

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Environmental and plant factors causing low legume
seedling establishment following oversowing
into drought-prone hill swards

A thesis presented
in partial fulfilment of the requirements
for the degree of Doctor of Philosophy (Ph.D.) in
Plant Science
at Massey University, New Zealand

Manzoor-ul-Haque Awan
June, 1995

634.3
Awa

DGO

ABSTRACT

Legumes are a valuable component of pastures since they tend to have higher feed quality than grasses and can also fix atmospheric nitrogen in the soil. The technology for oversowing legumes has had many improvements but the success rate is poor and the legume contribution to hill country pasture production remains low. It was concluded that unpredictable weather and plant factors were the major factors causing poor pasture legume establishment from oversowing.

To determine the environmental and plant factors responsible for poor pasture legume establishment from oversowing, a series of seven trials were carried out at AgResearch, Poukawa near Hastings. The five annual and seven perennial legume species oversown in order of establishment success were; subterranean clover (*Trifolium subterraneum*), barrel medic (*Medicago* ^{truncatula} truncatula), birdsfoot trefoil (*Lotus corniculatus*), white clover (*T. repens*), strawberry clover (*T. fragiferum*), murex medic (*M. murex*), arrow leaf clover (*T. vesiculosum*), lucerne (*M. sativa*), alsike clover (*T. hybridum*), persian clover (*T. resupinatum*), Maku lotus (*L. pedunculatus*) and caucasian clover (*T. ambiguum*). Seeds of each species were oversown in autumn, winter and spring, following defoliation with glyphosate and trodden with sheep. The greatest loss of potential seedlings after oversowing was non-appearance of seedlings, which accounted for about 80% of viable seed. Overall, the contribution of sown legume species to total herbage mass was less than 12% and seedling establishment success was typically between 5 and 30%.

The relationships between eight environmental factors and seedling establishment were explored and the main influences on establishment were found to be gravimetric soil water content, soil temperature, minimum air temperature and daily wind run. A simple model based on these four factors was developed from the field trial data and extrapolated to 10 years of Lawn Road, Hastings and 5 years of Poukawa climate data and the best time, on average, for oversowing was predicted.

To test the effect of high, medium and low soil surface moisture and also to find out the fate of oversown seed two experiments were carried out in a glasshouse using caucasian, strawberry and subterranean clovers. A simple and cheap technique

based on CoCl_2 saturated paper strips was developed to measure the changes in soil surface moisture. The soil moisture at depth was a poor indicator of seed germination compared with the surface soil moisture. The low soil surface moisture gave lowest seedling survival. The main cause of low soil surface ^{moisture} was wind run. The percentage of ungerminated seed was significantly higher for oversowing than to the standard seed germination test.

Two trials were carried out at AgResearch, Ballantrae, to test the effect of seed rate and seed size. It was observed that sowing rates greater than those usually recommended would increase the seedling density and legume contribution to the total herbage mass and might produce more seed for re-establishment of annual legumes in the subsequent years. Seed size did not significantly affect establishment.

The effect of seed coating and seed dressing was also monitored in a trial at Poukawa. The seed of subterranean and white clovers dressed with fungicide, insecticide and two commercial seed coatings were compared with bare seed. The commercial seed coating increased the early seed germination by 30% but not the final seedling density compared with bare seed. Apron fungicide seed dressing had a deleterious effect on seed germination. The effect of glyphosate residue and litter phytotoxicity was tested in a glasshouse experiment with birdsfoot trefoil and subterranean and white clovers. The species were oversown onto sods sprayed with glyphosate 20 days earlier and onto ordinary sand. The glyphosate residue and dead material did not have any major effect on seed germination and seedling survival.

Overall, environmental factors were found to be the key determinants of successful establishment for pasture legumes by oversowing. Both, the likely environmental conditions at the time of oversowing, and during the first few months of seedling growth need to be considered. The establishment of legume species suited to oversowing can be improved by using high sowing rates and seed coating but ultimately it is the moisture level and temperature at the soil surface that determines germination, and wind run and minimum air temperature that determines seedling survival in drought-prone hill swards.

ACKNOWLEDGEMENTS

I find no appropriate words to express my deepest sense of gratitude to almighty God, whose blessing did not let me deviate from the right direction even through trials and tribulations.

It is a great pleasure to acknowledge the stimulation and wise counsel of my chief supervisor Dr. P. D. Kemp. His friendship, scholastic supervision, guidance, advice, great patience and encouragement made this study fruitful. I express my appreciation for the enthusiastic, helpful, friendly and scholastic supervision of my co-supervisors Dr. D. J. Barker (Sustainable Agri. Division, AgResearch) and Dr. M. A. Choudhary (Agri. Eng. Dept.). The great patience and considerable attention of Dr. Kemp and Dr. Barker shown at regular weekly meetings during analysis of data and write up of thesis was highly appreciated. To me, this has been an invaluable educational experience, any errors remaining in this thesis are entirely mine.

During my computation and analysis of data, I had considerable help from Dr. I. L. Gordon, Dr. S. Ganesh and Dr. C. Matthew. Particularly, I appreciated the way of advice of Dr. Gordon on regression analysis and standardized regression coefficients, and I would like to thank him from the core of my heart.

The invisible help from Prof. J. Hodgson was highly appreciated, as was his charismatic personality which attracted me to return to Massey University. I would also like to thank Dr. I. Valentine for his invaluable criticism on the development of seedling establishment model and Prof. A. C. P. Chu and Mr. P. N. P. Matthews for their smile and sympathetic support.

I acknowledge the assistance given to me by the following:-

* Technicians of Plant Science Department: Ms. C. McKenzie, Ms. F. Brown and Mr. D. Sollit for assistance with laboratory work on seed germination tests and rhizobium inoculation.

* Field technicians Mr. T. Lynch, Mr. M. Osborne and Mr. G. Evans for assistance in layout of trials, herbicide spray, fixing soil sod in trays. Mr. R. Johnstone and Ms. L. Taylor of Plant Growth Unit for technical assistance during glasshouse trials. Mr. I. Painter (Agri. Eng. Dept.) for help in making the stud roller.

- * Dr. D. Smith and Mr. J. Lane of AgResearch, Poukawa (Hastings) and Dr. D. J. Barker and Mr. J. Napier of AgResearch, Ballantrae for the management of trial sites.
- * Forage Division, AgResearch, Palmerston North and Dr. D. Smith for the provision of valuable legume seed.
- * Mr. M. Suckling of International Seed Coaters Ltd. (Hodder and Tolly) for preparing different seed coatings, seed dressings and provision of free coated seed.
- * Mr. K. Johns, Dr. D. Smith and Dr. C. Korte for supply of Poukawa and Lawn Road, Hastings meteorological data.
- * Prof. M. Hill, Ms. K. Hill and Mr. M. Dehghan-shoar for helping my work in the Seed Technology Centre, on the Accelerated Aging test.
- * My friend Mr. B. Mahmood for his generous help in finalizing the setting up and production of the thesis.

I am particular thankful to the Miss E. L. Hellaby Indigenous Grassland Research Trust for their generous financial support. This study was not possible without their help. The financial support of Ministry of Foreign Affairs and Trade, New Zealand for fee scholarship, Helen E. Akers Scholarships and AJK Forest Department for grant of study leave is highly acknowledged.

Many thanks to all the graduate and members of Plant Science Department who provided me an excellent and friendly environment to complete this study.

Finally a special thanks to my beautiful fingers for typing this manuscript very slowly but well.

Special thanks to my life partner Mrs. Talhat Naheed Awan and my children Rabia, Usman, Saadhia and Tahibia for their patience, encouragement, sacrifices, forbearance and understanding which made my study easier.

Last but not the least, I can not be indifferent to my father, brothers, sisters and my friends Mr. Yousaf Qureshi and Mr. Rauf Qureshi, whose round the clock prayers and encouragement went a long way in enabling me to achieve what was previously considered unattainable.

3.2.5 Management of trials	25
3.2.6 Measurements	27
3.2.6.1 Plant density	27
3.2.6.2 Herbage yield and botanical composition	27
3.2.6.3. Early plant development	27
3.2.6.4 Micro-environment and environmental factors	28
3.2.7 Statistical analysis	28
3.2.7.1 General Linear Model (GLM) and repeat time measurements	28
3.2.7.2 Standardized regression coefficients	29
3.2.7.3 Regression analysis	29
3.3 Results	31
3.3.1 Climatic conditions	31
3.3.2 Environmental factors	31
3.3.3 Seed germination and vigour	31
3.3.4 Plant density	43
3.3.4.1 Response of seedling establishment over time	43
3.3.4.2 Response of legume species over time	43
3.3.5 Seedling survival from viable seed over time	52
3.3.6 Herbage yield and botanical composition	55
3.3.7 Early plant development	60
3.3.8 Influence of environmental factors	60
3.3.8.1 Response of environmental factors to sowing conditions over legume species and time	60
3.3.8.2 Response of environmental factors to legume species over sowing conditions and time	65
3.3.8.3 Response of environmental factors to time over legume species and sowing conditions	65
3.3.8.4 Standard regression lines	65

3.3.9 Survivorship pattern	69
3.4 Discussion	72
3.4.1 General	72
3.4.2 Seedling survival and establishment	72
3.4.2.1 Legume species	73
3.4.2.2 Seed vigour	75
3.4.2.3 Temperature	76
3.4.2.4 Moisture	76
3.4.2.5 Early plant development	77
3.4.2.6 Survivorship pattern	78
3.4.3 Botanical composition	79
3.4.3 Environmental vs plant factors	80
3.4.3.1 Soil moisture	80
3.4.3.2 Soil temperature	81
3.4.3.3 Minimum temperature	82
3.4.3.4 Wind run	82
3.5 Summary	84

CHAPTER 4 Seed rate and seed size effects on seedling density and herbage yield

4.1 Introduction	87
4.2 Materials and methods	90
4.2.1 Site	90
4.2.2 Materials and trial description	90
4.2.2.1 Experiment 1. Seed rate trial	90
4.2.2.2 Experiment 2. Seed size trial	92
4.2.3 Management	92
4.2.4 Statistical analysis	92
4.2.5 Measurements	94
4.2.5.1 Plant density	94

4.2.5.2 Yield and botanical composition	94
4.2.5.3 Plant dry weight	94
4.3 Results	95
4.3.1 Weather	95
4.3.2 Seedling survival	95
4.3.2.1 Seed rate trial	95
4.3.2.2 Seed size trial	95
4.3.3 Herbage mass and botanical composition	97
4.3.3.1 Seed rate trial	97
4.3.3.2 Seed size trial	101
4.3.4 Plant dry weight (sowing rate trial)	101
4.4 Discussion	104
4.4.1 Seed rate	104
4.4.2 Seed size	105
4.5 Summary	107

**CHAPTER 5 Soil surface moisture, its measurement, and
influence on early seedling survival and fate
of sown seed of three oversown legume species 108**

5.1 Introduction	108
5.2 Materials and methods	111
5.2.1 Glasshouse experiments	111
5.2.2 Field experiment	112
5.2.3 Measurements	113
5.2.3.1 Soil surface moisture test	113
5.2.3.2 Plant density	113
5.2.3.3 Fate of sown seed	113
5.2.4 Statistical analysis	114
5.3 Results	115
5.3.1 CoCl ₂ technique	115

5.3.2 Gravimetric soil water content (GSWC)	115
5.3.3 Early seedling survival and response of legume species	119
5.3.3.1 Experiment 1	119
5.3.3.2 Experiment 2	119
5.3.4 Fate of oversown seed	128
5.3.5 Ungerminated / hard seed	131
5.3.6 Radicle length	131
5.4 Discussion	134
5.4.1 Surface soil moisture and its measurement	134
5.4.2 Response of legume species to soil moisture	135
5.4.3 Radicle survival and death	136
5.4.4 Seed germination tests	137
5.4.5 Fate of oversown seed	137
5.5 Summary	139
CHAPTER 6 Effect of glyphosate residue, and litter phytotoxicity on oversown legumes	140
6.1 Introduction	140
6.2 Materials and method	142
6.3 Results	144
6.3.1 Seedling number	144
6.3.2 Dry weight per plant	144
6.4 Discussion	147
6.5 Summary	149
CHAPTER 7 Effect of seed coating and seed dressing on legume seedling survival	150
7.1 Introduction	150

7.2 Materials and Methods	152
3.7 Results	154
7.3.1 Climatic conditions	154
7.3.2 Response of seedling survival to seed treatments	154
7.4 Discussion	158
7.5 Summary	161

CHAPTER 8 Oversown seedling survival and

establishment model	162
--------------------------------------	------------

8.1 Introduction	162
8.2 Methodology	164
8.2.1 Model concepts	164
8.2.2 Meteorological data	164
8.2.3 Model parameterisation	166
8.3 Results	168
8.3.1 General	168
8.3.2 Performance of the model	168
8.3.2.1 Poukawa	168
8.3.2.2 Lawn Road, Hastings	173
8.3.2.3 Individual species behaviour	173
8.4 Discussion	178
8.5 Limitations of the model	180
8.6 Conclusion	182

CHAPTER 9 General Discussion and Conclusion 183

9.1 Introduction	183
9.1.1 Oversown seed	183
9.1.2 Germination of viable seed	185
9.1.3 Seedling survival	188

9.2 Seedling establishment	190
9.3 Seedling survival and establishment model	190
9.4 Conclusion	191
Bibliography	193

Appendices

Appendix 3.1 The standardized coefficients of slopes for sowing conditions over seven legume species from 0 - 90 DAS	220
Appendix 3.2 The standardized coefficients of slopes for different legume species over seven sowing conditions from 0 - 90 DAS	227
Appendix 4.1 Response of seedling density (number m ⁻²) over time for different seed sizes and legume species	234
Appendix 7.1 Response of seedling density (number m ⁻²) over time under different treatments	235

LIST OF TABLES

CHAPTER 3

Table 3.1 Soil analysis of the trial sites	23
Table 3.2 Legumes species sown at Poukawa trial area during 1992 and 1993	24
Table 3.3 Time of sowing and herbage yield harvesting times at Poukawa trial area for 1992 and 1993	26
Table 3.4 Climatic data (monthly average) data recorded at Poukawa AgResearch daily at 0900 hours.	32
Table 3.5 Climatic data (monthly average) recorded at Poukawa AgResearch daily at 0900 hours.	33
Table 3.6 Environmental data for seven trials encompassing 2 years and 3 seasons, at 15 days intervals after sowing.	34
Table 3.7 Seed germination test; accelerated aging test and seed moisture content, weight and number of seed sown of different legume species at Poukawa.	41
Table: 3.8 Responses of seedling density (plant m ⁻²) over time in Autumn A 1992.	45
Table: 3.9 Responses of seedling density (plant m ⁻²) over time in Autumn B 1992.	46

Table: 3.10 Responses of seedling density (plant m ⁻²) over time in Winter A 1992.	47
Table: 3.11 Responses of seedling density (plant m ⁻²) over time in Winter B 1992.	48
Table: 3.12 Responses of seedling density (plant m ⁻²) over time in Autumn 1993.	49
Table: 3.13 Responses of seedling density (plant m ⁻²) over time in Winter 1993.	50
Table: 3.14 Responses of seedling density (plant m ⁻²) over time in Spring 1993.	51
Table 3.15 The standardized regression coefficients, R ² and significance levels of different environmental factors related to different sowing conditions.	64
Table 3.16 The standardized regression coefficients, R ² and significance levels of different environmental factors related to different legume species.	66
Table 3.17 The standardized regression coefficients, R ² and significance levels of different environmental factors related over time after sowing the trials.	67
Table 3.18 The regression line intercept, slope and R ² of environmental factors over time for seven sowing conditions and seven legume species.	70

Table 3.19 Optimum time for oversowing different legume species
as observed under different trials at Poukawa 85

CHAPTER 4

Table 4.1 Species and sowing rates of viable seed 91

Table 4.2 Species and seed size, normal seed germination test
and seed diameter and weight 93

Table 4.3 Dry weight (mg) per plant for four sowing rates and
four legume species at 300 DAS. 103

CHAPTER 5

Table 5.1 Surface (5 mm depth) and total (30 mm depth) gravimetric
soil moisture content (%) for three moisture treatments imposed on
natural sods in the glasshouse. 117

Table 5.2 Fate of 216 seed oversown in plastic trays from 0 - 40 DAS
in Experiment 2 123

Table 5.3 Seedling survival of three legume species under
three moisture regimes from total seed sown and
viable seed sown. 125

Table 5.4 Days to half of the maximum seedling germination for
three species and three moisture levels. 127

Table 5.5 Fate of sown seed at the last harvest (40 DAS). 129

Table 5.6 Percentage of oversown seed of the three legume species after simulated sheep treading. Seed was regarded as on the surface of the soil if visible and buried in soil if not visible during the whole trial period. 130

Table 5.7 Percentage (average) of hard and ungerminated seed present in standard seed germination test, accelerated aging test and oversown on soil surface and then trodden. 132

CHAPTER 7

Table 7.1 Seed treatments of legume species 153

Table 7.2 Climatic data (monthly average) recorded at Poukawa AgResearch at 0900 hours for 1994 155

Table 7.3 Comparison and contrast of mean seedling density (number m⁻²) of two legume species oversown with different seed treatments 157

CHAPTER 8

Table 8.1 Comparison of actual and predicted values of seedling establishment (mean for seven legume species) for different sowing conditions (seasons) during 1992 and 1993 at Poukawa 171

LIST OF FIGURES

CHAPTER 3

<p>Figure 3.1 Seedling number per unit area for eleven legume species (A) under different sowing conditions in 1992 and for eight legume species (B) under different sowing conditions in 1993.</p>	44
<p>Figure 3.2 Percentage of seedling survival from viable seed sown of seven legume species and seven sowing conditions in 1992 and 1993.</p>	53
<p>Figure 3.3 Percentage of seedling survival from viable seed sown of seven sowing conditions over legume species and time.</p>	54
<p>Figure 3.4 Percentage of seedling survival from viable seed sown of seven legume species over sowing conditions and time.</p>	56
<p>Figure 3.5 The percentage contribution to December herbage mass of five annual legume species under different sowing conditions in 1992.</p>	57
<p>Figure 3.6 The percentage contribution to December herbage mass of six perennial legume species under different sowing conditions in 1992.</p>	58
<p>Figure 3.7 The percentage contribution to December herbage mass of eight legume species under different sowing conditions in 1993</p>	59

Figure 3.8 The relationship of plant development over time for eleven legume species during autumn and winter sowing conditions. 61

Figure 3.9 The relationship of plant development over time for five annual legume species during autumn and winter sowing conditions. 62

Figure 3.10 The relationship of plant development over time for six perennial legume species during autumn and winter sowing conditions 63

Figure 3.11 The average relationship of different environmental factors to percentage seedling survival from viable seed for seven sowing seasons and seven legume species over time. 68

Figure 3.12 The average seedling survivorship pattern over time, for all legume species in all trials. 71

CHAPTER 4

Figure 4.1 The average response of seedling density to four legume species and four seed rates over time 96

Figure 4.2 The average response of seedling density to two seed sizes for three legume species over time. 98

Figure 4.3 The average response of seedling density to three legume species over time. 99

Figure 4.4 The contribution of four legume species to herbage mass before grazing at 7 months after oversowing and after grazing 8 months after oversowing for different sowing rates. 100

Figure 4.5 The contribution of two seed sizes of three legume species to herbage mass 7 months after oversowing 102

CHAPTER 5

Figure 5.1 The relationship between the time for CoCl_2 paper strips to change from blue to pink and the gravimetric soil water content (GSWC) of the surface 5 mm of the soil in the glasshouse experiment. 116

Figure 5.2 a) Average response of surface gravimetric soil water content (GSWC) using the CoCl_2 technique to three levels of soil moisture in the glasshouse and one in the field conditions, and b) the occurrence of rain in the field experiment. 118

Figure 5.3 Average response of seedling number per tray of three legume species to three surface moisture treatments in the glasshouse and one in the field. 120

Figure 5.4 The response of seedling number per tray at 10 DAS to the GSWC of the soil surface measured by CoCl_2 test for three legume species in the glasshouse. 121

Figure 5.5 The total and net number of seedlings plus radicles that survived and died for three legume species at three surface moisture levels in the glasshouse 40 DAS. 122

Figure 5.6 Relationship of total number of seedlings and radicles over time for different legume species and different surface soil moisture.	126
---	-----

Figure 5.7 The average length of radicles present on the soil surface from oversown seeds of three legume species at three moisture levels from 0 to 20 DAS.	133
--	-----

CHAPTER 6

Figure 6.1 The average response of seedling number per tray of three legume species to two surface treatments in the glasshouse.	145
--	-----

Figure 6.2 The dry weight per plant of three legume species 40 DAS for two surface treatments in the glasshouse.	146
--	-----

CHAPTER 7

Figure 7.1 The average response of seedling number per unit area of two legume species under five seed treatments over time.	156
--	-----

CHAPTER 8

Figure 8.1 Flow diagram showing basic structure of the model for predicting germinated seedling, seedling survival and establishment indices from four environmental factors (values shown for one possible case).	165
--	-----

Figure 8.2 Interaction of GSWC and soil temperature on the germinated seedling index.	169
---	-----

Figure 8.3 Interaction of minimum temperature and wind run on the seedling survival index. 170

Figure 8.4 Model predictions for germinated seedling index, seedling survival index and seedling establishment index for mean of seven legume species oversown at Poukawa (1990 - 1994). 172

Figure 8.5 Model predictions for germinated seedling index, seedling survival index and seedling establishment index for mean of seven legume species oversown at Lawn Road, Hastings (1982 - 1991). 174

Figure 8.6 Model predictions for germinated seedling index, seedling survival index and seedling establishment index for subterranean clover oversown at Lawn Road, Hastings (1982 - 1991). 175

Figure 8.7 Model predictions for germinated seedling index, seedling survival index and seedling establishment index for birdsfoot trefoil oversown at Lawn Road, Hastings (1982 - 1991). 176

CHAPTER 9

Figure 9.1 Some environmental, seed and plant factors contributing for oversown legume seed germination and seedling survival 184