THE EFFECT OF PLANT DENSITY ON LUCERNE SURVIVAL AND PERFORMANCE ON A STONY SOIL ON THE WAIRARAPA PLAINS

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SUMMARY

Lucerne performance and survival were investigated on a stony soil on the Wairarapa Plains. A Nelder systematic spacing design was used to compare 24 sown populations ranging from 10 to 1400 plants/m 2 . Plant mortality and individual plant yield were density dependent and individual plant yield during thinning conformed approximately to a - 1.5 power law. An iron cemented gravel pan prevented lucerne roots reaching the water table and the implications of this with regard to lucerne performance and survival on such soils are discussed.

INTRODUCTION

The stony soils of the Wairarapa Plains would appear to be ideal for the growing of lucerne [**Medicago sativa** L.] crops and Lynch (1967) suggested that the Wairarapa was a district where expansion of the area in lucerne was justified. However, the area in lucerne on stony soils is still relatively small and Booth (pers. comm.) has observed that lucerne is unsuccessful on these soils, apparently because it does not root deeply and hence does not reach the water table. The investigation reported was designed to establish whether the factors responsible for the unsatisfactory performance of lucerne on these soils were density dependent (i.e. related to competition for nutrients, water etc.) or independent (i.e. relatea to crop management, insect damage etc.). The performance and survival of lucerne on a stony soil (Kawhatau stony silt loam) with an iron cemented gravel pan 0.5 — 1.2 m below the soil surface was studied over a range of plant densities.

METHODS

A type la Nelder (1962) systematic spacing design which is described by equation 1, where is the angle in radians between adjoining radii, R is the rectangularity and θ is the rate of change of spacing, was used in this study.

$$\theta = R(\alpha - 1)/\sqrt{\alpha} \qquad (1)$$

Values of R = 1 and α = 1.114 were used to obtain a design that permitted 24 sown populations, 10, 12, 15, 19, 23, 29, 36, 44, 55, 68, 84, 105, 130, 160, 200, 250, 305, 380, 470, 590, 730, 900, 1100 and 1400 plants/m^2 to be studied.

Four replicates of the 29 radius and 26 arc design were marked out on limed and cultivated ground using single strand PVC wire and concrete post staples to hold the wire in place. Two seeds were sown at each point in September 1970, and the weaker of the two seedlings removed approximately three weeks later. Gaps were filled by transplanting seedlings grown for this purpose.

Plants counts were taken on six occasions and accurate records of plant survival were possible even at the highest population densities because the grid permitted individual plant discrimination. Cuts were taken at regular intervals during the growing season using a motorised shearing hand-piece and only the lucerne plant material collected. Other plant species such as white clover and subterranean clover were cut and discarded. The plots were grazed with sheep during the winters of 1971 and 1972 to control weeds.

Samples of the primary root systems at four plant population, 900 plants/m^2, 200 plants/m^2, 44 plants/m ^{2} and 10 plants/m ^{2} were taken in the winters of 1971, 1972 and 1973. Root monolithes were extracted, washed, and the root samples obtained, dry weighted. Some of the root washing was **in situ.**

Empirical infiltration measurements using a double ring infiltrometer and associated gravimetric soil moisture measurements were made in August, 1971.

The mortality and yield data reported were derived from one replicate, the other three being used for root samples throughout the study. All data with the exception of the root weight data were logarithmically transformed to assist in normalising variance estimates.

RESULTS

Power law relationships described the population changes, thinning processes and yield/density relationships found in this investigation. Such relationships of the general form y = ax b ($\log_e y = \log_e a + b \log_e x$), where 'a' and 'b' are constants, indicate a linear relationship between the logarithms of the two variables and describe continued increase or decrease and not asymptotic situations.

Power law relationships between actual (surviving) and sown populations were obtained at all recordings with significant changes in exponent between December 1970 and April 1971, and between November 1971 and February 1972 (fig. 1). Changes in the exponent over the winter and spring were not significant. Highest mortality occurred during the second summer at the highest densities and total mortality between sowing and the conclusion of the experiment was related to the sown populations by a power law (table 1).

Mean individual plant yield was related to sown population by a power law (fig. 2).

Mean primary root weights and the standard errors of the means are given in table 2. Root weight tended to decrease with increasing plant population whereas at any one population, root weight increased over time. The **in situ** washing of roots revealed that most plant roots did not penetrate the iron cemented gravel pan but tended to run along it.

TABLE 1. Relationship of Total Plant Deaths to Sown Plant Populations

Source	Equation	S.E. of Exponent	% Total Variation accounted for	Significance
Black (1960)	$\log_e D = -6.18 + 1.69 \log_e P$	0.47	72.3	*
Jarvis (1962	$\log_e D = -2.65 + 1.29 \log_e P$	0.17	93.7	***
Takasaki (1970)	$\log_e D = -5.71 + 1.71 \log_e P$	0.30	94.5	**
Bircham and Christieson	$\log_e D = -2.73 + 1.33 \log_e P$	0.03	98.9	***

D = Total Plant Deaths/m ^{2}
P = Sown Plant population/m ^{2}

TABLE 2 Primary Root Weight (g)

Sown Plant Density	Winter 1971	Winter 1972	Winter 1973
900 plants/m ^{2}	0.63 ± 0.12	1.18 ± 0.18	1.53 ± 0.47
200 plants/m ^{2}	1.77 ± 0.36	1.72 ± 0.43	4.67 ± 0.69
44 plants/m ^{2}	3.43 ± 0.69	3.15 ± 0.57	4.86 ± 1.61
10 plants/m ^{2}	2.33 ± 0.69	4.00 ± 1.77	11.81 ± 3.06

Infiltration measurements in August of 1971 revealed a high infiltration rate of the order of 200 mm of water per hour. After the application of 200 mm of water, the moisture level of the topsoil and the soil immediately above the pan had been raised but there was relatively little effect on the subsoil (table 3). Moisture samples taken approximately 30 cm away from the outside ring of the infiltrometer showed that the soil immediately above the pan was wet at this point also. Auger holes revealed that the top of the pan itself was a slurry of water and sand both below the infiltrometer and 30 cm outside the outer ring. The moisture status of the soil under the pan was of the order of 9%, by weight, during these measurements.

TABLE 3 Soil Moisture Levels (% Dry Weight)

Horizon	Commencement	Under Ring	30 cm from Ring
Top soil	28	43	27
Sub soil	25	28	23
Above Pan	20	62	27
Below Pan	9	9	9

DISCUSSION

A systematic spacing design of the type used in this investigation allows accurate assessment of individual plant yield provided that sufficient guarding is incorporated into the design, but does not readily allow extrapolation to unit area yield because each population density has a different plot size. At one cut, the per plant yield of the five outermost plants from the ends of each arc was compared with the per plant yield from the remainder of the arc, and was overall significantly heavier. It is difficult to guard adequately when 24 populations are compared within an area of approximately 40 m ^{2} and plot size varies from 0.02 to 3.00 m ^{2} and hence such designs with rapidly changing plant density should probably be used in exploratory situations only. However, indications of relative performance and survival relationships can be satisfactorily obtained. The use of the same replicate in the derivation of the relationships reported was necessary if consistent relationships over time were to be obtained. It is considered that factors such as soil fertility have not influenced the reported relationships but balanced replicates should be used to ensure that such factors do not influence performance and survival relationships.

The maintenance of power law relationships between actual and sown plant populations over time means that plant mortality is density dependent and the power law relationship between total plant mortality versus sown population can be derived from the data of Black (1960), Jarvis (1962) and Takasaki **et al.** (1970), (table 1). The different constants reflect the different environments in which the lucerne crops were grown.

Power law relationships between individual plant yield and actual plant population have been reported by Takasaki **et al.** (1970) and both the second harvest data of Black (1960) and the total individual plant yield of Jarvis (1962) versus sown populations can be described by similar relationships which account for 98.4% and 97.8% respectively of total variation.

Yoda **et al.** (1963) found that individual plant yield (W) could be related to actual plant population (A) in pure stands undergoing thinning by an approximate power law of the form W = CA exp -1.5 where C is a constant This means that within any pure population, individual plant yield will increase, as thinning, due to plant mortality, occurs. White and Harper (1970) found that many plant species including lucerne conformed to this power law. Similar approximate relationships for the thinning process within individual populations were

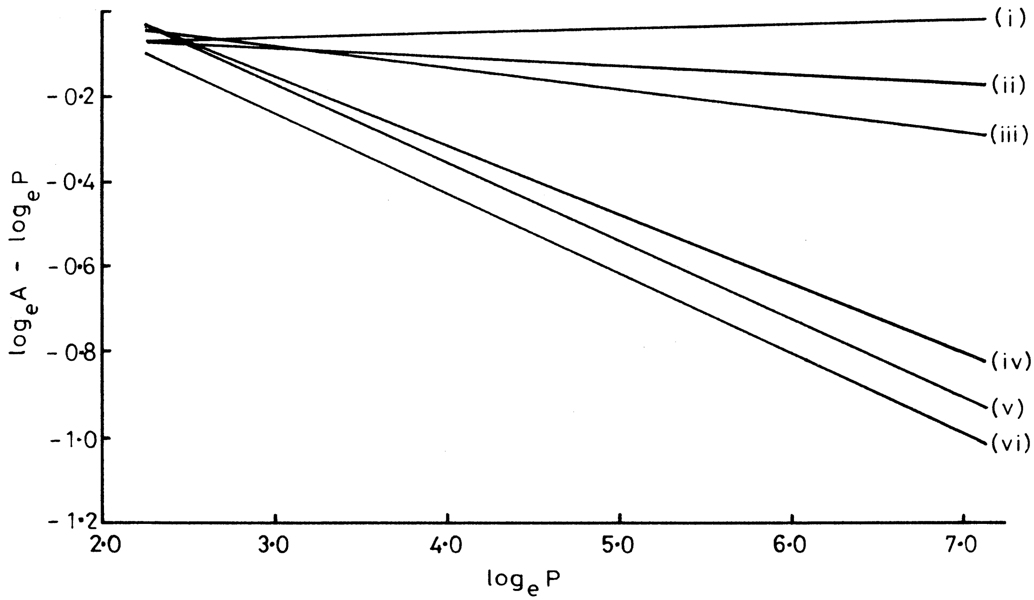

Figure 1. Difference between actual (A) and sown (P) populations versus sown population.

1. December, 1970
ii. April, 1971
iii. November, 1971
iv. February, 1972
v. November, 1972
vi. May, 1973

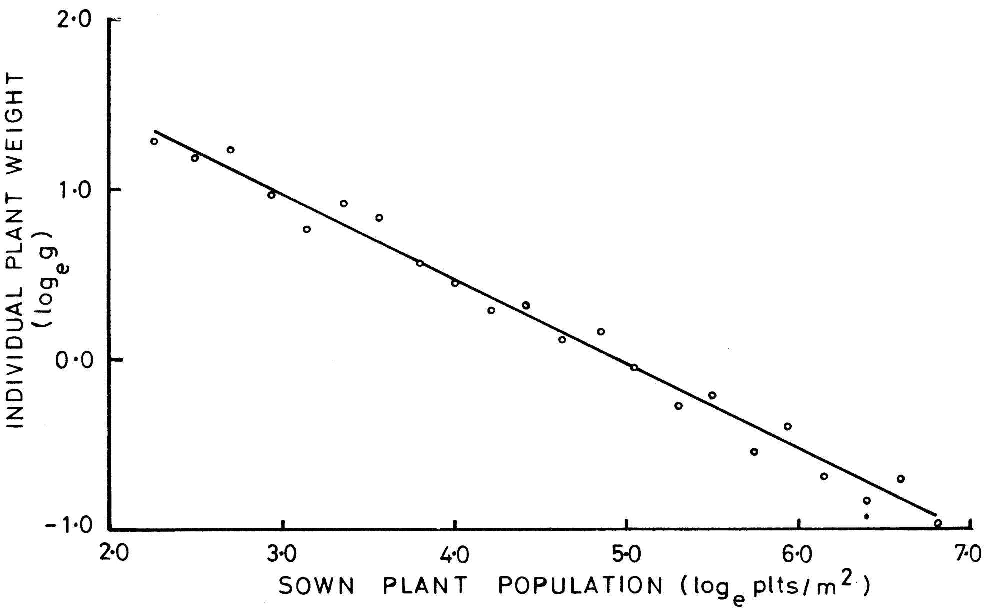

Figure 2 Mean individual plant yield versus sown population.

$\log_e W = 2.478 - 0.502 \log_e P$, S.E. of exponent, 0.016; % total variation accounted for, 98.1%

derived in this study and the mean equation for sown populations of 160 plants/m ^{2} or more is, in logarithmic form, $\log_e W = 6.86—1.29 \log_e A$ with standard errors of 0.20 and 0.03 respectively for the constant and exponent. Competition from white clover confused the thinning process relationship at populations of less than 160 plants/m ^{2} . Such relationships together with the power law relationships for plant mortality and individual plant yield all suggest that lucerne plant populations on the stony soils of the Wairarapa conform to expected density dependent patterns.

The infiltration study and soil moisture data suggest that water flows rapidly down the soil profile until it reaches the pan, along which it flows until a break in the p an allows it to flow deeper. It is interesting to speculate on the performance of lucerne on such soils in view of the fact that few roots penetrated the pan. In such situations the lucerne plant does not have the advantage that is classically assigned to it of a deep root system and a consequent ability to exploit soil moisture at depths beyond the reach of most pasture species. White clover under lucerne management could be expected to do well in such an environment and indeed it did in this trial and was a strong competitor with lucerne at the lower populations in spring and early summer.

The principal advantage that lucerne has on these soils compared with other pasture species is that it responds rapidly to summer rains. This advantage could be expected in view of the high permeability of the soil profile and the pan which holds up water which is readily available to the lucerne plant. Irrigation of lucerne, on such soils would overcome the limitations imposed by the soil and indeed one such irrigated stand on a stony soil does produce well.

Deep ripping of the pan would allow penetration of lucerne roots to the water table provided that a second pan approximately 1—1.5 m below the first is not present. Such a pan was present at the site of the reported investigation.

CONCLUSIONS

The lucerne populations studied conformed to expected mortality/density, yield/density and thinning relationships. The previously reported unsatisfactory performance of lucerne on the stony soils of the Wairarapa (Booth pers. comm.) is related, as he suggested, to the inability of the roots to reach the water table. The roots of the lucerne plant do not penetrate an iron cemented gravel pan and moisture stress during the summer causes stand thinning through density dependent relationships. Density independent factors such as poor crop management or insect/nematode attack while not primary causes of unsatisfactory lucerne performance would compound moisture stress effects and reduce stand life and vigour.

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