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THE EFFECTS OF TEMPERATURE AND IRRIGATION ON THE ESTABLISHMENT AND GROWTH OF LUCERNE (*Medicago sativa* L.) ON MANAWATU SAND COUNTRY.

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SUMMARY

This thesis reports on three experiments carried out in the summer and autumn of 1971/72. The first experiment was on a Himatangi sand (a very well drained soil with about 15 cm of black topsoil, over loose sand (Cowie <u>et al</u> , 1967)). 0.4 ha was sown on November 25 with Wairau lucerne, and areas of this were allocated to irrigated or non-irrigated main plots. Sub-plots had one of six different surface treatments (no mulch; bitumen; straw; straw over bitumen; white paint on bitumen; no mulch but sown with lupin).

Measurements made were plant counts and dry weights at several dates, soil moisture, soil temperature, rainfall, windrun, wind erosion, plant mortality, plant wilting, flowering, net radiation and surface albedo with the various treatments.

The main results observed were that plant mortality was high in the bitumen treatment, and also in the unmulched and lupin treatments and these results were attributed to the high 2 cm depth mean maximum soil temperatures recorded. The 2 cm soil temperatures were highest under the bitumen, followed by the unmulched and lupin treatments. The lowest temperatures recorded were on the two straw treatments. Yield per plant and per unit area were highest on the bitumen treatment, despite the greater plant mortality, and lowest on the straw treatments.

Subsequently, to check on the effects of high soil and soil surface temperatures on plant mortality and growth, two glasshouse experiments were carried out. Equipment was designed and built to independently vary the soil surface temperature from the soil temperature (below approx. 2.5cm). In the first experiment with four surface temperatures (25, 35, 45, 55°C) for 3 - 3¼ hours/day and two soil temperatures (25, 35°C) continuously it was found that plants in a pot with a 45 or 55°C surface temperature died, while there were no significant differences in growth rates between 25 and 35 35°C for either soil or surface temperature.

In the second glasshouse experiment a temperature of 50°C was used for either 3, 6 or 24 hours per day. This increased duration reduced dry matter yield, while increasing the number of days treated (from 1 to 3 or 7 days) had no effect. Seedlings 10 days from planting were affected much more by high temperature than those 13 days old.

It was concluded that the soil temperatures recorded on the sand country in the summer months could be too high for the survival of lucerne seedlings from seedings carried out at that time of the year.

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INTRODUCTION

This research was undertaken to study the establishment of lucerne on one of the drier soils of the Manawatu sand country. Lucerne has often been difficult to establish on these soils, yet once established grows well, possibly due to the large supply of water that is to be found in the water table a metre or so below the surface.

Difficulty in establishing lucerne has often been attributed to shifting of the unconsolidated cultivated sand surface by wind, and also to the low moisture holding capacity of the soil. Lucerne stands are usually sown in the spring, but the available soil moisture may be quickly evaporated by the strong prevailing westerly wind at this time and wind erosion may occur, often burying plants with sand and leaving other young plants with their root systems exposed.

Another possible reason for poor establishment of lucerne could be the high surface temperatures often experienced on the bare surface.

The aim of the field study was to examine the effects of soil temperature, soil moisture and wind erosion on lucerne establishment. Subsequently, glasshouse experiments were conducted to investigate the effects of temperature variations in the soil and on the surface on the growth and survival of lucerne seedlings.

Chapter One REVIEW

1.1 Introduction

The aim of the experiments was to examine the effect on lucerne establishment and survival, of some factors that are characteristic of the Manawatu sand country. It is not intended to review all aspects of germination and establishment of lucerne. Rather, attention will only be paid to the three factors of wind erosion, soil moisture and soil temperature since these were the factors considered in this study. The main emphasis in this review will be on the early growth of the seedling, until it is considered to be established. Since "establishment" appears to have been rarely defined in the literature, it is here defined as the stage at which the plant could be reasonably expected to continue to grow under normal seasonal climatic conditions and management practices.

In this review, use has often been made of information available on other species, in an attempt to present a reasonably complete picture. Most of this information is drawn from work on other legumes, but this is not always the case. Unless otherwise stated the literature quoted refers to lucerne.

1.2 Description of the Sand Country

Soils formed from wind blown sands cover an area of over 110,000 ha on the West coast of the southern part of the North Island of New Zealand. A full description of the soils was given by Cowie, Fitzgerald and Owers (1967). Briefly, the soils in the Manawatu can be divided into 3 age groups, the oldest group furthest inland from the sea. Within each age group the soils are further subdivided into dune and plain soils. The plain soils are further classified into soil types largely on the basis of drainage and the type of humification.

A characteristic of the sand country is a fluctuating water table, which from a maximum level in the winter, may drop 1 to 2 metres in the summer. This water table has a distinct influence both on the soils and on the types of vegetation that can be grown on them. (Cowie _et al_, 1967; Esler, 1969; 1970)

The area is characterised by warm summers and mild winters. Rainfall is reliable and evenly spread throughout the year with about 75 mm a month. Most of the rain is brought by the prevailing westerly and north-westerly winds. Air temperatures are highest in February and lowest in July with mean monthly temperatures of 17.3°C and 8.0°C respectively (Cowie et al, 1967). During spring and early summer strong winds frequently reaching gale force are common. These decrease over the summer with only light winds over the late autumn to early spring period.

1.3 Requirements for establishment of lucerne

Establishment of lucerne can be considered as occurring in 3 related and not well defined phases. The first phase is germination, which does not have a uniform meaning in the literature. Some workers have regarded a seed as germinated when the seed coat is burst, while others only consider a seed germinated after the root or shoot has emerged or after the root or shoot have attained a certain length. Often there is a specification that growth must be "normal" (Shaw, 1952). Mayer and Poljakoff-Mayber (1963) define germination "as that consecutive number of steps which cause a quiescent seed, with a low water content, to show a rise in its general metabolic activity and to initiate the formation of a seedling from the embryo." This definition is desirable in that it differentiates between germination and growth but is not practical, because growth is usually the only way in which germination can be readily identified.

The second phase of establishment is the emergence of the seedling from the ground. In lucerne the unopened cotyledons emerge first, and open as they appear above the ground surface.

The third phase is growth of this seedling until it is considered established. The importance of the micro climate during this phase will be discussed in more detail later. Establishment of lucerne on sand country is considered to be complete when the lucerne covers the surface.

Shaw (1952) points out that fully ripened seed can germinate only when external conditions are favourable. Temperature, moisture, oxygen, carbon dioxide, soil pH, mineral elements and activities of micro-organisms may all affect the speed and completeness of germination. Parle (1967) and McElgunn and Heinrichs (1970) point out that there may also be antagonisms from other plants or micro-organisms. The viability of the seed is of obvious importance (Mayer and Poljakoff-Mayber, 1963). All the above factors also affect emergence and establishment of the seedling, and in addition the seedling must also be able to force its way through the soil. Hence depth of seedling, soil compaction and crusting are important (Williams, 1963; Triplett and Tesar, 1960).

Competition with weeds can affect the establishment of a stand (Allen, 1967). In particular on the sand country there is competition from subterranean clover (Trifolium subterraneum L.) and Indian doab (Cynodon dactylon (L.) Pers.) both of which are difficult to control with selective weedkillers at present available (L.W. Blackmore, pers. comm.).

Further information on requirements for lucerne germination and establishment may be found in several references e.g. Bolton, 1962; Langer, 1967; Bringans, 1971.

Briefly these are a firm, fine and weed free seed bed, with an adequate supply of nutrients and moisture. The soil may need lime to raise the soil pH for successful nodulation and growth.

Sowing is normally done on the Manawatu sand country in early spring or autumn to avoid the winds in the spring months and the hot, dry conditions in the summer months. The rate of seed sown is usually between 10 and 16 $kg.ha^{-1}$. Innoculation of the seed with a suitable strain of Rhizobium meliloti is essential for nodulation. The seed is usually sown 1 to 2 cm deep, without a companion crop.

Selection of sites for lucerne involves finding areas that are far enough above the average water table height not to be flooded during the winter.

Temperature and moisture are particularly important for the germination and establishment of lucerne and will be considered in more detail on the following pages.

1.3.1.1 Influence of temperature on plant growth

Temperatures related to plant growth are usually classified according to the "cardinal temperatures" proposed by Sachs in about 1860. A plant shows three cardinal temperatures; the minimum, the lowest temperature at which growth is exhibited; the optimum, the temperature at which growth is most rapid; and the maximum, the highest temperature at which growth will occur (Shaw, 1952).

These points are now realized not to be definite, but range over at least several degrees celsius, depending on the plant material, the period of exposure and other factors.

The influence of temperature is very complex, possibly affecting most of the growth processes of the plant. Hagan (1967) and Levitt (1972) discuss some of these possible processes, and the possible influences of high temperature on them. There is some evidence that plants can adjust to lower or higher temperatures (Shaw, 1952; Kramer, 1969; Levitt, 1972).

Temperature may also affect the plant growth through the effect on activity of micro-organisms in the rhizophere or nodules, or of pathogens.

1.3.1.2 Soil temperature, germination and emergence

Germination and emergence are intimately related to soil temperature (Shaw, 1952). The cardinal temperatures for germination of lucerne are about 4 - 5°C for the minimum, an optimum of about 25°C and a maximum of about 38°C. Germination is similar within the range 15 - 30°C (Dubetz et al, 1962; Williams, 1963; Larsen, 1965; Heinrichs 1967) although there are varietal differences.

Alternating temperatures are found to be more favourable for the germination of many seeds (Shaw, 1952). For lucerne seed germination, the Seed Testing Station of the New Zealand Ministry of Agriculture and Fisheries uses 20°C for 8 hours and 18°C for the remaining 16 hours (M. J. Hill, pers. comm).

The soil temperature is extremely variable and shows both diurnal and seasonal fluctuations. There is also usually a temperature gradient with depth (Chang, 1968). Germination is determined mainly on a suitable combination of temperature and moisture (Mayer and Poljakoff-Mayber, 1963) but these large fluctuations and steep gradients of temperature appear not to have been examined for lucerne. Cohen and Tadmor (1969) found the optimum temperature for seedling root elongation near the surface (2-12 cm) was generally higher than in the 12-22 cm depth.

Generally moderate daily fluctuations in soil temperature are desirable as they aid in soil moisture distribution and soil aeration and may be directly beneficial to plant growth (Kohnke, 1968). Shaw (1952) reported that growth in young pea plants proceeded equally well whether root temperature was constant or fluctuated as much as 22°C within 7 and 29°C as approximate limits. There appears to be little evidence that alternating temperatures favour root growth; rather sudden shifts in temperature may temporarily retard growth (Shaw, 1952).

1.3.1.3 The influence of soil temperature on root and top growth.

It is impossible to cite optimum temperatures for lucerne growth, because of evidence that optimum temperatures are much influenced by other environmental factors.

Brouwer (1962) showed that the influence of soil temperature on shoot growth may be considerable for a number of species. Gist and Mott (1957) found lucerne root growth was decreased as temperatures increased from 15.5 to 32°C at the light intensities used in their experiments. The maximum light intensity used was 1200 foot candles. Root growth was decreased more than top growth by increased temperature and decreased light.

Trevino (1965) found lucerne seedlings up to one month old were favoured by high temperature (30°C or 30°C day/15°C night at the high light intensity in their trial. McElgunn and Heinrichs (1970) found better growth of lucerne roots and tops at 20°C than at 10 or 15°C soil temperature. Heinrichs and Nielson (1966) found a maximum herbage production at 27°C soil temperature, while most root and nodular tissue was produced at 12°C. Leach (1971) with high levels of light found better growth at 27 and 33°C than at 15 and 21°C. Garza et al (1965) found that early in their growth lucerne seedlings were favoured by high temperatures, while later on they were favoured by lower temperatures. They found day and night temperatures of 30° and 15°C respectively gave the best growth. Rogers (1969) found with 3 month old plants a lower D.M. yield with high temperature in pots exposed to the sun than those that were cooled. Robison (1966) found that warm nights reduced growth, although initially there was a growth response to warm nights in seedlings. Henderson (1970) also found better top growth with cool (11 or 15°C) than warm (22°C) night temperatures.

Shaw (1952) gives results of trials with lucerne and red clover growing in pots, with the temperature ranging from 12 to 36°C in 3°C steps. The maximum top growth of lucerne at 9 weeks was at 21°C, with little growth below 15°C but reasonable growth up to 36°C. Red clover had little growth below 18 or above 33°C. As the plants became older and with more light Shaw reported that the dwarfing at 12 and 15°C disappeared. Shaw (1952) reports that with a range of air temperatures and light intensities the optimum temperature for soyabeans was 22 to 27°C. There was a smaller increase in top weight from 7 to 27°C with low light than with higher light intensity. The optimum temperature also increased with higher incident light intensity indicating some care must be used in interpreting experiments under low light intensities. Brouwer (1963) showed that temperature effects were dependent on high light intensity.

As the plants get older there is evidence of a shift to a lower optimum temperature (Shaw, 1952; Hagan, 1967). With cotton Shaw (1952) shows that the optimum temperature for a few days after germination is about 33 to 36°C, while by the seventh day the optimum is 27 to 30°C. In lucerne there has been a shift demonstrated towards a lower optimum temperature with age (Garza et al, 1965; Robison, 1966) over the first few weeks or months.

Shaw (1952) and Hagan (1967) report increasing top growth with temperature in strawberries up to a soil temperature of about 25°C, while root growth reached a maximum at about 10 - 12°C less. The roots were finer and more branched at the higher temperature. Shaw (1952) gives another example with tomatoes where top growth was greatest at 30°C in nutrient solution and root growth was greatest at 20°C. With soyabeans the roots reached a weight plateau from about 18 to 36°C, while top growth had a maximum at 27°C. There was an increase in the top : root ratio as temperatures increased, as in some lucerne trials (Heinrichs and Nielson, 1966).

The maximum temperature at which growth will occur is likewise difficult to cite. A plant can stand for several minutes temperatures which would kill it if the plant was exposed for several hours or days (Shaw, 1952). Lethal temperature effects could be due to disruption of protoplasm, desiccation of tissues, or disturbance of the photosynthesis - respiration balance (Shaw, 1952; Hagan, 1967; Kramer, 1969; Levitt, 1972). Erwin and Kennedy (1957) noted lucerne 'scald' was the result of xylem necrosis and root collapse which was reproducible in the glasshouse at 39°C. The range between the upper figure for the optimum temperature and the maximum temperature may be only several degrees. For example lucerne germination can occur up to about 38 - 39°C (Williams, 1963; Larsen, 1965) with good germination right up to about 35 - 36°C.

Herbel and Sosebee (1969) on some range grasses found that high temperatures were not so detrimental when the soil was kept at field capacity. Shaw (1952) and Kramer (1969) indicate that tops of plants can survive high atmospheric temperatures because of transpirational and convectional cooling provided transpiration can occur. Shaw presents data showing that high relative humidity increases the killing effect of high temperatures on the plant, and that by submerging conifers in heated water it was found that roots died at lower temperatures than did tops. It is usually assumed that roots are at approximately the same temperature as the soil, and that the only place this is not likely to be true is near the soil surface where the flow of transpirational water may cool the roots and the bottom of the stem (Geiger, 1950). However, the temperature of tops of plants may lag considerably behind the atmospheric temperature.

The minimum temperature for growth is not well defined. Growth will continue slowly at low temperatures. Generally soil temperatures lower than the optimum delay maturity of plants, (Shaw, 1952; Hagan, 1967; Smith, 1969; Ueno and Smith, 1970; Evenson and Rumbaugh, 1972).

In general terms, it thus appears from the literature that the optimum soil temperature for lucerne growth and development is 12 to 33°C. Young seedlings appear to grow well at the higher temperatures while older plants and/or those in unfavourable environments make better growth at low temperatures. It may be that only when other growing conditions for roots are suboptimal may the growth rate of the plants be strictly determined by temperature of the root system. Shaw (1952) gives some evidence for this from work on tomatoes, for which root growth was greatest at about 20°C, but shoot growth was high from 16 to 32°C root temperature. Where nutrient solutions used were considered less suitable the growth rates were determined to a greater extent by the soil temperature.

1.3.1.4 Soil temperature and nodulation

In general the temperatures favourable for the growth of the legume rhizobia coincides with the optimum temperature range for the host plant. Freezing in the winter is not believed to have much effect on rhizobia, but the high soil surface temperature during summer may be detrimental. A temperature of 60°C for 2 – 3 minutes will destroy legume bacteria in a water suspension. *Rhizobium meliloti* requires a temperature of 41°C to stop its growth which is higher than that for red clover (Shaw, 1952). The number of nodules with lucerne was reduced above 33°C and below 18°C.

Gibson (1971) found that lower root temperatures than those optimum for plant growth retarded root hair infection more than they affect nodule initiation, nodule development (including bacteroid tissue development and degeneration) or nitrogen assimilation. Above optimum root temperatures upset the formation of bacteroid tissue and hasten its degeneration. Low and high shoot temperatures affect nodulation and nitrogen fixation, but the effect is less severe than that of similar root temperatures.

With subterranean clover Gibson (1963) found nitrogen fixation was reduced below 22°C and at 5°C was only 10 – 17% of that at 18°C. At 30°C there was a marked reduction in nitrogen fixation by some host-strain combinations. There were significant interaction of varieties and strains on both dry weight and nitrogen fixation throughout the temperature range examined (5°C – 30°C). At higher temperatures nodule production was independent of the amount of nitrogen fixed. Possingham (1964) found that high temperatures increased the number of nodules but reduced the protein and total nitrogen percentage compared with fertiliser nitrogen supplied plants. A high shoot temperature did not affect percentage nitrogen in the tops, but reduced plant yield compared with nitrogen supplied plants.

Rogers (1969) found with lucerne that with high temperatures, both the plant nitrogen yield and the D.M. yield were reduced in the uncooled pots on the soil surface compared with those cooled by a water bath. When the heat stress was removed nitrogen fixation recovered.

1.3.1.5 Extreme temperatures and plant damage

Both high and low temperatures may kill plants, the roots being more susceptible than the shoots (Shaw, 1952).

Temperatures in the soil near the surface can fluctuate between wide limits, from below 0°C to 70°C (Shaw, 1952; Geiger, 1950 and 1965; Herbel and Sosebee, 1969; Levitt, 1972). These temperatures may well be outside the limits for plant survival. At low temperatures, death could be due to ice crystal formation in the tissues or to the effect of frost heave (Shaw, 1952; Langer, 1967; Kohnke, 1968; Kramer, 1969; Levitt, 1972).

High temperatures in soils directly exposed to insolation, as in a recently cultivated soil, may kill plants. Shaw (1952) reports examples of death from heat in flax, buckwheat, wheat, barley, rye, cowpeas, beans, parsley, carrots, cucumber, cotton, ash, beech and several conifers. He also notes that heat damage is more common in saline soils. Young stems near the ground may be killed by high temperatures at the soil surface (Shaw, 1952; Herbel and Sosebee, 1969; Levitt, 1972). A band of discoloured tissue forms around the stem and shrinks. The plant usually dies.

The aerial portion of plants may be injured as a result of root damage at high soil temperatures. Accelerated root maturation may cause water deficits. After heating cotton plant roots to 60°C for 75 minutes the plants showed pale areas in the older leaves within 60 minutes, which disappeared when the roots were cooled but reappeared several days later as yellow or yellow-brown patches. Arndt (1937) suggested a toxic substance was formed in the roots and carried to the tops. These leaves became abnormally rigid and leathery, never recovered and eventually fell from the plant. Levitt (1972) presents similar hypotheses and evidence, and he suggests many possible mechanisms that may be involved.

1.3.1.6 Soil temperature characteristics

The soil temperature zone of importance to the germinating and establishing seedlings is the volume of the soil with which it is in contact. The zone is at first small, but increases in size with the size of the plant. As Geiger (1965) points out, after the plant emerges from the soil it begins to modify its own environment. The main source of heat for the soil is the radiant energy from the sun. The surface of the earth is the layer for exchange of radiant energy. Net radiation, Rn, may be defined as :-

$Rn = (1-a)K + Li - Lo$ eqn 1.3.1.1

or $Rn = E + H + G + P + V$ eqn 1.3.1.2

where a = albedo of the soil or crop surface
K = incoming short wave radiation
Li = incoming long wave radiation
Lo = outgoing long wave radiation
E = latent heat flux
H = sensible heat flux
G = ground heat flux
P = energy exchange in photosynthesis and respiration
V = energy stored in vegetation

For most agricultural crops P and V are small (less than 2%) and can be ignored for our purposes. Nor is any account made for advection.

The microenvironment in which the plants grow is dominated by the magnitude of Rn, and E, H and G.

The amount of heat going into the soil is therefore dependent on the albedo, moisture content (which influences the latent heat loss) and the thermal conductivity of the soil. The temperature rise of a unit of soil depends on the reciprocal of the units volumetric heat capacity and on the heat input. With higher conductivity there is less rise in the surface temperature but a higher rate of temperature increase in the soil below the surface.

The surface layers of sand soils are characterised by large diurnal fluctuations in temperature (Geiger, 1950; Shaw, 1952; van Wijk, 1963; Nakshabandi and Kohnke, 1965; Rose, 1966; Chang, 1968; Kramer, 1969). It also has been shown by several workers that darker coloured soils tend to be warmer than lighter coloured soils (Geiger, 1950; Daubenmire, 1959; Kohnke, 1968). This is because the albedo is lower. The volumetric heat capacity of a damp soil is higher than a dry soil, and at the surface there is likely to be a greater proportion of heat used in vapourising water, so the soil is not likely to get as warm as a dry soil. Nakshabandi and Kohnke (1965) found that thermal conductivity was closely related to soil moisture tension for a variety of soils. The effect of moisture content on volumetric heat capacity was much less than the effect on thermal conductivity.

It seems likely, then, that on a dry Himatangi sand surface the heat capacity and thermal conductivity are low with a low albedo and low latent heat losses so the surface is prone to rapid and extreme fluctuations in temperature.

van Kraayenoord (pers.comm.) measured temperatures in a black sand and a lighter coloured sand during a period of 10 weeks in the spring, after sowing lupin on some of it on 18th September, 1958. The first weeks measurements began on the 6th October, using samples brought to a common location (Palmerston North) from Himatangi (light sand) and Wanganui (black sand). By the end of the measurement period the lupins were about 50 cm high. Table 1.3.1 shows the weekly mean temperatures on the lighter coloured sand, which only differs slightly from the black sand. The highest temperature recorded on any day was 53°C on the bare sand at the 0.6 cm. depth. On the sand country itself on several occasions in January and February, the maximum temperature exceeded 61°C, the maximum thermometer reading. The black sand was reported to reach a higher maximum temperature than the lighter coloured sand.

Table 1.3.1 Temperatures at varying distances below and above the surface on sand with and without a developing lupin cover.

Mean Weekly Temperatures in Sand

Bare Surface (No lupins)

	Below Surface				Above Surface	
Week	7.5 cm 9 am	2.5 cm 9 am	.6 cm max.	.6 cm min.	2.5 cm max.	2.5 cm min.
1st	15.7	16.5	31.8	12.0	27.5	11.9
2nd	16.3	22.6	29.9	7.9	23.1	7.8
3rd	14.4	16.4	28.9	7.8	24.7	9.0
4th	16.1	29.6	32.1	11.7	30.2	10.8
5th	17.6	21.8	43.6	11.5	33.6	9.3
6th	19.2	22.5	41.6	13.3	33.2	11.1
7th	17.8	27.9	38.8	7.6	29.9	5.2
8th	20.3	26.1	35.6	8.9	28.9	7.8
9th	20.6	26.7	41.9	13.3	32.3	14.4
10th	22.2	26.7	37.8	13.6	32.2	14.4

Table 1.3.1 contd.

Mean Weekly Temperatures in Sand

Lupins growing on surface

	Below Surface				Above Surface	
Week	7.5 cm 9 am	2.5 cm 9 am	.6 cm max.	.6 cm min.	2.5 cm max.	2.5 cm min.
1st	16.3	16.7	30.8	12.8	28.9	16.7
2nd	16.1	19.9	27.4	8.6	20.1	7.5
3rd	13.3	15.4	26.0	8.8	26.3	9.0
4th	15.8	17.6	27.8	12.4	29.1	10.6
5th	16.5	17.6	32.5	12.6	34.8	9.3
6th	16.9	18.5	30.7	14.3	28.4	10.8
7th	13.7	15.6	21.8	8.7	28.3	4.9
8th	15.0	17.5	19.4	9.2	26.9	7.8
9th	17.2	16.7	21.7	13.3	20.8	13.9
10th	17.2	17.2	23.3	13.3	21.1	15.0

1.3.2.1 Properties of water in soils and plants

Water is a constituent of protoplasm, constituting 80-95% of the fresh weight of herbacious plants. Water is a solvent for gases, minerals and other solutes. It is also a reactant or reagent in many processes, and is essential in the maintenance of turgidity in plants (Kramer, 1969). Currier (1967) indicates the importance of water in transport in the plant and soil, how it acts as a buffer against temperature changes because of its high specific heat, and how its high heat of vapourisation allows cooling of plants leaves by transpiration.

Water has a high surface tension and tensile strength because of its high internal cohesive forces. It also is strongly adsorbed to the surface of cellulose, clay micelles, proteins and many other substances.

In the soil, water may exist as a solid, liquid or gas. The forces that keep soil and water together are all based on the attraction between soil and water (adhesion) and among the water molecules themselves (cohesion) (Kohnke, 1968). As water is withdrawn from a saturated soil the force needed to withdraw successive increments increases. This may be due to soil shrinkage and/or capillary attraction which together are referred to as matric forces, or if the water is withdrawn through a semipermeable membrane there may be a mounting solute concentration increasing the osmotic forces on the water. Soil water is also subject to forces originating from the gravitation field and from gas pressure. These forces may be described in thermodynamic terms by assigning potentials to soil water. The total potential of soil water is then the sum of the matric, osmotic, pressure and gravitational potentials. The total potential may be identified with the partial molal Gibbs free energy of the soil water relative to pure free water at the same temperature, and represents the capability of the soil water to do work compared with the pure free water. For a full description of the terms see Rose, (1966); Slatyer, (1967); or Day et al (1967).

As water movement takes place in response to potential gradients, only the differences in potentials are of significance. The potential concept may be applied to water in all parts of the soil-plant-atmosphere continuum, and differences in potential between any two points will be due to osmotic or matric potentials, as the pressure and gravitational potential differences can be assumed negligible.

In addition to this potential concept soil water has been described in other terms. Field capacity is the water content after gravitational forces have drained the water with a high potential from the soil. Generally field capacity is equated to $-\frac{1}{3}$ bars potential (Buckman and Brady, 1968) or -0.1 bars for undisturbed soil samples and -0.3 bars for dried, ground and seived samples (Slatyer, 1967). Field capacity is not a constant, but it does characterise the soil water storage value following soil water recharge (Slatyer, 1967; Kramer, 1969).

Permanent wilting point is the point at which plants remain permanently wilted, unless water is added to the soil. Slatyer (1967) has criticised attempts to relate permanent wilting point to a soil water potential of -15 bars, as wilting occurs because of a lack of turgor in the leaves, and the potential at which this occurs depends on the osmotic characteristics of the cell sap in the leaves. Kramer (1969) indicates for most crop plants the osmotic potentials at wilting range from about -10 to -20 bars, and there is little water content change over this range, so -15 bars is probably a useful term to describe permanent wilting point.

Readily available soil water is taken to be the water content between field capacity and permanent wilting point. The potential concept makes it apparent that soil water is not equally available over this range (Slatyer, 1967; Kramer, 1969).

Soil moisture is a function of income from rain, dew, irrigation and movement from a water table, while soil moisture losses are in evaporation, transpiration, drainage and runoff. From equation 1.3.1.2,

$$Rn = E + H + G + P + V$$

it may be seen Rn provides energy for E, the loss of water in evaporation and transpiration. The magnitude of E depends on the potential difference of the water in the plant or soil from that of the air, and the resistance to its movement. Another source of energy for evaporation and transpiration can be in warm dry winds (advection) which have a low water potential.

Water flow through the plant appears to be principally in response to potential gradients, as there is evidence that active water uptake is absent or of minor importance normally in the plant (Slatyer, 1967; Kramer, 1969). The water passing through the plant encounters the main resistance in the root surface layers, or at the leaf-atmosphere interface where the resistance can be modified by the opening or closure of stomata.

There is a diurnal fluctuation of the potential gradients. During the day there is a steep gradient between the soil and atmosphere. Plant transpiration is rapid and the water content and potential of the plant may drop. With the rapid uptake of moisture from around the root, soil moisture in the vicinity of the roots may drop (at the same time resistance will increase) causing plants to wilt even when the average soil potential is high (Slatyer, 1967; Kramer, 1969). This increased resistance may cause closure of stomata via the effect on leaf water potential (Stanhill and Vaadia, 1967).

The water potential in the plant is, therefore, a function of soil and atmospheric conditions, as well as genetic and adaptive controls.

The response of crops to soil water is mediated via the plants water status. There is data to indicate the maximum growth occurs where plant water potential is high (i.e. low water stress) (Stanhill and Vaadia, 1967; Vaadia and Waisel, 1967;

Slatyer, 1967; Kramer, 1969). Low water potentials result in reduced plant growth by closure of stomata, reduced cell expansion, division and leaf area, as well as reduced photosynthesis, and increased respiration. There may be a change in the structure of proteins, affecting enzyme activity. Translocation of assimilates and growth regulators may be disturbed and there may be an effect on nitrogen metabolism (Slatyer, 1967; Kramer, 1969).

1.3.2.2 Influence of soil moisture on lucerne germination and emergence.

The first change that occurs in the germination of a seed is imbibition of water. Seeds have a low water potential, and water stress *per se* is not likely to be a factor in the initiation of embryo growth. It does reduce the rate of radicle emergence, and, as a consequence affects the germination percentage because of increased chances for microbial infection (Peters and Runkles, 1967).

Uhvits (1946) used sodium chloride and mannitol to vary the osmotic potentials of petri dish and sand cultures around the lucerne seed. With lower osmotic potentials the rate of water uptake and the germination percentage were reduced. To overcome problems of solute entering the seed and to equate osmotic and matric potentials McWilliam, Clements and Dowling (1970) used high molecular weight (about 20,000) polyethylene glycol. There was no lucerne germination at -12 bars.

Collis-George and Sands (1962) considered the effects of osmotic and matric potential were not the same on lucerne germination. This work was criticised by Sedgley (1963) who pointed out that Collis-George and Sands had assumed the permeability of the soil-seed interface was the same at different matric potentials, while in fact it may be quite different as Sedgley showed.

McWilliam and Phillips (1971) found with perennial ryegrass that there was no difference between the effect of osmotic and matric potential on germination, under conditions where soil moisture diffusivity and seed-soil contact were non-limiting. There was a difference between osmotic and matric potential with phalaris, this difference being attributed to a large resistance of the phalaris seed coat to the absorption of water, and equality of osmotic and matric potential no longer held.

The germination behaviour of lucerne appears to be controlled by two soil moisture properties; the potential and the resistance to moisture movement to the seed (Collis-George and Sands, 1959, 1962).

Seedlings emergence is highly sensitive to soil moisture and other soil conditions at the time of emergence. Both osmotic and matric potential strongly influence the emergence percentage and the rate of emergence (Peters and Runkles, 1967). Triplett and Tesar (1960) showed that compaction of the soil partly overcame the effect of low soil water potential, presumably because of improved contact between the soil and seedling and reduced resistance to water movement.

The strength of the soil can be a large factor in emergence, and water can influence the formation and strength of crusts (Shaw, 1952; Hillel, 1959).

Germination and emergence are both dependent on an oxygen supply. Aeration of the soil is influenced by water content, and a saturated soil may have a low air content (Peters and Runkles, 1967).

Soil moisture stress and temperature appear to interact in germination. Tadmor et al (1969) and Hillel (1972) found germination was increasing affected by moisture stress the more temperature varied from the optimum.

1.3.2.3 Influence of soil moisture on lucerne root and top growth.

Water influences the direction of root growth, the extent and depth of rooting and the root : shoot ratio (Peters and Runkles, 1967).

Roots will follow moisture in the soil when they are in contact or in close proximity to moisture. The lateral extent and depth of penetration of roots are under genetic control, but are subject to modification by the environment (Peters and Runkles, 1967).

Under water stress the growth rate of the tops is usually reduced more than that of the roots (Peters and Runkles, 1967; Slatyer, 1967; Kramer, 1969).

When the rate of transpiration exceeds water uptake for any length of time internal water deficits occur, and competition between organs occurs. The priority usually remains with the growing tip (Kramer, 1969) as the growing tip can develop a lower water potential than other parts of the plant. Kramer (1969) considers that the amount of water needed for the functions of the plant is probably less than 5% of the water passing through the plant.

1.3.2.4 Influence of soil moisture on nodulation.

Much of the work in this field has been carried out on legumes other than lucerne. A composite picture is therefore given but exceptions to the general pattern may be expected (Nutman, 1965).

All stages of nodulation including pre-infection and nitrogen fixation are affected by the environment and host (Masterton and Sherwood, 1970; Lie, 1971).

The formation and longevity of root nodules has been shown to be affected by the availability of the water in the soil (Wilson, 1921; Sprent, 1971). Formation of nodules probably depends on adequate moisture in the soil for rhizobial multiplication in the rhizosphere. Reduced root growth because of water stress will reduce the sites for nodule formation. With very low moisture levels the survival of both host and rhizobia may be affected. Once infection has taken place the development and function of the nodules will depend on the plant's water balance, which may directly effect the hydration of enzymes and transport of assimilates to and from the nodule, but which will also influence the plants growth processes and so indirectly influence the nodule development and function.

Lucerne nodules are most likely to be found at depths where soil moisture levels are favourable (personal observation and Stiefel, pers.comm.)

Sprent (1971) found that if the fresh weight of nodules in soybean fell below 80% of the fully turgid value, the nitrogen fixation ceased and irreversible gross structural changes occurred, and she considered that the nodule would be shed. Between 80 and 100% of the fully turgid weight there was a reduced rate of fixation but the effect was reversible.

Submerging nodules in water reduced their rate of nitrogen fixation because of a lack of O_2 (Sprent, 1971). In the soil lack of O_2 (due to high water content) is not likely to limit nodule function according to Dart and Day (1971) but it may inhibit nodule formation (Loveday, 1963). It seems likely, however, that a waterlogged soil would also inhibit function.

McKee (1961) reported decreased nodulation of birdsfoot trefoil (Lotus corniculatus L.) under a low soil moisture regime, but the growth of tops and roots was much less affected. Kawatake et al (1962) found nodulation was depressed with 30% soil moisture compared with 70%. Masefield (1952, 1955, 1957, 1958, 1961 quoted in Chu, 1971) found heavier nodulation of several species under moist conditions irrespective of soil type.

1.3.2.5 Working hypothesis of the plant response to changing soil water potential.

In the lucerne plant, with initially an adequate water and nutrient supply and an otherwise favourable environment for growth, only small diurnal water deficits will occur. These may reduce cell division in the cells experiencing the maximum water deficit, and a reduced rate of shoot apex elongation. Growth of the whole plant should progress virtually unimpeded.

As the soil dries, there will eventually be continued stress, with an imposed daytime lag of absorption behind transpiration. There may be a gradual reduction in the rate of cell division. Initially each day there will be only a short reduction in metabolism, but this period will become longer each day. Stomatal closure at this time will retard transpiration and increase leaf temperature, and may also reduce gross photosynthesis by reducing CO_2 exchange. Net photosynthesis may also be reduced by effects on cell turgor and by increased respiration. Reduced cell expansion and division, which will reduce leaf area, all combined reduce net photosynthesis. This may limit the supply of assimilates to the bacteroids in the nodules and reduce nitrogen fixation.

The soil water will become depleted to successively greater depths, with increasing resistance to water uptake and decreased soil water potential.

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As stress becomes more severe with soil water depleted nearly to wilting point the diurnal water deficits will become less marked. Plant potential will become increasingly dominated by soil potential and turgor pressure will approach zero. Cell division will be markedly reduced and cell enlargement cease. The stomata will be closed virtually all day, with marked increases in leaf temperature. There may be a decline in respiration, but net photosynthesis will decline to almost zero because of direct dehydration and reduced CO_2 transport.

Nitrogen fixation will have ceased, and it is likely many nodules will have been shed. Root growth will cease and root hairs may die. Maturation and suberization of the roots proceeds rapidly.

Associated with a breakdown of proteins and carbohydrates there will be a migration of soluble P and N compounds to the stems, and an increase in osmotically active carbohydrate breakdown products.

As dehydration continues it will reach critical levels and individual cells and tissues will die. With a gradually imposed stress the older leaves are shed first.

If water supply is renewed before death, recovery to normal metabolic activity takes several days.

The drought tolerance of lucerne is usually credited to its deep rooting system (Leach, 1967), but in an establishing lucerne stand the roots are neither deep nor extensive. As a result there is a smaller volume of soil to supply the moisture requirements of the young lucerne plants than in an older stand.

1.3.2.6 Moisture characteristics of the sand country.

P.J. Rumball (pers.comm.) has studied in some detail the moisture holding capacity of several soils on the sand country. In the top 18 centimetres of a Himatangi sand he found the field capacity was 31%, and the wilting point was 7%, giving available water as 24%. With a bulk density of 1.22 this meant about 5.2 centimetres of available water. Between 18 and 46 cm the respective figures were 15% and 3% giving an available percentage of 12.

Rumball comments that because of slow water uptake of the sand the water supply in the field is not well related to what may be expected from the above parameters.

1.3.3 The Influence of Wind on Lucerne Establishment

The soils on the Manawatu sand country are prone to wind erosion (Cowie et al, 1967), until the lucerne plants cover the surface.

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 or 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).

Chepil and Woodruff (1963) in their extensive review consider saltation is the major component of soil movement, although suspension may appear more spectacular. As the wind erosion on bare or sparsely-covered soil depends mainly on wind velocity at the soil surface, methods of overcoming wind erosion usually involve methods of reducing surface windspeeds or of increased cohesion of the particles on the soil surface. Vegetation covers effectively reduce surface wind speeds (Chepil and Woodruff, 1963) and may bind surface particles. Shelter belts may reduce wind speed (Caborn, 1965; Williams, 1972).

The Himatangi sands have little cohesion between sand grains when the surface is dry (Cowie et al 1967; Esler, 1969). Once the vegetation is removed there is little to bind the surface.

Williams (1972) lists 4 known harmful effects of wind on crops and the farming system as : -

(i) The actual removal of surface soil, including seeds, seedlings, fertilisers and herbicides.

(ii) Crop losses, or the failure of the crop to establish satisfactorily. Sand or soil blasting the aerial parts of the plant can be very harmful.

(iii) Wind rocking of plants, causing cracking and twisting of stems.

(iv) In prolonged high velocity wind, transpiration losses can be harmful.

Another effect not specifically mentioned by Williams is burial of seeds and seedlings under blown sand.

Kramer (1969) points out that most of the effect of wind on transpiration occurs at low wind velocity (0 to 3 m.p.h.). 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) pointed out 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.

Whitehead (1964-65) and Winter (1964-65) found that plants grown in wind could adapt to the wind, and reduce their transpiration rate per unit leaf area.

The abrassive effect of sand blasting the plant may damage the cuticle causing increased water losses.

1.3.4 Influences of Mulches

Any material spread over and allowed to remain on the ground surface is referred to as a mulch (Chang, 1968). Straw, polyethylene films and bitumen have been among the materials used. The main influence of interest of the mulches in this discussion are those on temperature, moisture and wind.

Van Wijk (1963) points out that there is an extensive literature on the effects of mulches but few articles on the theoretical background. The energy budget approach provides a useful aid to understanding. From the equations 1.3.1.1 and 1.3.1.2

$$Rn = (1 - a) K + Li - Lo = E + H + G + P + V$$

it is apparent a knowledge of the physical properties of a mulch should allow a prediction of the effect on the soil temperature. For example, dyeing a soil black should reduce "a" without substantially influencing the emissivity of the soil for long wave radiation. This would therefore cause an increase in Rn, and in E, H and/or G. As a result the soil temperature would increase particularly during the day, as has been found (Geiger, 1950; Shaw 1952; Jacks, <u>et al</u> 1955; van Wijks, 1963; Chang, 1968), and there is also likely to be an increased moisture loss.

Many mulches achieve their effect by changing the thermal conductivity of the surface by the presence of a layer of still air (Waggoner et al, 1960; Collis-George et al, 1962). They also form a physical barrier at the surface to moisture evaporation. Most evidence shows that a straw mulch conserves soil moisture (Jacks et al, 1955).

A straw mulch may have a higher albedo than the soil, but has a much lower thermal conductivity than the soil. As a result the mulch surface will have warmer temperatures during the day and cooler temperatures at night than adjacent soil (van Wijk, 1963) while the soil below the mulch will be cooler during the day and possibly warmer at night than the adjacent soil (Geiger, 1950; Jacks et al 1955). Generally a straw mulch keeps the average soil temperature lower and more uniform during summer, and warmer in the winter.

Bitumen mulches reduce evaporative moisture losses from the soil (Smith, 1960; Collis-George et al, 1962; Anon, 1962; van Kraayenoord pers. comm.; Bowler pers. comm.). Smith (1960) found that bitumen mulches applied to clay soils may reduce the rate of water infiltration into the soil, but that fast breaking emulsions reduced this tendency. On sand the rate of infiltration with fast breaking emulsions was not impaired.

Temperature increases of the soil under bitumen during the day are marked (Bowler, pers. comm.; van Kraayenoord, pers. comm.) because of the lower albedo of bitumen than most soils (Smith, 1960), and the absence of an insulating air layer (Collis-George et al, 1962).

On a dark soil with low albedo the increase in temperature under bitumen would not be expected to be as great and may depend on differences in evaporation. Collis-George et al (1962) found that a bitumen surface painted white reduced the daytime temperatures of the soil compared with the adjacent unmulched soil.

As the lucerne develops the influence of the plant alters the albedo of the surface and also intercepts the light over a distance of several centimetres. Transpiration from the plant is also important and the influence of the mulch on soil temperature and moisture declines (Geiger, 1950; Collis-George et al, 1962).

Mulches will also alter the effect of wind on the plant. Straw mulches reduce the velocity of the wind at the soil surface, and hence reduce the likelihood of sand blasting (Chepil, 1965; Bagnold, 1946).

The moisture microenvironment under straw is also likely to be more favourable for early seedling development because of a higher relative humidity (Dowling et al, 1971) although temperature during warm times of the year may be too high (Shaw, 1952; Waggoner et al, 1960) and light intensity may be below the optimum for seedling development.

Bitumen and other chemical mulches may increase the cohesion between surface particles (Williams, 1972) or form a protective layer against wind moving the soil particles. The wind velocity at the soil surface may increase slightly as the surface will present less resistance to the wind (Chepil and Woodruff, 1963).

Mulches may have other effects on plant growth. Waggoner et al (1960) found an increased incidence of disease on strawberry roots under plastic mulches. Decaying straw or vegetation mulches may utilise nitrogen (Jacks, 1955) or, alternatively, may supply nutrients to the plant. They may harbour insects and plant diseases.

Bitumen is not toxic to plants, (though bitumen for roading purposes may have toxic chemicals added) nor is it likely to supply appreciable quantities of plant nutrients (Collis-George et al, 1962). Smith (1960) and Collis-George et al (1962) found that rates of 3.8 to 4.5 litres.m^{-2} of emulsion did not appreciably reduce emergence of the grasses and legumes studied except where the bitumen formed pools on uneven ground. The usual rates of application are about 0.5 to 1.1 l.m^{-2} and appeared to have no inhibiting effect on emergence. Smith (1960) did find that emergence was reduced where the bitumen was applied to clay and silt soils on top of seed that was broadcast and not covered with some soil.

Collis-George et al (1962) found that as the rate of application of bitumen increased, the daytime temperature also increased while soil moisture losses decreased.