weight Range Initially Allocated to Treatments.

Treatment		Individual larva weight range (mg.)							
Soil Moisture	Larval population/plot.	40–50	50–60	60–70	70–80	80–90	90–100	100–110	Total No.
Dry	1		3	9					12
	2		2		12		10		24
(10% M.C.)	4	4			2	13	9	20	48
Wet	1		4	8					12
	2				12		12		24
(10% M.C.)	4	5			1	14	8	20	48

TABLE III.12. Numbers of Larvae in each Weight Range Surviving at end of Experiment.

Treatment		Individual larva weight range (mg.)								
Soil Moisture	Larval population/plot.	50–60	60–70	70–80	80–90	90–100	100–110	110–120	120–130	Total No.
Dry	1		1	4		2	1			8
	2			6	2	5	3			16
	4	1	1	1	11	5	4	6		29
Wet	1		3	1	2	1		2		9
	2			2	4	5	3	1	1	16
	4	1	1	1	4	7	8	5	4	31

TABLE III.13. Significance Levels for Experimental Measurements.

Measurement	Treatment		
	Moisture	Initial larval population.	Moisture X initial larval population.
Larval mortality	N.S.	N.S.	N.S.
Lucerne mortality	**	N.S.	N.S.
Root dry weight of surviving plants.	N.S.	N.S.	**
Top dry weight of surviving plants.	N.S.	N.S.	N.S.
Top /root ratio of surviving plants.	**	N.S.	N.S.
Plant life span.	N.S.	N.S.	N.S.
Root residue dry weight.	**	*	*

TABLE III.14. Percentage Survival of Larvae in each Treatment.

Soil Moisture	Initial larval population per plot.		
	1	2	4
Dry	66	66	60
Wet	75	66	65

TABLE III.15. Percentage Total Weight Gain of Larvae in each Treatment.

Soil Moisture	Initial larval population per plot.			
	1	2	4	Mean
Dry	33.3	8.2	3.1	14.7
Wet	37.8	12.6	9.4	19.9
Mean	35.6	10.4	6.3	

TABLE III.16. Lucerne Plant Measurements for Parallel Study in the Absence of Larvae.

Soil Moisture	Measurement.			
	Mean root d.wt. (g.)	Mean top dry d.wt. (g.)	Mean shoot/ root ratio	Mean root residue d.wt. (g.)
Dry	81.66	75.93	0.93	155.0
Wet	87.80	68.60	0.80	127.3

TABLE III.17. Lucerne Plant Mortality in each Treatment.

Soil Moisture	Initial larval population per plot.				
	1	2	4	Total	Mean
Dry	23	27	38	88	2.44
Wet	13	12	24	49	1.36
Total	36	39	62		

L.S.D. Moisture ($P<0.01$) = 0.39

TABLE III.18. Mean Root Dry Weight (g.) of Surviving Plants in each Treatment.

Soil Moisture	Initial larval population per plot.			
	1	2	4	Mean
Dry	84.41	62.27	57.48	68.05
Wet	64.41	70.48	66.97	67.16
Mean	74.23	66.37	62.23	

L.S.D. Moisture x larval population ($P<0.01$) = 18.4

TABLE III.19. Mean Top Dry Weight (g.) of Surviving Plants in each Treatment.

Soil Moisture	Initial larval population per plot.			
	1	2	4	Mean
Dry	57.16	53.36	48.86	53.13
Wet	73.68	82.55	92.89	83.04
Mean	65.42	67.96	70.88	

TABLE III.20. Mean Top /Root Ratio of Surviving Plants in each Treatment.

Soil Moisture	Initial larval population per plot.			
	1	2	4	Mean
Dry	0.80	0.82	0.91	0.84
Wet	1.30	1.18	1.40	1.30
Mean	1.10	1.00	1.16	

L.S.D. Moisture (P 0.01) = 0.05

TABLE III.21. Mean Life Span (days) of Plants in each Treatment (maximum possible life span = 42 days).

Soil Moisture	Initial larval population per plot.			
	1	2	4	Mean
Dry	39.0	39.2	35.4	37.9
Wet	41.1	40.5	39.0	52.8 40.2
Mean	40.0	39.9	37.2	

TABLE III.22. Mean Root Residue Dry Weight (g.) of Plants in each Treatment.

Soil Moisture	Initial larval population per plot.			
	1	2	4	Mean
Dry	226.0	177.5	150.0	184.5
Wet	92.5	124.0	96.6	104.4
Mean	159.25	150.8	123.3	

L.S.D. Moisture ($P<0.01$) = 10

L.S.D. Initial larval population ($P<0.05$) = 9.8

L.S.D. Initial larval population x Moisture ($P<0.05$) = 94

Chapter IV: Discussion.

(A) FIELD EXPERIMENT.

1. Climate Factors.

1.1 Wind-Speed.

Average wind-speeds for each measurement interval range from 2.7km/hr to 13.7km/hr (Figure III.1.). Cowie et al (1967) found there was a distinct annual pattern of wind-speed in the Manawatu sand country but the results from this experiment are not consistent with these findings. This could be due to the shelter belt on the western side of the experimental site reducing the speed of the prevailing west and north-west winds. Thus easterly and north-easterly winds which are the most frequent as recorded by Thomson (1930) at Waitatapia, probably cause the peaks in average wind-speed which are shown on the graph (Figure III.1.). These peaks are most common during late summer and autumn when according to Cowie et al (1967) winds from the easterly direction become more frequent.

1.2 Rainfall.

Average monthly rainfall for the period April, 1973 to March, 1974 was 62.4mm. The highest monthly rainfall occured in September (113.5mm) while the lowest monthly rainfall occured in March (13.99mm). These figures can be compared with an average monthly rainfall of 70mm with highest monthly rainfall occuring in June (average 86.25mm) and the lowest monthly rainfall occuring March (average 52.5mm) recorded at Foxton from 1912 to 1954 (Cowie et al 1967). Thus this 1974/74 period had a slightly lower annual rainfall than the 42 year average rainfall but a much greater range in monthly rainfall. Moreover, the normal annual pattern of rainfall as outlined by Cowie et al (1967) differs from the pattern for this period. Rainfall for July (38.75mm), August (53.75mm), October (47.62mm), January (27.29mm) and March (13.99mm) was below recorded 42 year averages of 75mm, 78.7mm, 80.0mm, 58.0mm and 52.5mm respectively while rainfall for September (113.5mm) was above the recorded average of 62.5mm.

2. Soil Factors.

2.1 Water Table.

As can be seen from Figures III.2 and III.3, the water table rose from June, 1973 to September, 1973 and then fell from October, 1973 to March, 1974. Thus the highest and lowest water table level coincided with the months

of highest and lowest rainfall. Within the month, the water table depth fluctuated according to daily rainfall from June to November but from December to March, the water table fell regardless of rainfall. This would suggest that the rainfall infiltrating into the soil from December to March was either utilised by plants or evaporated from the soil before it could penetrate down to the water table.

The mean monthly water table also differed between measurement sites (location of measurement sites shown in Appendix 2.) The water table was constant over sites 1-3 (plain) at any one time but was lower at sites 4 and 5 (dune). Changes in mean monthly water table maintained this pattern. No reasonable explanation could be found for the lowered water table under the dune compared with that under the plain.

2.2 Soil Moisture Tension.

Soil moisture tension will be discussed in terms of changes with time, soil depth and position.

(a) Changes in soil moisture tension with time.

Soil moisture tension changed with time according to the amount of rainfall which preceded each measurement date. From May, 1973 to August, 1973, some rainfall occured during most measurement intervals and soil moisture tension at 5cm. depth seldom rose above 10 atmospheres (Figure III. 4.). This situation continued in September, 1973 but from October, 1973 to April, 1974 less regular periods of rainfall together with long periods without rainfall occured (Figures III.5 and III.6.). This resulted in greater and more frequent changes in soil moisture tension with time.

(b) Changes in soil moisture tension with depth.

Soil moisture tension changed with depth at any one measurement date from September, 1973 to April, 1974. Generally, soil moisture tension at 10cm. depth was higher than at 30cm. depth which in turn was higher than at 90cm. depth. However, from October, 1973 to December, 1973 and again during March, 1974, soil moisture tension at 30cm. depth was greater than at 10cm. depth. The former differences would be expected for as depth increases, so is the soil more buffered against losses of moisture by plant uptake and evaporation, and gains of moisture from the percolation of rainfall through the soil profile. This was reflected in the slower and lower responses in the soil moisture tension at 30cm. depth compared with 10cm. depth. However, as the lucerne roots expand downwards with time, soil moisture at greater depths would be expected to become depleted as found by Kiesselbach et al (1929).

The other factor that could affect changes in soil moisture tension with depth is the water table as it affects the supply of moisture to upper horizons of the soil by capillary rise. Hillel (1971) claims that a sandy

loam soil can evaporate water at an appreciable rate even when the water is as low as 180cm., but as the water table becomes deeper and the soil moisture tension at the soil surface increases, the actual evaporation rate approaches a limiting value regardless of how high the potential evaporation rate may be. Thus when the water table was high during winter and early spring, capillary rise from the water table could have occured to influence soil moisture tension at 10cm. and 30cm. depth.

From September 18 to October 8, many of the gypsum blocks at 90cm. depth were below the water table (see Appendix 3.). Even when the water table fell capillary rise appeared to be responsible for the constant low soil moisture tensions at 90cm. (see Appendix 4.).

. (c) Changes in soil moisture tension with position.

Soil moisture tension changed with position both at the 10cm. and 30cm. depths. From May, 1973 to August, 1973, soil moisture tension at 5cm. depth in Position III was higher than in Position II which in turn was higher than in Position I. However only on two occasions during this period did measurements indicate that the soil moisture tension was at wilting point (assumed to be 15 atmospheres).

From September, 1973 to December, 1973, soil moisture tension at 10cm. depth was higher in Position III than in Position II which in turn was higher than in Position I. The soil in Position III first reached wilting point on October 11 followed by Position II on December 3 and Position I on December 6. After reaching wilting point, the soil moisture tension fluctuated from wilting point to lower values with rainfall.

Following rainfall in late December, soil moisture tension at 10cm. depth was greater in Position I than in Position II which in turn was greater than in Position III. This situation continued until late January when all positions dried out to wilting point. Rainfall in February reduced soil moisture tension in all positions. Although a gap in soil moisture tension measurements occured from February 2 to March 15, since rainfall was low over this period the soil in all positions could be assumed to be drying out to the high soil moisture tensions recorded from March 15 to April 4.

The other notable feature of the 10cm. depth soil moisture tension data is that the soil in Position III tended to dry out at a faster rate than the soil in Position II which in turn dried out at a faster rate than the soil in Position I from May, 1973 to December, 1973.

For almost the entire period from Spetember, 1973 to December, 1973, soil moisture tension at 30cm. depth in Position III remained at 15 atmospheres while soil moisture tension in Position I remained at less than 1 atmosphere with soil moisture tension in Position II fluctuating between

these two extremes. After rainfall at the end of December, the soil in Position III wetted up sufficiently to maintain a lower soil moisture tension than in Position I which itself dried out in January to give higher soil moisture tensions than in both Positions II and Position III. This situation continued until the end of the experiment with the soils in Position II and Position III eventually drying out to wilting point.

Soil moisture tension at 90cm. depth was similar in all positions although the soil moisture tension averaged over all measurements increased slightly from Position I to Position III (see Appendix 4.).

Cowie and Smith (1958) state that the Manawatu sand country soils with their coarse texture, hold very little moisture during dry periods. Being situated in a district of low rainfall, their productivity usually depends on their natural drainage as this is the main factor in determining the amount of soil moisture available during the growing season. Natural drainage is used by Cowie and Smith (1958) in the sense of rapidity and extent of removal of water from the soil and this largely depends on the water table depth and the texture, structure, organic matter content and slope of the soil. Moisture loss by evaporation is also important but this is considered uniform except between soils on sunny and shady faces of dunes.

The differences in soil moisture tension between positions at 10cm. and 30cm. depths will be discussed in terms of the above factors. The soil in all three positions can be classified in the textural class of sand in all horizons of the soil profile with a weakly developed crumb structure in the A horizon grading down to structureless B and C horizons (see Plates II, III and IV).

It is in organic matter content and depth of topsoil that the soils in the three positions differ most (Table III.2 and Appendix 7.). Organic matter content at 10cm. depth averaged over all measurement sites in Position I (5.86%) and Position II (5.77%) is higher than in Position III (3.58%). Buckman and Brady (1969) claim that a well drained mineral soil containing 5% organic matter will retain more moisture than a comparable soil with 3% organic matter content. Most of the benefit of organic matter in this case is attributed to its favourable influence on soil structure and in turn on soil porosity. At 30cm. depth, organic matter content averaged over all measurement sites is higher in Position II (3.65%) than in Position I (2.45%) and Position III (2.35%).

The soil in Position I had a topsoil (A horizon) depth ranging from 25 to 30cm. while the topsoil depth in Position III ranged from 15 to 20cm. The soil in Position II had a topsoil depth ranging from 20cm. to 40cm. at the change of slope from dune to plain. Presumably, the build-up of organic

matter which occurs at the change of slope was due to the movement of topsoil from the dune during periods of heavy rainfall. This could have taken place while the dune was still relatively unconsolidated during the initial sowing of pasture in the paddock. Thus, topsoil depth explains the greater ability of the soil in Position II at 30cm. depth to retain moisture compared with Position I and Position III during periods of low rainfall.

According to the claims made by Hillel (1971), the different water table depths could have affected the soil moisture tension at 10cm. and 30cm. depths between positions. However, water table depth was not highly correlated with soil moisture tension in this experiment.

Thus the majority of the differences in soil moisture tension between positions appear to be due to differences in the ability of the soils to retain moisture according to their soil organic matter content and depth of topsoil. The major anomaly in this explanation is the change in the order of soil moisture tension in the three positions at 10cm. depth during January but this can be explained in terms of plant factors. From January, 1974 to April, 1974, there was a sparse cover of vegetation in Position III and the upper half of Position II compared with the lower half of Position II and Position I (see Plates 9 and 10). It is probable that the uptake of moisture by plants from the area where vegetation was sparse would be much less than the uptake of moisture by plants in the area where vegetation was still abundant. Although soil moisture would still be lost by evaporation from the soil surface over the entire experimental site, it is suggested that transpiration was a more important factor in increasing soil moisture tension over this period.

2.3 Soil Organic Matter.

Soil organic matter content for the soil from each position was consistent with values given by Cowie and Smith (1958) and Cowie et al (1967). The latter workers consider that organic matter in the Manawatu sand country soils range from low to very high. This increase is correlated with poorer natural drainage resulting in increased plant growth on wetter soils.

2.4 Soil Nutrient and pH Tests.

The application of lime to the experimental site before sowing increased the soil pH (30 days after sowing) in Puke Puke black sand by 0.4 pH units and in Motuiti sand by 0.5 pH units. The application of fertiliser elevated the phosphate status of Puke Puke black sand from high to very high but did not alter the very high phosphate status of Motuiti sand. The medium potassium status of both soils before sowing was elevated to a high status. At the end of the experiment, the pH and status of all the soil nutrients had remained relatively constant in both soil types except for the phosphate

status in Puke Puke black sand which was reduced.

3. Lucerne Growth Factors.

Lucerne establishment and growth will be discussed in three phases covering the duration of the field experiment. Phase I will cover the period from 0 to 31 days after sowing, Phase II the period from 31 to 110 days after sowing and Phase III the period from 110 days to one year after sowing.

3.1 Phase I.

Percentage establishment of lucerne 31 days after sowing averaged 42% over all treatments and positions which is consistent with percentage lucerne establishment recorded by other workers. (Blair, 1971; Athow, 1957; Tyler et al, 1956; Zaleski, 1957). In the case of this experiment the disparity between the laboratory germination of the seed and the actual percentage establishment of seed 31 days after sowing can be discussed in terms of several factors.

Soil moisture tension measured at 5cm. depth one day after sowing averaged 8.1 atmospheres for Position I, 10.4 atmospheres for Position II and 15 atmospheres for Position III. Both Triplett and Tesar (1960) with Vernal lucerne and Collis-George and Sands (1959) with Medicago species found that germination was negligible when soil moisture tension after sowing was greater than 10 atmospheres but following a reduction in soil moisture tension final germination percentage was unaffected. Therefore the 35mm of rainfall that fell in the first week after sowing and reduced soil moisture tension to below this critical level in all positions would have ensured that final germination percentage was unaffected but the rate of germination was possibly slower in Positions II and III than in Position I.

Minor damage to the lucerne seedlings by Springtail (Sminthurus viridis L.) was noticed 24 days after sowing and an immediate application of insecticide minimised any damage from this insect.

Soil pH tests carried out 30 days after sowing showed that the application of lime before sowing had elevated the soil pH to an average of 6.15 over the experimental site (Table III.1.) - a level considered adequate for lucerne seedling growth and nodulation by White (1967).

Fourteen days after sowing (7days after seedling emergence) healthy seedlings were observed to change to a brownish colour and eventually completely rot. Seedlings showing these symptoms were extracted from the soil and examined by the Plant Pathology Department, Massey University where fungi of the genera Pythium and Fusarium were identified. MacKenzie et al (1972) found that damping-off in lucerne seedlings by Pythium irregulare was evident within

a week of emergence and seedlings disappeared within a few days of death. This fungous disease factor is considered to be the major factor causing the low establishment of lucerne during this phase in the present trial.

Lucerne plants sown at 15.22cm. inter-plant spacing had a significantly higher ($P<0.01$) percentage establishment 31 days after sowing than plants sown at 9.16cm. or 2.02cm. spacings (Table III.6.). Zaleski (1957, 1959) showed that the mean percentage of plants established decreased significantly at higher seed rates where a high proportion of hard seed was present. The later germinating seedlings derived from hard seed were apparently at a competitive disadvantage. In the present experiment, laboratory germination after 7 days was greater than 90% for both varieties suggesting a very small proportion of hard seed. Therefore it is unlikely that the above difference was due to the competitive exclusion of late emerging seedlings derived from hard seed under the close spacing treatment.

Inter-specific competition during Phase I could be assumed to be negligible since at this stage the pre-emergent weed control method used had effectively controlled weeds. Exceptions were occasional clumps of perennial ryegrass (Lolium perenne L.) and toadrush (Juncus bufonius L.) seedlings on the plain. If the toadrush seedlings had been affecting establishment then a significant position effect would have appeared in the analysis.

A more likely explanation for these differences in establishment between plant spacings would be that at close spacing cross infection of seedlings was greater than at wider spacings and produced an epidemic outbreak of damping-off.

Wairau had a significantly higher ($P<0.01$) percentage establishment 31 days after sowing than College Glutinosa. This varietal difference in lucerne establishment confirms experimental results from Flock House F.R.A. where establishment of Wairau was superior to establishment of other lucerne varieties including College Glutinosa. Although there is no proof it appears likely from this experiment that College Glutinosa was more susceptible than Wairau to pathogenic fungi under the prevailing conditions.

3.2 Phase II.

From Figures III.7 and III.8 it can be seen that during Phase II mortality was reduced considerably compared with Phase I. During Phase II, plant mortality was not significantly different between treatments. However the significant differences between spacing and variety present at the end of Phase I were maintained during Phase II (Tables III.6. and III.7.).

During Phase II, adequate moisture was still available for lucerne plant growth except for infrequent short periods in Position III (see Figure III.4.).

PLATE 5 Lucerne establishment at 19.8.73 (Replicate 3) - view down strips from dune

PLATE 6 Lucerne growth in Position I - relatively free of larval damage (9.4.74)

There was no evidence of any insect damage during Phase II.

The measurement of nodule numbers carried out 40 days after sowing (see Appendix 10) indicated that nodulation had been achieved over all lucerne plots. However, MacKenzie et al (1972) found that there was no positive association between the number of established plants at 10 weeks after sowing and nodulation despite obvious growth differences associated with nodulation.

From the beginning of July, ingress of various weed species occured (see Appendix 13). The growth of weed species was however very slow during this period and it is unlikely that they were in competition with lucerne.

Blair (1971) used innoculation experiments to show that whereas many Fusarium fungi readily produce pre-emergence decay and seedling damping-off, others in less virulent form or through infection being delayed until after seedling establishment, appear to damage the roots and consequently impair seedling growth. It is likely that the plants that died during Phase II were those that had suffered various degrees of fungal attack in the first 31 days after sowing.

The changes in plant numbers for different plant spacings over the first three establishment counts (Phase I and II) are shown in Figure III.7. Although the number of plants established increased at closer plant spacings as found by Palmer (1971), death rates of plants were higher in the denser plots as found by Jarvis (1962) and Takasaki et al (1970). After 110days, plots sown at 9.16cm. spacing had densities very similar to those sown at 15.22cm. In plots sown at 2.02cm. the population had declined at a faster rate than plots at wider spacings and was still declining (see Figure III.7.).

The rate of decline in the mean number of lucerne plants per square metre with time after sowing is relatively similar in all three positions although Position I has a slightly lower rate of decline (see Figure III.8.).

3.3 Phase III.

(a) Percentage establishment after one years growth.

The number of plants present after one year was considerably less than the number present at the end of Phase II in all positions and treatments. There was a significantly higher ($P<0.05$) percentage establishment of plants in Position I than in Position III. This large reduction in plant numbers with time is thought to be due to two main factors. Firstly, high soil moisture tensions reduced the amount of soil moisture available to the lucerne plants. Secondly, white fringed weevil larvae damaged the roots of many lucerne plants. This will be further discussed later.

Percentage establishment was significantly higher ($P<0.01$) at 15.22cm. spacing than at 2.02cm. spacing (Table III.6.). This suggests that plants at closer spacings may be more susceptible to attack by white fringed weevil

larvae, and/or suffer more severe competition for moisture than plants at wider spacings.

(b) Plant components.

Shoot number per five plants is significantly higher ($P<0.01$) at 15.22cm. spacing than at 2.02cm. spacing. The increase in shoot number per lucerne plant with decreasing plant density has also been found by Cowett and Sprague (1962).

There are no significant differences in top dry weight, root dry weight or total dry weight per five plants between different plant spacings. However plant dry weight increases as plant spacing increases from 2.02cm. to 9.16cm. to 15.22cm. which would be expected from results of Rumbaugh (1963) and Cowett and Sprague (1962). The absence of significance between means could be due to an insufficient number of plants sampled.

There were, however, significant differences in root dry weight and top /root ration per five plants between positions (Table III.4.). This implies that plants in Positions II and III are responding to a higher soil moisture tension be expanding their root systems as shown by Weaver (1926), or possibly that plants in the relatively weed free Position III and to a lesser extent Position II are not shaded to the same degree as plants in Position I. Pritchett and Nelson (1951) found that shading depressed the weight of roots more than that of the tops as shown by increasing top to root ratios with increasing shade.

College Glutinosa lucerne plants have a significantly higher ($P<0.05$) top /root ration than Wairau plants which suggests that the more rhizomatous root system of the College Glutinosa plant is more efficient in extracting water than the tap root system of the Wairau plant in the first year of growth under the conditions prevailing in this experiment.

(c) Nodulation.

Plants spaced at 15.22cm. and 9.16cm. had significantly higher ($P<0.05$) nodule dry weights than plants spaced at 2.02cm. (Table III.6.). As has been shown, plants at the 2.02cm. spacing were smaller than those at wider spacings. This supports the findings of Kawatake et al (1962) who demonstrated a significant positive relationship between nodule weight and the dry matter of roots and tops.

In contrast, nodule number per five plants is significantly higher ($P<0.05$) at 9.16cm. than at 15.22cm. spacing. This implies that in this situation, plants at wider spacings have a small number of large nodules while plants at closer spacings have a large number of small nodules. However, the nodule numbers for plants spaced at 2.02cm. do not fit into this trend. This is probably because only five plants per plot is an insufficient number

to give a reliable estimate of this measurement and these results should be interpreted with caution.

Ratios of nodule dry weight to top , root and plant dry weight are all significantly higher at 15.22cm. and 9.16cm. spacing than at 2.02cm. apacing. Only for nodule dry weight per unit of shoot dry weight are values significantly higher ($P<0.05$) at 15.22cm. than at 9.16cm. spacing. These differences would be expected from the nodule weight per plant results and demonstrates the dependence of nodule growth on the growth of the host plant at this stage.

College Glutinosa plants have a signficantly higher ($P<0.05$) nodule dry weight per root dry weight than Wairau plants which suggests that the greater branching of the root system of College Glutinosa may provide more infection sites than the tap root system of Wairau. There were no other significant differences between varieties for nodulation measurements.

Nodule dry weight per five plants is significantly higher ($P<0.05$) in Position III than in Position I and II. Bond (1951) and Virtanen and von Hausen (1936) found that the weight of nodules per plant was markedly reduced by lower oxygen supply but nodule number was less affected. This explanation appears unlikely in this experiment since over the period from sowing to when this measurement was taken (12.10.73), the soil in the root zone of the lucerne plants was not waterlogged by a high water table, even in Position I. Another possible explanation is that the relative freedom of the lucerne plants from competition with weeds in Position III compared with Positions I and II as shown by the first production cut has resulted in less competition for light between lucerne and other species thus providing a greater supply of carbohydrate to the roots and hence greater nodule growth. This explanation is also supported by the greater total plant dry weight in Position III compared with Positions I and II (Table III.5.).

Nodule dry weight per unit of top dry weight is significantly higher (P 0.05) in Position III than in Position II. Nodule dry weight per unit of plant dry weight is significantly higher ($P<0.01$) in Position III than in Positions I and II and signficantly higher ($P<0.05$) in Position II than in Position I. These differences between positions would again be expected from the nodule dry weight per plant results. The absence of significant differences in nodule dry weight per unit of root dry weight between positions emphasises the correlation between nodule dry weight and root dry weight.

(d) Dry matter production.

At the first production cut, College Glutinosa plots produced significantly higher ($P<0.05$) total dry matter than did the Wairau plots. There

was, however no significant difference between varieties in lucerne dry matter production and the significantly higher ($P<0.05$) weed dry matter production in College Glutinosa plots is responsible for the difference in total dry matter production. From the data collected, no reasonable explanation can be suggested for this varietal difference in weed growth.

From general agronomic considerations it would be expected that lucerne at closer spacings would produce more dry matter at the first production cut. This was in fact the case, dry matter production being significantly higher ($P<0.01$) at 2.02cm. that at 9.16cm. and 15.22cm. plant spacings. Conversely it would be expected that at the closer lucerne plant spacing fewer weed seedlings would become established due to the competition from the lucerne. No weed population data was collected and therefore no conclusions can be drawn regarding weed numbers. However the weed dry matter data obtained, although not significant indicates a considerably greater weed dry matter production at 15.22cm. plant spacing compared with 2.02cm. and 9.16cm. spacings.

Although there were no significant differences in lucerne dry matter production between positions, lucerne dry matter production was greater in Position III than in Position I and II (Table III.5.). Conversely, weed dry matter production decreased from Position I to Position II to Position III. Thus although soil moisture tension was higher in Position III than in Positions I and II and could therefore have limited lucerne growth, it would appear that the weed species were more affected than the lucerne plants in Position III during this period. The weed species present at this production cut are shown in Appendix 13.

At the second production cut, lucerne comprised a larger proportion of the sward than at the first production cut. This could be attributed to the effect of high soil moisture tensions on plants of other species over the growth period leading up to this production cut plus the seasonal decline in the growth of Lotus subbiflorus L. and Trifolium subterraneum L. following the first production cut (see Appendix 13.).

Lucerne dry matter production was again significantly higher ($P<0.01$) at 2.02cm. plant spacings than at 9.16 or 15.22cm. spacings but was also significantly higher ($P<0.01$) at 15.22cm. spacings than at 9.16cm. spacings. This latter difference was unexpected and no explanation is suggested by the data available. Lucerne plants spaced at 9.16cm. and 15.22cm. had a significantly higher ($P<0.05$) weed dry matter production than those spaced at 2.02cm, which is compatible with the lucerne dry matter production differences.

Increasing number of dessicated plants were observed during January,

1974. On 4.2.74 it was found that dessicated plants as a percentage of total plants present per square metre was significantly higher ($P<0.01$) in Position III than in Position I and significantly higher ($P<0.05$) in Position III than in Position II (Table III.5.).

The majority (92.7%) of the plants categorised as dessicated and the majority (92.1%) of plants categorised as green on 20.2.74, immediately before the second production cut were still dessicated or green when the plants were recategorised 14 days after the second production cut. This confirmed the utility of the categories used. In the partially dessicated category, a large proportion (72.7%) of the plants were recategorised as green at the second count. As shown in Table III.9, more plants recovered in Position I than in Position II than in Position III while plants remaining partially dessicated, and plants moving from the partially dessicated to dessicated categories increased from Position I to Position II to Position III.

To test the assumption that the percentage of dessicated plants indicated larval concentration, and in an attempt to correlate plant damage with white fringed weevil larval population numbers the data presented in Table III.10. was collected. This confirmed the validity of the visual distinction made between the two levels of infestation on the basis of plant damage. Highly infested had a mean larval density of 40 larvae/m^2. There were also significant differences in the interactions between infestation, plant spacing and position. The density of larvae in the 2.02cm. spacing Wairau plots in Position III at the high level of infestation was higher than in all other combinations.

Although larval density increased from Position I to Position II to Position III, there are no significant differences in larval density between positions. This could be due to large variations in larval density between replicates. However these differences do not completely account for the differences in the degree of damage to lucerne plants between position as shown by earlier results. (Table III.5.). It was suspected that an interaction between root damage attributable to larval activity and soil moisture tension might account for these position differences. This hypothesis was tested in a glasshouse experiment and will be discussed later.

In view of the apparent differences in plant damage between positions (see Plates 9 and 10), significant differences in lucerne dry matter production were also expected. These expected differences did not occur and this could be partly accounted for by the following factors. Firstly the lucerne dry matter production results included dessicated plant material (see Appendix 12.), the proportion of which increase from Position I to Position

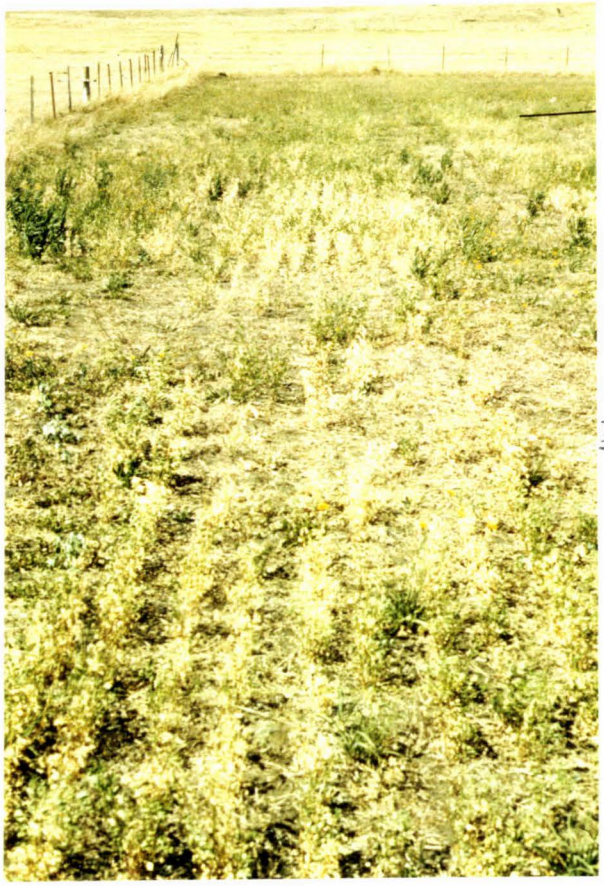


PLATE 7 Dessication of lucerne plants at 31.1.74 - view down 2.02 cm. spacing plot from dune

PLATE 8 A dessicated lucerne plant (31.1.74)

PLATE 9 View across Position I showing vegetative cover (9.4.74)

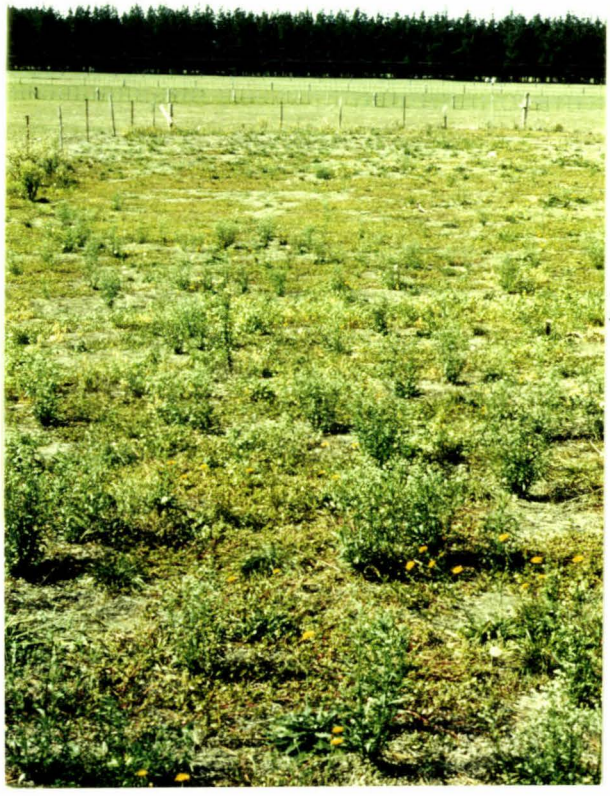


PLATE 10 View across Position III showing vegetative cover - Replicate 3 in foreground (9.4.74)

III. Secondly there were large variations in lucerne growth between replicates in Position III. Lucerne plants in Replicate 3 (nearest trees) appeared to be relatively unaffected by white fringed weevil larvae (see Plate IX) and this tended to mask differences between positions. It is unlikely, however, that these two factors either alone or in combination fully account for the lack of difference.

At the third production cut, a further reduction in the growth of all components of the sward was observed. It is suggested that this was due to continuing high soil moisture tensions and the effect of white fringed weevil larvae on lucerne plants. There is significantly higher ($P<0.01$) lucerne dry matter production at 2.02cm. plant spacing than at 9.16cm. or 15.22cm. spacings but no significant differences in total, lucerne or weed dry matter production between other treatments and positions.

Total dry matter production from the three production cuts was very low. This was due to several factors. From December, 1973 to April, 1974, monthly rainfall was substantially lower than previously recorded mean monthly rainfall for these months resulting in high soil moisture tensions in the experimental site. This limited the growth of both weed species and lucerne which at this stage had not been established long enough to expand its root system into the lower soil horizons where adequate moisture was available.

College Glutinosa plots had a significantly higher ($P<0.05$) total dry matter production over the three preduction cuts than Wairau plots. There were no significant differences in lucerne dry matter production between varieties and the above difference was due to the significantly higher ($P<0.05$) weed dry matter production in College Glutinosa plots than in Wairau plots.

There were no significant differences between positions for weed dry matter production over the three production cuts although an increase from Position I to Position II to Position III was apparent. Again there were no significant differences in weed dry matter production between plant spacings over the three production cuts although weed dry matter production increased from 2.02cm. to 9.16cm. to 15.22cm. plant spacing. The lack of significance in differences in weed dry matter production between positions and spacings can be partly attributed to the large variations in weed growth between replicates. (see Appendix 11).

Lucerne dry matter production from the three production cuts is significantly higher ($P<0.01$) at 2.02cm. plant spacing than at 9.16cm. or 15.22cm. which would be expected from the results of the three separate production cuts. This increase in lucerne yield in the first year of production at higher plant densities compared with lower plant densities has also

been found by Jarvis (1962), Takasaki et al (1970), Rumbaugh (1963) and Palmer (1971). There were no significant differences in lucerne dry matter production between varieties for the three production cuts. Lucerne dry matter production from the three production cuts did not differ significantly between the three positions. During the growth period up to the first production cut, weed competition and adequate soil moisture resulted in smaller plants with less root development in Positions I and II compared with Position III. Thus when weed competition diminished and soil moisture tensions increased after the first production cut, lucerne dry matter production in Position III still remained superior to that in Positions I and II up to the second production cut despite the large reductions in lucerne plant numbers due to white fringed weevil larval damage. At the third cut, lucerne dry matter production was similar in all positions.

(B) GLASSHOUSE EXPERIMENT.

The main objective of this experiment was to attempt to explain the differences in white fringed weevil damage to lucerne plants in different positions in the experimental site which were obvious both to the eye and as measured as percentage of dessicated plants in Table III.5.

The survey carried out on 14.3.74 at random sites within the experiment site (Appendix 13) showed there was a patchy distribution of larvae within the site. Although more larvae were found in Position III than the other two positions, the difference in larval numbers between positions did not reflect the large differences in the degree of damage between positions. This patchy distribution of larvae within a field has also been reported by Wright (1961) and Todd (1964).

Although research has been conducted on the effects of grass grub (Costelytra zealandica White) and soil moisture on the growth of pasture species (Radcliffe, 1971; Wightman, 1973) there is a scarcity of literature relating to the effects of white fringed weevil larvae and soil moisture on the growth of crop or pasture plants.

Tables III.13 and III.14 show that there are no significant differences in percentage survival of larvae between treatments. This would suggest that the mortality of larvae is due to some factor common over all the treatments such as the handling involved in collecting, weighing and placing in the respective plots. The mean larvae survival over all the plots was 66%. However there was no means of determining exactly when during the experimental period individual larvae died. The body of only one dead larvae was found in the soil of any of the plots at the end of the experiment which would suggest that the majority of the larvae died soon after introduction into the plots but this assumption would depend on the time taken for the dead larvae to decompose in the soil.

Table III.15 shows that the percentage total weight gain of larvae decreased as the initial larval population increased at both soil moisture levels with larvae in the wet soil moisture treatments having a larger percentage total weight gain than the larvae in dry soil moisture treatments. This decrease in percentage total weight gain with increasing initial larval population may have been due to the fact that the proportion of larvae of higher initial individual weight range increased with increasing larval population. The growth rate of these larvae could be expected to decrease as they approached the pre-pupal stage when it is reported they cease feeding (Gross et al, 1972). Another possible explanation for these results is a competition effect between larvae for a source of food from the root systems

of the fixed number of plants in each treatment. However, this explanation seems unlikely as there were at least four lucerne plants surviving in each plot at the end of the experiment. The difference in percentage total weight gain of larvae between the two soil moisture levels may indicate that soil moisture is necessary for some aspect of larval growth.

The lucerne plant measurements for the parallel study in the absence of larvae do not correspond to equivalent measurements in the treatment plots both in terms of soil moisture and initial larval population due to lack of replication. Thus the growth in the presence of different larval populations at either of the two soil moisture levels. However, it can be assumed that plants with no larvae present will have a 100% survival rate if all other growth conditions are favourable.

From Table III.17, it can be seen that lucerne plant mortality is significantly higher ($P<0.01$) at 10% soil moisture content than at 20% soil moisture content. This difference in plant mortality could be due either to the direct effect of soil moisture on the feeding activity of the larvae and/or the indirect effect of soil moisture on the growth of the lucerne plant so as to enable it to survive despite its root system being damaged.

Although it is reported that flooding the soil may kill young larvae (Anonymous, 1956) there is no other available experimental evidence to show the direct effect of soil moisture on the larvae. However it is unlikely that a soil moiture content of 20% of the dry weight would be extreme enough to have a deleterrous effect on the larvae.

Considering previous experimental work (Gross et al, 1972; Berry, 1947) and observations and root weight results from this experiment it would appear that the moisture effect on the lucerne plants is the more plausible explanation. Gross et al (1972) report that soya bean seedlings had minimum vigour under dry conditions and thus were more vigorously and thus help to offset the injuries to the plant roots even though the treatment does not kill the larvae.

In this glasshouse experiment, several plants in the wet soil moisture treatments which had their main root severed some distance below the crown still survived with no wilting of the leaves. This was apparently due to several fibrous roots emanating from the main root just above where it had been severed as show in Plate 11. Presumably, in a situation where soil moisture was not limiting, these roots enabled the plant to withdraw sufficient moisture from the soil to continue normal growth. In contrast, other plants from the wet soil moisture treatments which had large portions of the root tissue destroyed at one particular spot some distance below the crown as shown in Plate 12, had very few fibrous roots present above the damaged

PLATE 11 Lucerne plant with main root severed but demonstrating root regrowth

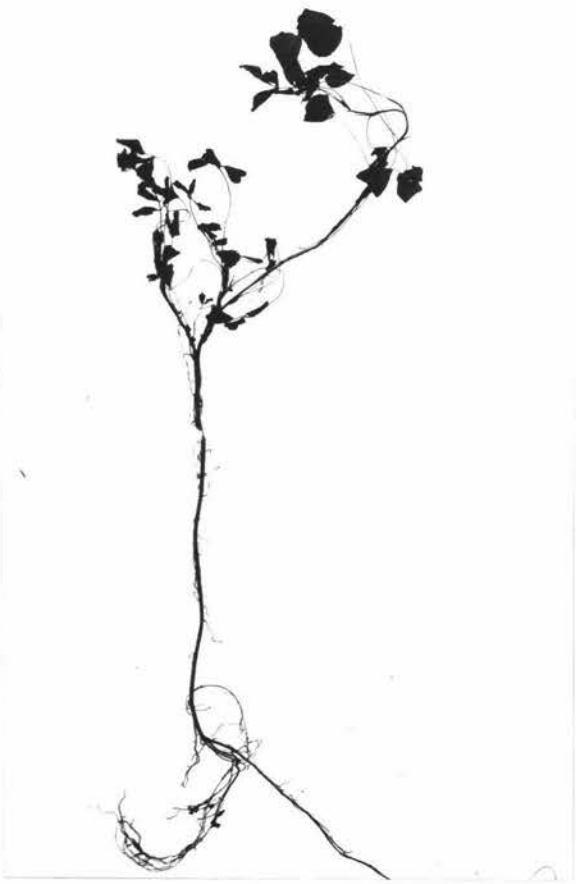


PLATE 12 Lucerne plant with main root partially severed - no root regrowth evident

portion and the plants were severely wilted. Although roots are still present below the damaged portion, it is doubtful whether enough xylem still remains functional in the tissue linking the two parts of the main root to enable water to be transported through to the tops.

Although plant mortality increased as the initial larval population per plot increased in both the combined soil moisture treatments and within the dry soil moisture treatment, the means of each treatment were not significantly different ($P<0.01$ or $P<0.05$). This was probably due to the increase in the proportion of larvae of higher initial individual weight range with increase in larval population. Gross et al (1972) reported that larger larvae in the prepupal stage ceased feeding while Steven (pers. comm.) observed that the feeding activity of the larvae declines as they near the pupal stage.

Table III.18, shows that the mean root dry weight of surviving plants is significantly higher ($P<0.01$) for the 1 larva per plot/dry soil moisture level inter-action than the 2 or 4 larvae per plot/dry soil moisture interactions. This implies that the amount of plant root consumed by the larvae increases with larval population at the dry soil moisture level with a consequent reduction in root weight. Gross et al (1972) report that extensive pruning of the fibrous root system of rye plants in plots infected with white fringed weevil larvae was evident. The mean root dry weight of surviving plants in the dry soil moisture level/1 larva per plot treatment interaction is also significantly higher ($P<0.01$) than the wet soil moisture level/1 larva per plot treatment interaction. This would indicate that at low larval populations, lucerne plants will have a more extensive root system in response to a lower soil moisture content. Weaver (1926) found that in a dryland soil where water was very scarce in the first 30cm. three month old lucerne plants had a shallower, more profusely branched root system than lucerne plants grown in irrigated soil.

Although the mean top dry weight of surviving plants decreases with increasing initial larval population with the dry soil moisture treatment and is higher in the wet than in the dry soil moisture treatment, there are no significant differences ($P<0.01$ or $P<0.05$) between treatment or treatment interaction means. These trends would be expected since the higher soil moisture content would result in greater top growth. The decreasing root weight as the larval population within the dry soil moisture treatment increases as shown in Table III.19, would also result in reduced top growth. Peters and Runkles (1972) report that overall plant growth diminished with increasing water stress, but root growth is less influenced than is top growth.

Table III.20 shows that the mean top /root ratio of surviving plants

in the wet soil moisture treatment is significantly higher ($P<0.01$) than in the dry soil moisture treatment. Generally the top /root ratio decreases with decreasing soil moisture content as shown by Harris (1914) for corn, wheat and peas.

Although the mean life span of plants decreased with increasing initial larval population and was higher for the wet soil moisture treatments than the dry soil moisture treatments no significant differences ($P<0.01$ or $P<0.05$) between means were evidnet as shown in Table III.13. However the above trends suggest that either increasing soil moisture reduced the feeding activity of the larvae so that their rate of severing main roots of plants is reduced or the plants in the wet soil moisture treatment, although damaged early in the experiment survived longer because of the compensatory effect of non-limiting soil moisture.

The interpretation of the root residue results is difficult because the source of the root material could be fine roots shed by the plant due to soil moisture stress, roots pruned by the larvae from still living plants or roots from dead plants. The mean root residue dry weight is significantly higher ($P<0.01$) in the dry soil moisture treatment than in the wet soil moisture treatment. Weaver (1926) states that in dry soil conditions, both root hairs and young rootlets die.

The 1 larva per plot and 2 larvae per plot treatments have significantly higher ($P<0.05$) mean root residue dry weights than the 4 larvae per plot treatment. This suggests that the greater number of larvae present in the latter treatment are actually consuming a greater proportion of the root material present. The mean root residue dry weight for the 1 larva per plot/ dry soil moisture treatment is significantly higher than the mean root residue dry weights for all three initial larval population/wet soil moisture treatments which is compatible with the other root residue results.

(C) GENERAL DISCUSSION AND PRACTICAL IMPLICATIONS.

This study has highlighted some of the problems associated with the establishment of lucerne in the Manawatu sand country.

Although Wairau had a significantly higher percentage establishment than College Glutinosa, 110 days after sowing the difference was not apparent at the end of the experiment. It is suggested that the early difference was due to a greater susceptibility of College Glutinosa to damping-off by fungous species. It is probable that the damage associated with white fringed weevil larvae which was greater where plants were more closely spaced, was responsible for the similarity in plant survival at the end of the first year.

The percentage establishment 110 days after sowing was significantly higher at the wider spacings. It is suggested that this was due to seedling mortality caused by damping-off being greater at these closer spacings. However, in spite of this, the greater number of lucerne plants per unit area at the closer spacing resulted in a significantly higher lucerne dry matter production in the first year after sowing.

Lucerne sown at wider spacings had a higher nodule dry weight per plant than that sown at closer spacings. Since these differences were not reflected in lucerne dry matter production it must be assumed that either the nodules on plants at wider spacings were less efficient or as seems more likely, nitrogen was not the factor limiting dry matter production at this stage.

It was found that soil moisture tension in Position I was initially lower than in Position II than in Position III. Subsequently, low rainfall resulted in high soil moisture tension in all positions. Thus the observed differences in soil moisture tension between positions were not as great as had been expected due almost certainly to the atypically low rainfall experienced during the course of the experiment. As a result of this, no large differences between positions in lucerne dry matter production was found and total lucerne production was extremely low.

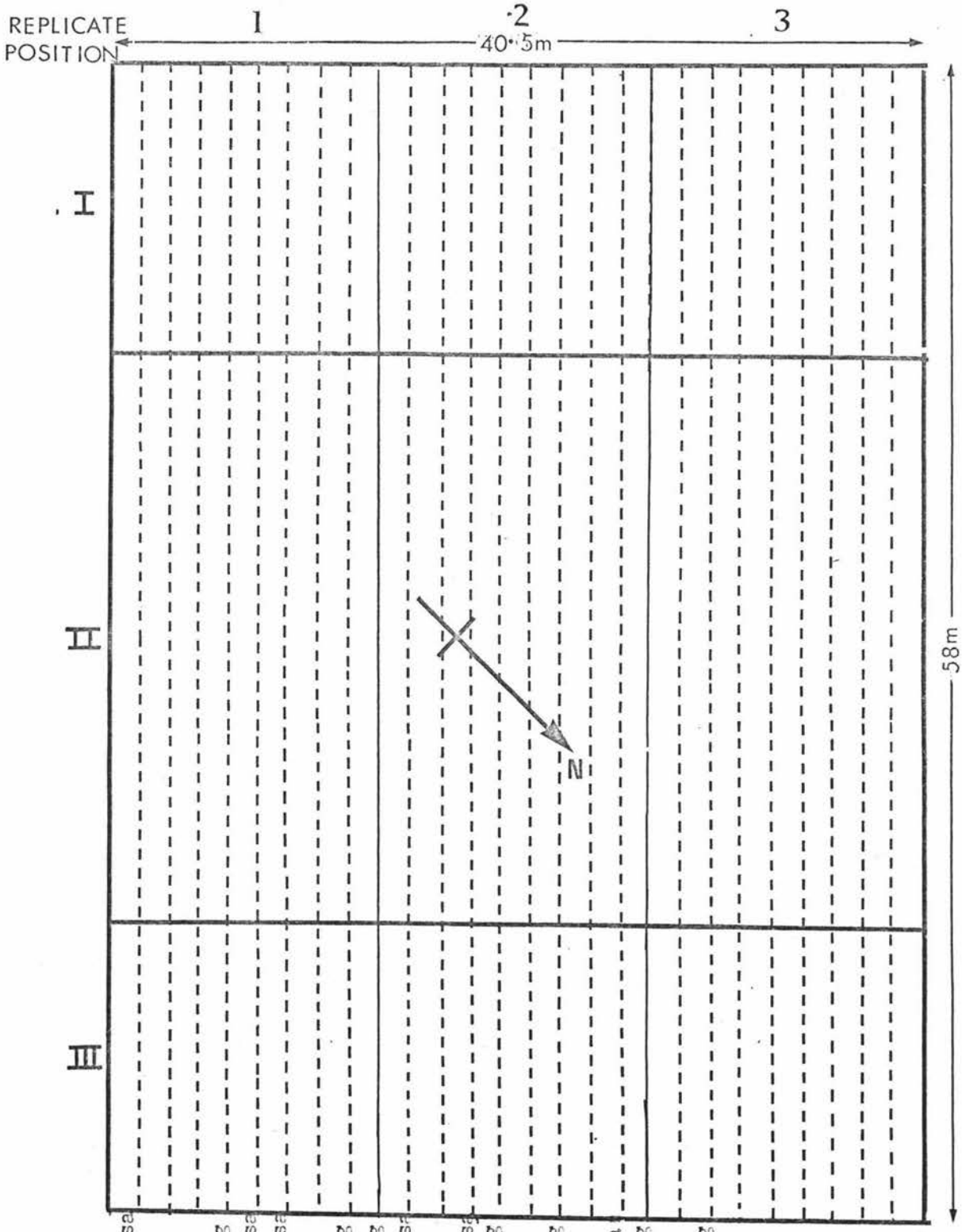
This low production can not be entirely attributed to the low soil moisture status.

Results from the glasshouse experiment showed the existence of an interaction between larval population and soil moisture status in determining plant mortality. Thus it appears that the lower moisture status of the soil in Position III during December and the greater number of larvae present in this position together resulted in the differences in the degree of damage to plants between the positions. Although dessication of plants was not observed until early January it can be assumed that the larvae were active

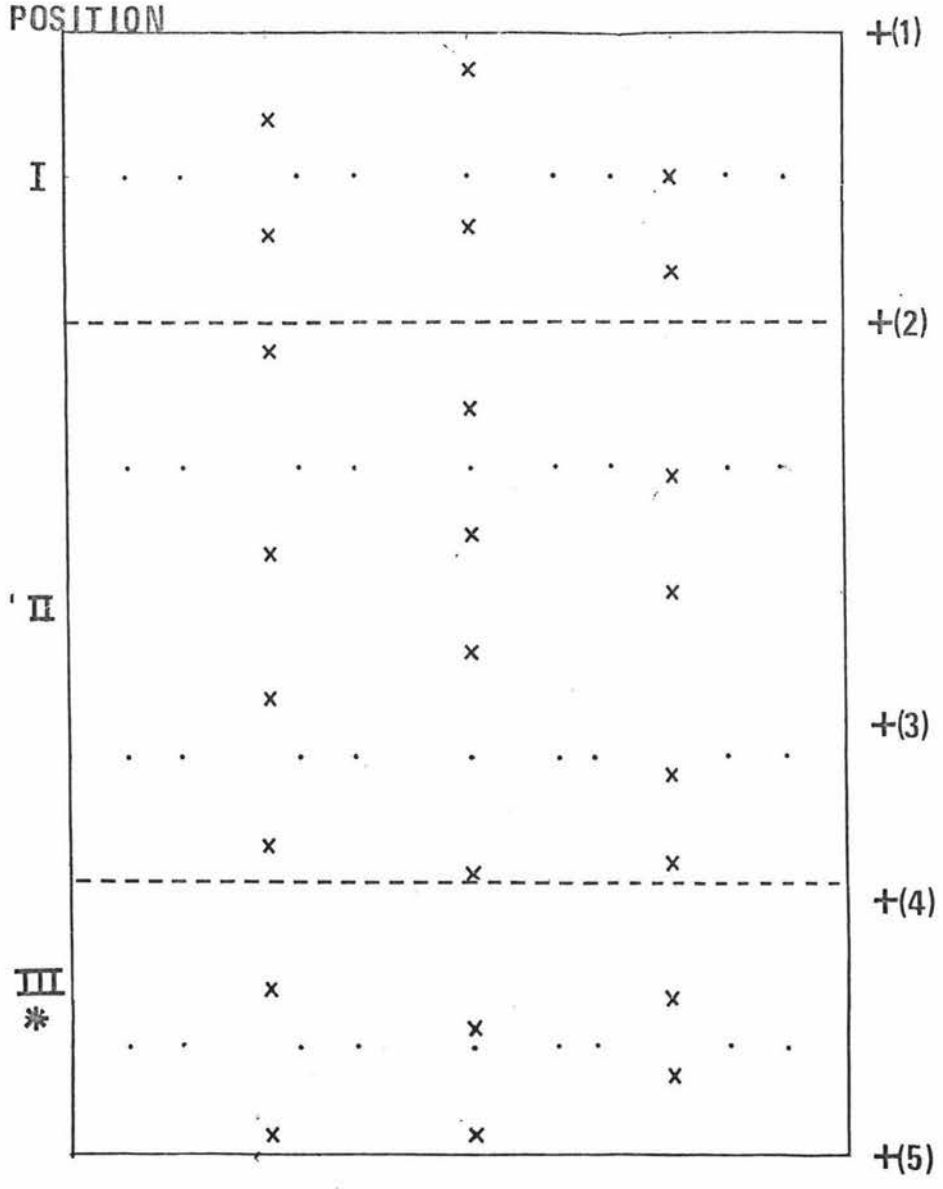
before this period. Presumably if regular rainfall had fallen over the summer months or irrigation had been used the larval damage to lucerne plants could have been reduced as suggested by the results of the glasshouse experiment.

From the evidence of the field experiments, it seems that it is impractical to attempt to establish lucerne on well drained sand country soils with large numbers of white fringed weevil larvae present in an unirrigated situation until new methods of larval control are found. On the poorer drained soils, sufficient lucerne plants may survive in a season of normal rainfall to give a productive lucerne stand in susequent years. Established lucerne stands in this area showed no evidence of larval damage and it appears that the increase in diameter and development of secondary thickening of the main root of the plant with time is responsible for this. However, even in a situation where conditions are conducive to plant survival during establishment, lucerne production is likely to be reduced where larvae are present compared with production in an uninfested stand.

APPENDIX 1: Field experiment layout.



APPENDIX 2: Location of measurement sites.



. gravimetric soil moisture measurement sites.

× gypsum block soil moisture measurement sites.

\+ water table depth measurement sites.

* wind-speed and rainfall measurement site.

APPENDIX 3: Weekly water table depths.

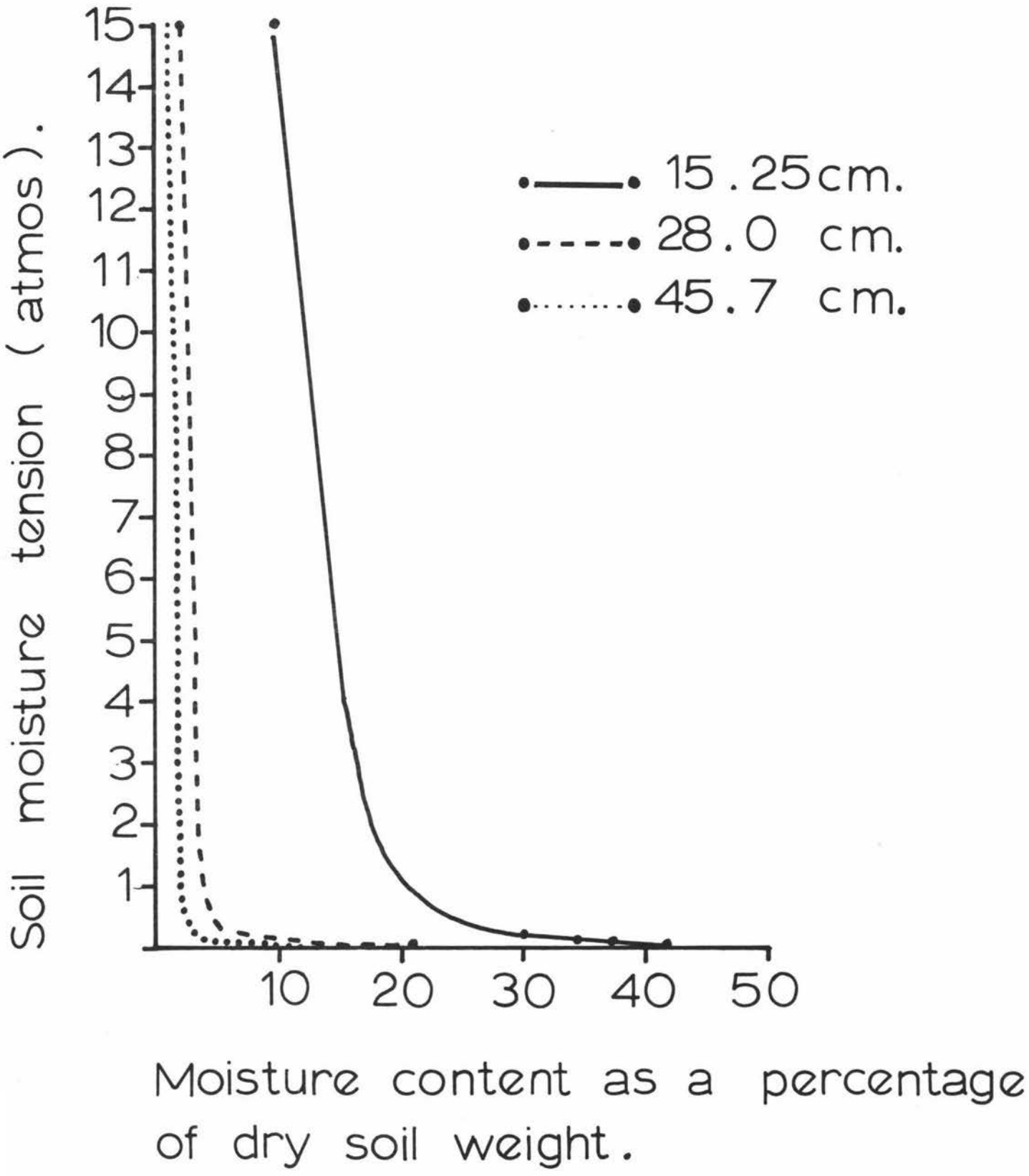
Date		Distance below soil surface (cm.)				
1973	Site: (1)	(2)	(3)	(4)	(5)
25.5	135	142	171	250	243
30.5	132	144	172	252	242
7.6	116	130	163	241	236
12.6	101	115	144	226	221
19.6	107	124	136	221	215
26.6	120	115	140	225	201
3.7	101	118	135	221	216
10.7	94	109	133	216	215
17.7	104	117	132	216	211
24.7	95	109	133	219	215
31.7	98	106	131	216	212
7.8	96	111	132	217	213
14.8	90	105	130	216	211
21.8	89	107	128	214	209
28.8	97	110	126	210	204
3.9	104	116	130	216	211
10.9	96	113	129	216	211
18.9	29	53	97	195	171
24.9	43	54	75	159	156
1.10	72	84	94	177	171
8.10	87	101	109	194	181
15.10	95	109	119	204	200
22.10	105	120	132	211	210
29.10	101	116	131	216	212
5.11	113	127	139	225	220
12.11	115	131	144	230	226
19.11	100	119	151	230	226
26.11	122	135	150	234	231
3.12	130	143	156	241	237
10.12	138	150	162	247	244
17.12	144	158	170	255	251
23.12	146	157	173	257	254
31.12	146	164	180	264	260
1974					
7.1	151	163	181	267	263
14.1	155	173	190	274	269

APPENDIX 3: Cont.

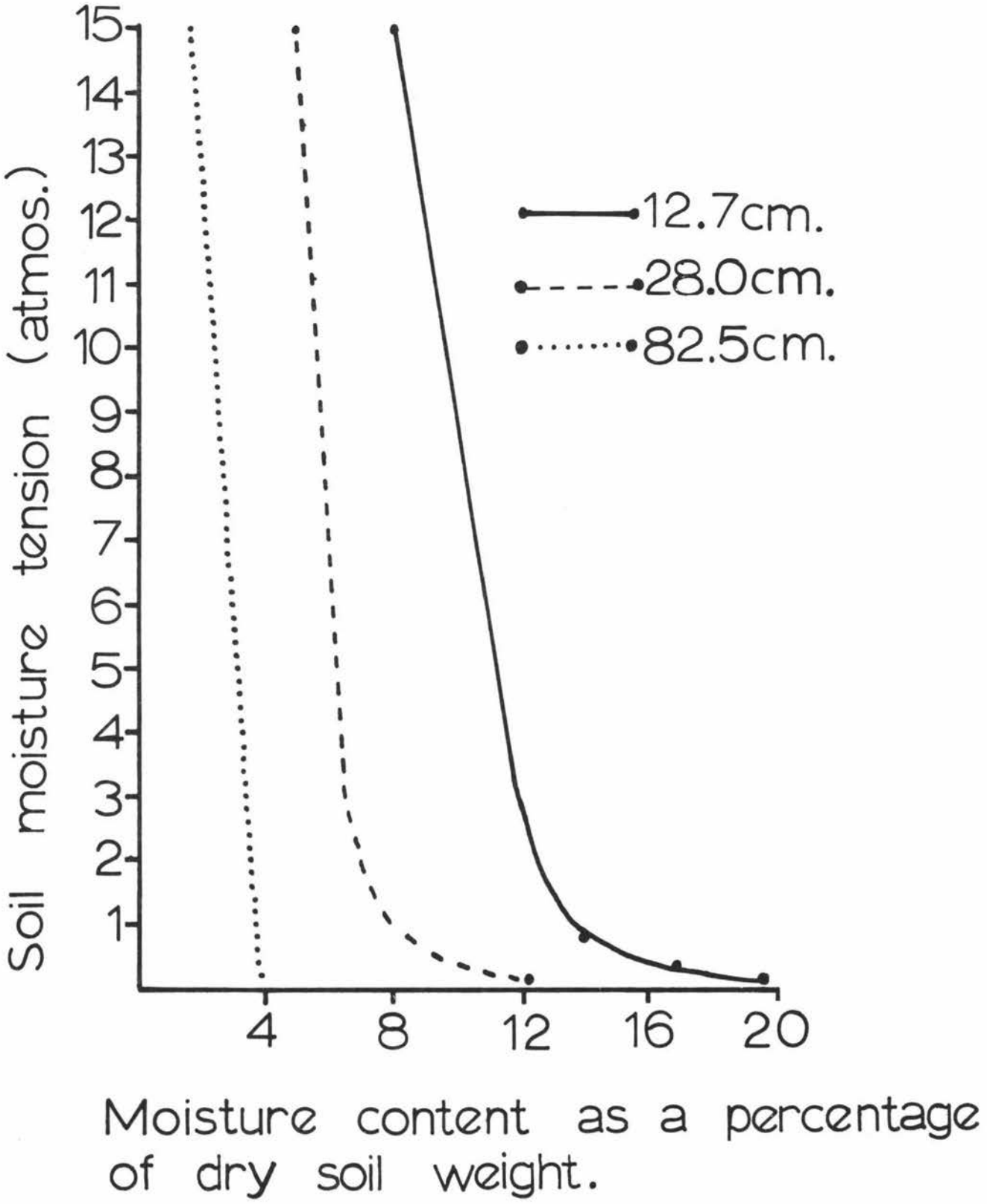
Date		Distance below soil surface (cm.)				
1974	Site:	(1)	(2)	(3)	(4)	(5)
21.1		160	178	204	278	271
28.1		165	184	206	279	276
4.2		168	189	207	286	280
12.2		175	196	212	292	287
18.2		176	197	212	292	290
25.2		177	197	212	292	291
31.2		178	198	217	294	291
7.3		179	199	223	295	291
15.3		186	206	227	296	290
21.3		188	208	232	298	290
28.3		193	214	234	301	292
4.4		195	216	236	304	298

APPENDIX 4: Soil moisture tension (atmosphere) at 90cm. soil depth. (September, 1973 to February, 1974)

Position	I	II	III
Mean	0.05	0.09	0.54
Range	0.05-0.05	0.05-0.30	0.05-1.60

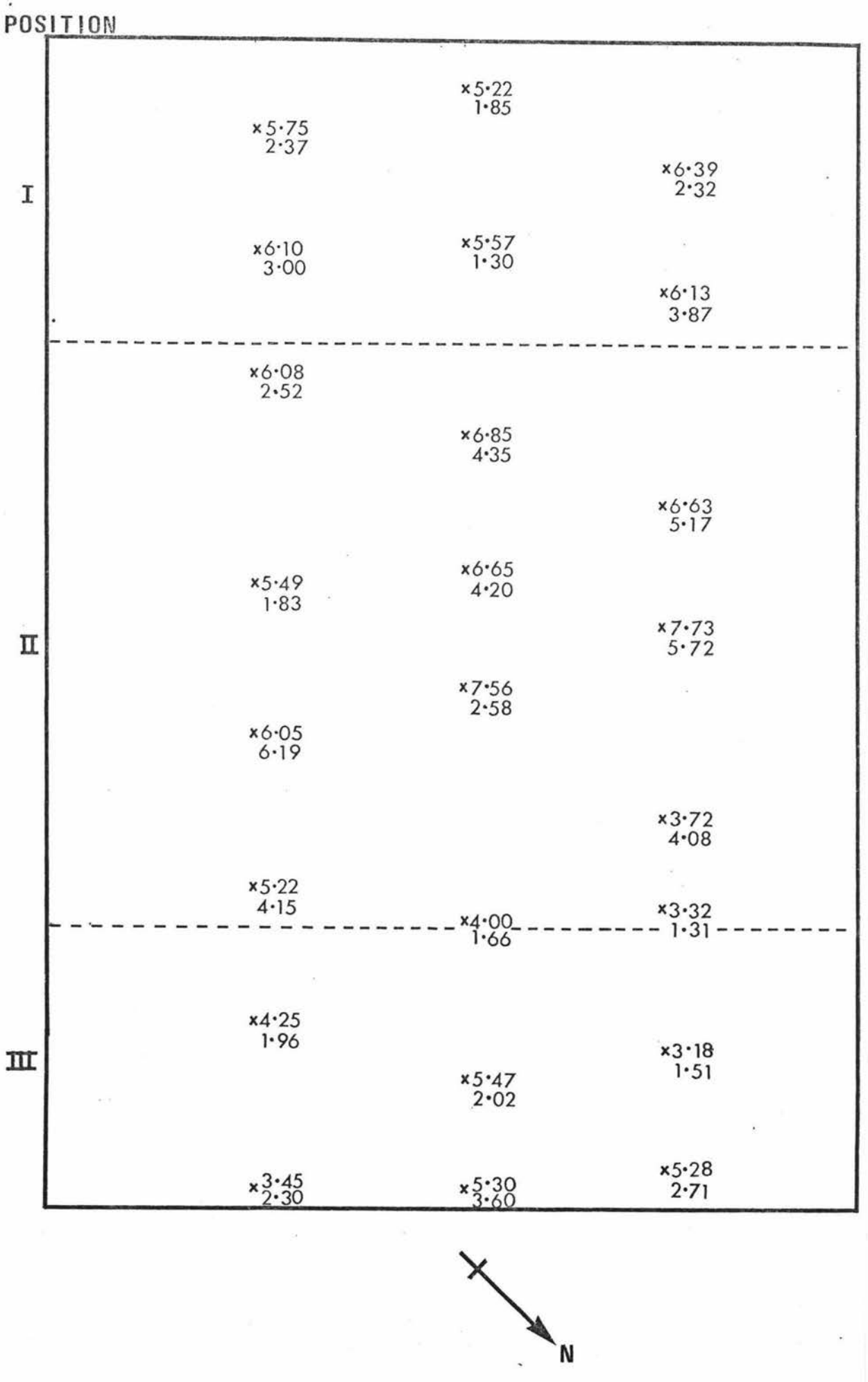


APPENDIX 5 SOIL MOISTURE TENSION/MOISTURE CONTENT CURVE FOR PUKEPUKE BLACK SAND



APPENDIX 6 SOIL MOISTURE TENSION/MOISTURE CONTENT CURVE FOR FOXTON BLACK SAND

APPENDIX 7: Soil organic matter at 10cm. (upper) and 30cm. (lower) depth.



APPENDIX 8: Manufacture of the gypsum blocks.

The procedure outlined below is that used for the manufacture of F.F.F. Blocks described by Aitchison et al (1951) with various modifications.

(i) Preparation of wires.

The desired length of plastic insulated twin-care flex (214/0.0076 Olympic) according to the depth of placement of the particular block was cut and the wires separated for about 10cm. at one end. The insulation was carefully stripped for 6cm. and the wires evenly tinned by immersing in molten 50/50 tin-lead solder. The bared portion of the wires was straightened and cut to 5.2cm. as accurately as possible. This procedure was repeated at the other end of the length of flex with 2.5cm. being stripped and tinned to facilitate soldering on to the socket board connection.

(ii) Mould.

The moulds used consisted of 8cm. lengths of 2cm. inner diameter plastic pipe sawn down the centre to give two even halves. These were joined together by two rubber bands and stoppered at one end by a rubber cork also split in two with holes made to accomodate the flex. The bared ends of the wires were threaded through the cork and held in position 1cm. apart by a length of 3mm capilliary tubing at the end of the bared portion. The moulds were then inverted to pouring the plaster.

(iii) Pouring of plaster.

160g. of F.F.F. dental plaster was added to 120ml of distilled water in a rubber mixing bowl. This was mixed thoroughly and poured before the plaster could set. The mould was filled and after the plaster had set the rubber bands were removed and the two halves of the mould seperated to give a cylindrical block 7cm. in length and 2cm. in diameter. The blocks were manufactured in batches of ten.

APPENDIX 9: Percentage establishment of lucerne plants at four counts.

Replicate 1.

Position	Treatment		Percentage live plants as percentage seed sown			
	Variety	Spacing (cm.)	31.5.73	3.7.73	16.8.73	23.4.74
I	College Glutinosa	2.02	35	31	27	1
		9.16	34	32	32	8
		15.22	61	60	58	17
	Wairau	2.02	47	37	35	2
		9.16	45	33	30	12
		15.22	58	50	36	6
II	College Glutinosa	2.02	33	27	24	1
		9.16	30	23	18	4
		15.22	53	47	44	12
	Wairau	2.02	50	40	34	8
		9.16	37	33	32	5
		15.22	61	54	49	10
III	College Glutinosa	2.02	26	25	21	0
		9.16	30	30	27	0
		15.22	25	25	25	5.5
	Wairau	2.02	40	36	28	1
		9.16	33	33	30	1.7
		15.22	66	66	66	5.5

Replicate 2.

I	College Glutinosa	2.02	34	32	27	11
		9.16	36	30	23	20
		15.22	50	49	47	19
	Wairau	2.02	56	41	35	10
		9.16	40	40	38	18
		15.22	55	54	53	17
II	College Glutinosa	2.02	27	26	24	2
		9.16	33	30	24	1
		15.22	43	43	41	13
	Wairau	2.02	44	40	37	3
		9.16	32	27	27	10
		15.22	47	42	39	17
III	College Glutinosa	2.02	36	34	29	0
		9.16	30	30	28	0
		15.22	33	33	31	3
	Wairau	2.02	40	37	34	0
		9.16	34	33	33	0
		15.22	66	66	61	6

APPENDIX 9: Cont.

Replicate 3.

Position	Treatment		Percentage live plants as percentage seed sown			
	Variety	Spacing (cm.)	31.5.73	3.7.73	16.8.73	23.4.74
I	College Glutinosa	2.02	37	30	28	14
		9.16	40	32	30	8
		15.22	47	47	39	22
	Wairau	2.02	47	43	37	14
		9.16	55	40	35	30
		15.22	69	50	47	43
II	College Glutinosa	2.02	27	22	19	5
		9.16	33	28	28	13
		15.22	40	33	31	14
	Wairau	2.02	42	38	32	9
		9.16	37	36	33	15
		15.22	47	42	40	10
III	College Glutinosa	2.02	23	23	22	5
		9.16	22	22	22	13
		15.22	42	39	39	11
	Wairau	2.02	44	43	37	8
		9.16	55	55	52	7
		15.22	60	56	56	29

APPENDIX 10: Plant component and nodulation measurements for a total of five plants per plot.

Replicate 1.

Position	Treatment		Measurement			
	Variety	Spacing (cm.)	Nodule number	Nodule dry weight (mg.)	Top dry weight (g.)	Root dry weight (g.)
I	College Glutinosa	2.02	6	30	2.88	1.19
		9.16	20	40	1.92	1.15
		15.22	11	40	4.75	0.96
	Wairau	2.02	9	60	2.55	1.54
		9.16	9	10	4.10	1.83
		15.22	8	30	2.81	1.75
II	College Glutinosa	2.02	15	35	2.48	1.26
		9.16	12	30	2.37	1.18
		15.22	10	65	2.66	0.15
	Wairau	2.02	15	80	2.99	1.66
		9.16	16	30	2.73	1.50
		15.22	10	105	3.05	1.72
III	College Glutinosa	2.02	7	70	2.40	1.77
		9.16	10	70	2.61	1.63
		15.22	12	140	2.00	1.69
	Wairau	2.02	11	80	3.38	3.03
		9.16	20	140	3.22	2.70
		15.22	11	70	1.70	1.48

Replicate 2.

I	College Glutinosa	2.02	17	10	2.93	1.21
		9.16	12	80	3.23	1.63
		15.22	15	90	4.25	1.49
	Wairau	2.02	11	10	2.07	1.02
		9.16	13	60	2.78	1.44
		15.22	6	40	2.85	1.61
II	College Glutinosa	2.02	17	45	2.91	1.36
		9.16	13	50	2.58	1.35
		15.22	10	95	3.23	1.39
	Wairau	2.02	16	55	2.61	1.53
		9.16	11	80	5.73	1.69
		15.22	14	50	2.57	2.90
III	College Glutinosa	2.02	13	60	2.70	1.88
		9.16	20	130	3.58	2.54
		15.22	13	90	2.57	2.02
	Wairau	2.02	19	80	2.66	2.38
		9.16	11	70	2.64	1.82
		15.22	5	50	2.61	2.41

APPENDIX 10: Cont.

Replicate 3.

Position	Treatment		Measurement			
	Variety	Spacing (cm.)	Nodule number	Nodule dry weight (mg.)	Top dry weight (g.)	Root dry weight (g.)
I	College Glutinosa	2.02	8	20	1.71	0.92
		9.16	12	30	1.76	0.82
		15.22	6	40	1.82	0.86
	Wairau	2.02	11	20	2.58	1.04
		9.16	15	60	2.18	1.15
		15.22	7	40	1.79	1.04
II	College Glutinosa	2.02	8	30	2.49	0.98
		9.16	13	110	2.72	1.13
		15.22	10	95	3.07	1.13
	Wairau	2.02	17	45	2.66	1.39
		9.16	14	70	3.01	1.64
		15.22	13	55	3.00	1.09
III	College Glutinosa	2.02	18	110	3.65	2.75
		9.16	25	130	4.93	2.43
		15.22	11	190	5.88	1.77
	Wairau	2.02	17	40	2.40	1.32
		9.16	14	90	2.52	1.99
		15.22	19	120	3.55	2.10

APPENDIX 11: Total dry matter production (TDM) and lucerne dry matter production (LDM) (kg/ha) at the three production cuts.

Replicate 1.

Position	Treatment		5.12.73		21.2.74		9.4.74	
	Variety	Spacing (cm.)	TDM	LDM	TDM	LDM	TDM	LDM
I	College	2.02	1237	232	207	49	223	60
	Glutinosa	9.16	389	9	255	3	149	27
		15.22	2287	160	197	71	148	60
	Wairau	2.02	738	148	147	109	182	81
		9.16	280	44	186	24	197	35
		15.22	453	5	172	33	314	53
II	College	2.02	808	132	291	170	85	58
	Glutinosa	9.16	1931	119	257	72	100	37
		15.22	408	24	257	392	112	35
	Wairau	2.02	787	401	334	331	212	87
		9.16	724	145	241	86	166	54
		15.22	518	30	250	90	111	30
III	College	2.02	730	197	328	269	240	104
	Glutinosa	9.16	373	63	313	158	177	96
		15.22	1056	60	354	264	247	69
	Wairau	2.02	495	188	397	311	303	109
		9.16	392	118	185	49	218	37
		15.22	810	15	341	224	360	115

Replicate 2.

I	College	2.02	705	133	271	149	138	80
	Glutinosa	9.16	816	67	199	85	123	25
		15.22	521	138	331	243	223	163
	Wairau	2.02	705	133	271	149	138	141
		9.16	560	26	286	146	203	116
		15.22	673	15	294	101	149	89
II	College	2.02	322	89	321	234	146	120
	Glutinosa	9.16	557	216	188	77	175	93
		15.22	218	30	573	321	297	160
	Wairau	2.02	580	270	339	262	175	148
		9.16	493	53	330	169	167	94
		15.22	465	26	204	121	130	40
III	College	2.02	230	104	226	216	117	54
	Glutinosa	9.16	359	91	214	14	227	14
		15.22	947	540	367	189	112	58
	Wairau	2.02	485	177	226	217	182	66
		9.16	280	50	279	192	79	21
		15.22	511	82	119	73	174	24

APPENDIX 11: Cont.

Replicate 3.

Position	Treatment		5.12.73		21.2.74		9.4.74	
	Variety	Spacing (cm.)	TDM	LDM	TDM	LDM	TDM	LDM
I	College Glutinosa	2.02	1807	423	321	172	279	179
		9.16	1051	214	276	128	177	126
		15.22	2277	141	215	114	169	78
	Wairau	2.02	1088	219	284	238	221	217
		9.16	362	112	295	217	224	152
		15.22	752	67	276	175	174	103
II	College Glutinosa	2.02	709	168	598	315	252	197
		9.16	776	239	572	291	400	259
		15.22	453	24	255	117	216	137
	Wairau	2.02	953	433	692	453	306	228
		9.16	462	68	747	339	350	169
		15.22	910	42	467	130	328	165
III	College Glutinosa	2.02	1104	552	355	293	274	255
		9.16	528	186	316	159	272	212
		15.22	541	166	164	96	241	171
	Wairau	2.02	1005	510	422	410	450	450
		9.16	489	262	249	139	164	121
		15.22	499	132	448	376	261	217

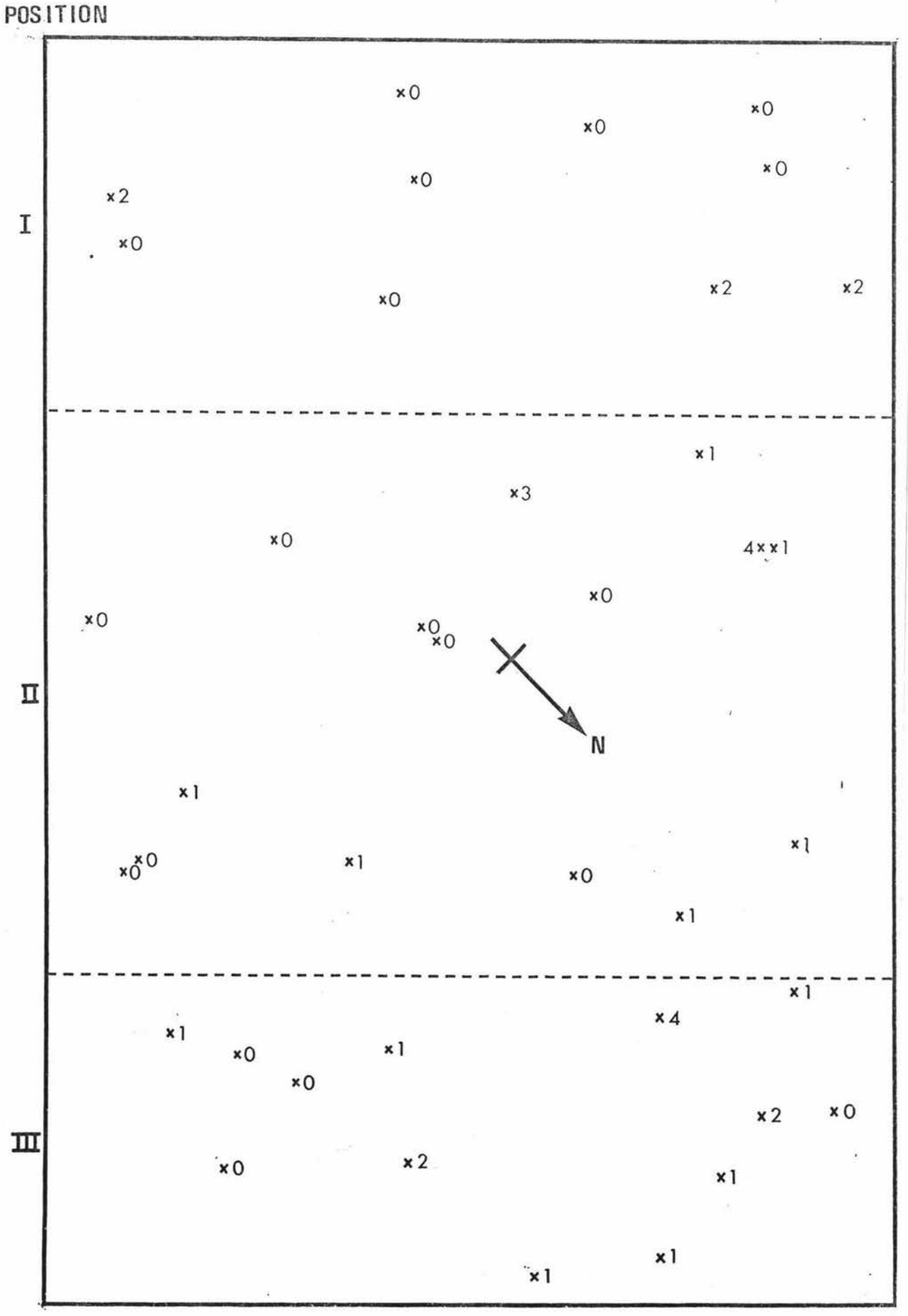
APPENDIX 12: Percentage of dessicated lucerne in the lucerne component at second production cut. (21.2.74)

Position	Mean percentage of dessicated lucerne
I	12.13
II	19.54
III	29.66

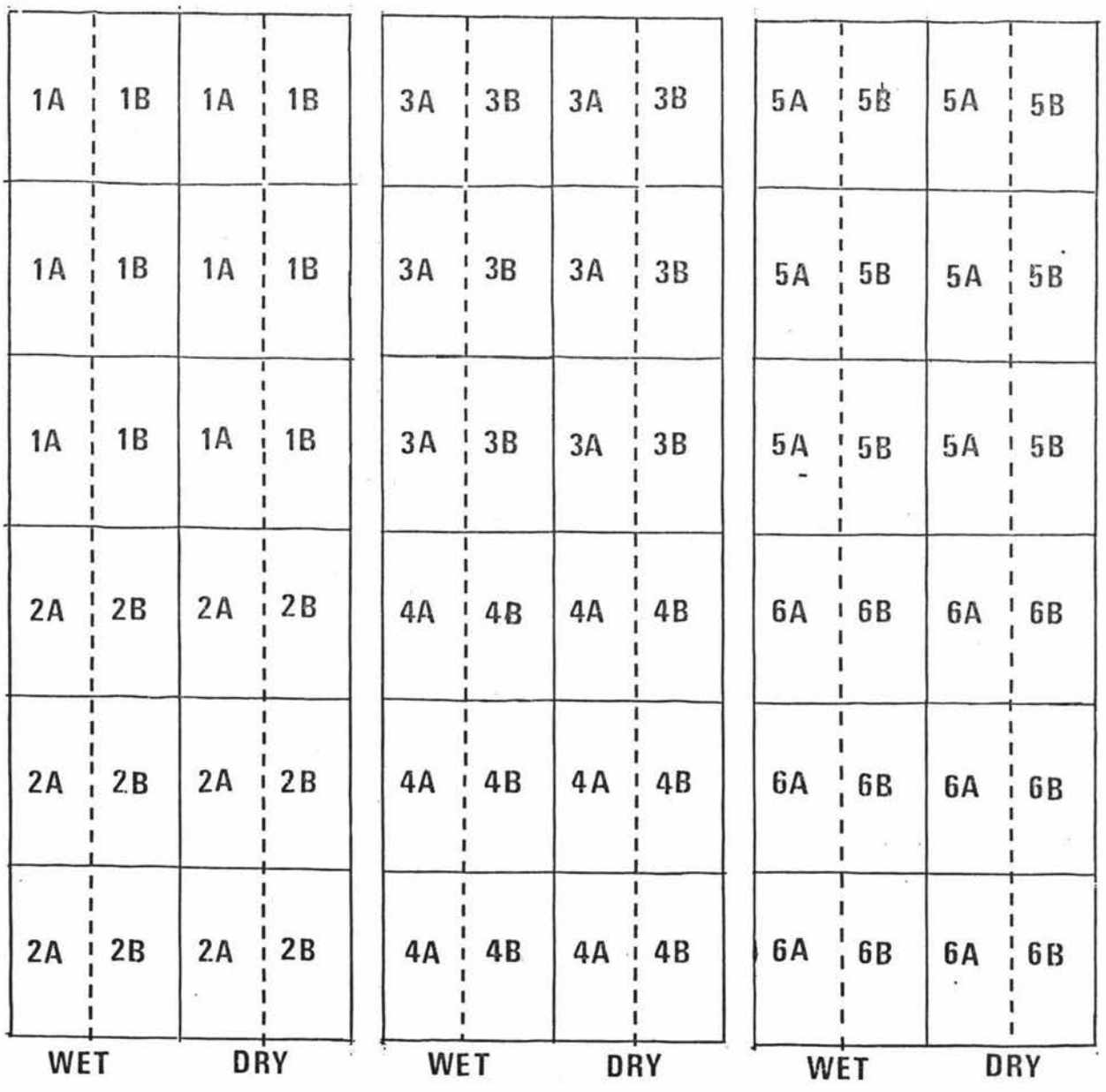
APPENDIX 13: Observations on weed growth during the course of the field experiment.

Weed Species	Position	M	J	J	A	S	O	N	D	J	F	M
Trifolium subterraneum L.	I II III				Dense growth Uneven distribution Effectively nil							
Lotus subbiflorus Lag	I II III						Dense growth Uneven distribution Effectively nil					
Leontodon taraxacoides Vall.	I II III						Dense in Rep. 3. Uneven moderate infestation Reps 42 " " " " " " Slight infestation. Uneven distribution					
Juncus bufonius L.		Seedlings in Position I only										
Lolium perenne L.		Isolated clumps over whole site										
Hordeum murinum L.					Position III (Rep.1) Slight infestation							
Bromus catharticus L.					Position III (Rep. 1) Slight infestation							
Stellaria media L.					Slight infestation over whole site							
Erodium cicutatium L.					Slight infestation over whole site							
Rumex acetosa L.					Slight infestation over whole site							
Trifolium fragiferum L.							Position III Slight infestation					
Trifolium repens L.							Whole site. Slight infestation					
Portulaca oleracea L.									Positions II and III Moderate infestation			
Lupinus arboreus L.									Positions II and III Isolated plants			

APPENDIX 14: Distribution of white fringed weevil larvae at 14.3.74.



APPENDIX 15: Glasshouse experiment layout.



Blocks: 1-6

Replicates within blocks: A,B

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