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Over-Drilling New Zealand Tussock Rangeland with or without a Previous Legume Phase

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Abstract: A nineteen year trial at Lake Tekapo compared the longer term trends of over-drilling legume and grasses into either previous undeveloped tussock country or following a previous legume phase. Tall oat grass (from summer sowing) and cocksfoot (from spring sowing) were the most successful of the sown grasses. They remained a low proportion of the swards but greater with prior herbicide treatment, sown with an experimental drill giving partial cultivation and with starter nitrogen fertiliser. Perennial lupin became the main species in the previous undeveloped block and was increasing in the previous developed block. The analysis stage considered the inclusion of covariates for contoured location responses as well as treatment effects in such multi-plot field trials on uneven ground.

Keywords: New Zealand, rangeland, pasture development, perennial lupin, cocksfoot, tall oat grass, experimental design.

INTRODUCTION

In the New Zealand cool temperate, somewhat maritime climate, tussock rangelands it is now relatively easy to establish inoculated summer-growing legumes in the moister areas with sulphur and phosphate fertilisers to increase the animal production from developed pastures [1]. However, the introduction and persistence of more cold tolerant improved grasses remains a difficulty. In this there is an uncertainty of whether to introduce the grasses along with the legumes in an initial sowing in the hope that sufficient survive the early stages while legumes build up the soil nitrogen levels, or alternatively consider a second grass introduction stage.

The present trial is among a series in the recent decades investigating methods of improving grass establishment on different tussock grassland sites of moderate to low annual rainfall and different treatment combinations.

Those treatments included: with or without a previous development legume dominant phase; sowing method (surface broadcast, disc drill, or experimental drill giving partial cultivation); prior herbicide treatment; use of starter nitrogen fertiliser; fertiliser placement in relation to seed; sowing season; grass species and accompanying legume species [2-6].

Most of the trials focussed on the establishment phase of the early years while the present one followed effects for up to two decades.

In the analysis stage the trial also investigated how to accommodate the back-ground effects of dispersion of treatments on a non-uniform environment or previous treatment effects.

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METHODS

The trial was at the AgResearch Mt John trial site (long. 43º 59'S, lat. 170 º 27'E, and 820 m a.s.l.), Lake Tekapo on previously hieracium (*Hieracium pilosella* L.) infested fescue tussock (*Festuca novae-zelandiae* (Hack) Cockayne*)* grasslands and commenced in 1990. One block of the trial had been partially developed eight years previously with sod-seed drilling of different grass species with legumes and two annual superphosphate x three nitrogen fertiliser treatments [2]. That trial had been largely unsuccessful with a good early phase of alsike clover (*T. hybridum* L.) dominance but poor establishment of sown grasses. The vegetation had reverted to principally fescue tussock, hieracium, browntop (*Agrostis capillaris* L.), and sweet vernal (*Anthoxanthum odoratum* L.) at the start of the present trial. The adjacent block used was undeveloped.

The seeding was a mixture of four main legumes, six grasses and minor amounts of some other species. The main species were perennial lupin (*Lupinus polyphyllus* L., 2 kg ha^{-1}), white clover (*Trifolium repens L.,* G. Huia, 2 kg ha^{-1}), caucasian clover (*T. ambiguim* M.Bie, 2 kg ha^{-1}), alsike clover (*T. hybridum, L.,* 0.5 kg ha^{-1}), cocksfoot (*Dactylis glomerata* L., G. Kara, 8.8 kg ha^{-1}), upland brome *Bromus marginatus* Nees., G. Hakari, 14 kg ha^{-1}), tall fescue (*Festuca arundinacacea* Schreb., G. Roa, 4 kg ha^{-1}), phalaris (*Phalaris aquatica* L., G. Maru, 4 kg ha^{-1}), perennial ryegrass (*Lolium perenne* L., G. Nui, 10 kg ha^{-1}) and tall oat grass (*Arrhenatherum elatius* (L) J.Prestet C.Presl, <0.2 kg ha^{-1}).

The establishment treatments were a factorial of two previous developments x two prior herbicide treatments (nil or a light glyphosate spray) x two sowing seasons (spring or late summer) x two drill types (disc drill or experimental drill giving partial tyne cultivation before seeding [7]) x two types of super-phosphate (super or 'maxi-super' of 0:5:0:50, N:P:K:S) at three rates (50 or 150 kg ha^{-1} yr^{-1} or 150 kg^{-1} ha^{-1}

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every 3rd year) x two rates of nitrogen in first two years (nil or 150 ka N ha^{-1} yr^{-1} as urea) x two spatial replications. Each fenced and grazed plot of 8.5 x 50 m plot contained the sub-plot combinations of the two drill types and two nitrogen levels. Adjacent plots were the different super-phosphate types and rates for one drilling occasion. Grid coordinates of plot centres were established.

The drillings were done in spring (Sept. –southern hemisphere) and late summer (Feb.). The herbicide treatment had had little visual effect. The super-phosphate fertiliser treatments were applied for the first four years, in two of the next four years and ceased after the eighth year.

There was some grazing of the previous developed plots in the autumn of the first growing season. In each subsequent year the plots were grazed generally twice for approximately weekly periods, with sheep numbers adjusted to give approximately equal residual swards. The grazing-days achieved were recorded. The maintenance and recording of the trial has continued to date.

Mean sward height of new seedlings (3 per treatment plot) were measured in the first year in February for the spring sowing and in May for the late summer sowing. Relative yields were measured with capacitance probe (15 per treatment plot) in late spring in 2nd and 3rd year prior to first grazing. Species vegetation composition as made at a similar time in all years prior to grazing from visual ranking up to ten species per plot and estimated ratio of the relative yields of the 5th to 1st species. Those measurements were also made on occasions back to the level of the treatment plots of the previous trial on which the developed treatment block had been superimposed.

Plant species rank data were transformed to species proportions assuming a log/linear relationship with the gradient determined by the ratio of the 5th to1st species [8]. Within-year and between-year species proportions and plot grazing capacities in relation to treatments were analysed by regression or general linear model ANOVA of split-split-split plot or split-split plot design and consideration of Type 1 or Type 3 significance. In some analyses previous trial plot treatment were included as covariates, and topographic covariates coordinate contouring of some variables ([9] – proc reg, proc glm, proc contour). Least significant differences were determined for the treatment means presented. Only results which are significant (P <0.05) or highly significant (P <0.01) are presented unless described as 'trends'.

RESULTS AND DISCUSSION

Establishment Phase (Years 1-3)

There was a consistent highly significant general adventage to seedling growth in the first year within the herbicide treatments and for the experimental drill treatments with partial cultivation (Table **1**). There was an initial advantage in seedling height within the prior developed block. Nitrogen fertiliser had a significant effect on the spring sowing, but not the late summer sowing.

For the spring sowing assessed in early summer (Dec.) there was a significant interaction between herbicide and development treatments with a lack of a beneficial herbicide effect in the undeveloped block. Also in the spring sowing there was a positive interaction with greater seedling growth with both herbicide and the experimental drill, though with the effect decreasing subsequently. Neither interaction was present in the late-summer sowing assessment (May). There was no effect of the different rates or types of super-phosphate fertiliser.

Table 1. Treatment Means: Sward Heights of New Seedlings in Early Summer and Autumn of 1st Year; Pasture Yields in 2nd and 3rd Year as Percentage of Grand Mean; and Mean Annual Relative Grazing Capacity in Two Subsequent Periods as Percentage of Grand Mean

Treatment	Height (cm)		Relative Yield	Grazing (yrs)	
	eSum.	Aut.		2-4	6-19
Development					
Nil	2.9	1.2	82	83	116
Prior	5.8	1.5	125	119	82
Herbicide					
Nil	3.0	1.6	85	96	105
Plus	5.8	2.3	115	104	96
Sowing					
Spring			113	97	90
Summer			85	103	111
Drill					
Disc	3.8	1.5	90		
Expt.	4.9	2.5	110		
N fertiliser					
Nil	3.9	1.9	85		
150	4.9	2.0	115		
LSD5%	0.37	0.12	5.6	4.3	3.1

The combined measurements from the 2nd and 3rd year's late spring yields from the capacitance probe measurements (scaled to a mean of 100 for each year) showed significant effects. These were, in the order of decreasing magnitude, of greater yields in the previous developed block, greater with herbicide, nitrogen fertiliser, spring sowing, and with the experimental drill with partial cultivation. There was a significant herbicide by development interaction with a greater relative yield within the herbicide treatments within the prior developed block. The nitrogen effect had become greater by the 3rd year compared to the 2nd.

The significant development and sowing date effects needs to be tempered with the continued greater general vegetation bulk on the previous developed block, and, at least for the 2nd year measurements, that the original spring sowing treatment had a near full seasons growth advantage over the late summer sowing.

Table 2. Mean Pasture Composition (%) of Seven Species Groups in Three Periods following Over-Drilling in Prior Developed Block (left) Compared with Previously Undeveloped Block (right). The Average within-Year Standard Error for Group Proportions was 1.02%

Period (yrs)	Developed			Undeveloped		
	2-6	7-12	13-18	2-6	7-12	13-18
Clovers	12.1	4.3	1.3	37.6	7.9	0.7
Lupin	0.6	1.2	11.2	14.4	28.0	41.2
Cocksfoot	7.1	4.4	0.7	4.4	5.8	1.1
Tall oat	6.5	11.4	10.8	0.5	5.5	9.1
Small grass	20.0	27.3	26.6	6.9	18.1	18.1
Tussock	15.2	24.8	25.2	8.4	21.5	19.2
Hieracium	6.3	10.6	17.6	22.8	9.0	8.6

Subsequent Species and Vegetation

There was large highly significant difference in the species response and resulting vegetation in the undeveloped block compared to that with previous development block. The two blocks were better regarded as almost two different trials after the establishment period with somewhat different pattern in species proportions changing over the years (Tables **2** and **3**). There was a clover prominent phase in both, a rise to dominance of perennial lupin in the undeveloped block, the low success of sown grasses, moderate proportions of adventive grasses and tussock, and slow changes following ceasing of fertiliser.

The results are given in terms of the changes in compositional contribution for seven groups of principal species. Such compositional data are relative measures, and are dependent on the treatment response of a particular species group relative to simultaneous response of other groups.

The group of sown clovers had a phase in the 3rd-6th year period and were more prominent in the previously undeveloped block (Table **2**). This was principally alsike

Table 3. Treatment Means of Species Proportions (%) in Annual Measurements Over Second to Eighteenth Year in Previously Developed and Undeveloped Blocks of Seven Species Groups of Clovers (C), Lupin (L), Cocksfoot (D), Tall Oat Grass (T), Small Grasses (G), Fescue Tussock (F) and Hieracium (H)

Treatment	Developed							Undeveloped						
	C	L	D	T	G	F	H	C	L	D	T	G	F	H
Herbicide														
Nil	6	2	1	7	35	25	9	14	31	3	4	14	16	15
Plus	5	6	6	12	17	20	14	14	26	4	7	15	16	11
Sowing														
Spring	6	6	7	4	26	23	14	14	28	7	0	18	16	13
Summer	5	2	0	18	23	22	9	13	29	1	10	11	16	12
Drill														
Disc	6	3	3	9	25	25	13	15	27	2	4	14	19	14
Expt.	5	6	5	11	25	19	11	13	31	5	7	15	14	12
N fertiliser														
Nil	6	5	3	13	25	19	9	16	29	2	5	15	17	11
150	5	4	5	7	25	25	14	12	28	5	6	13	16	15
Super type														
Super	4	5	3	11	4	23	11	12	31	4	4	12	17	13
Maxi	7	4	5	9	7	21	9	16	26	3	6	16	16	13
Super rate														
50	6	4	4	10	6	22	10	13	34	4	4	13	12	16
150/3	5	7	4	12	5	21	12	11	34	4	9	12	13	12
150	6	3	4	7	6	24	7	17	19	4	3	17	24	11
LSD 5%	0.6	0.9	0.7	1.2	1.1	1.3	1.2	1.0	1.5	0.6	1.0	0.9	1.1	0.9

clover, with a small component of white clover and occasional plants of caucasian and zig-zag clover (*T. medium* L.). In order of significant explanatory value they were depressed by the nitrogen fertiliser treatment, promoted by the higher sulphur content super-phosphate and slightly better from the disc drill (Table **3**).

Perennial lupin was the most successful of the sown legumes and rising over the years to being the dominant species component in the previously undeveloped block and continued slow increase in the previous developed block (Table **2**). Its proportions, in order, were higher with the lower rates and lower sulphur content super-phosphate treatments and sown with the experimental drill (Table **3**). The drill effect probably relates to the partial cultivation giving lesser competition from other species in the early establishment phase as my experience in this and other trials is that the slow growth of lupin seedlings in the first year made them vulnerable to competition at that stage. There was further thickening up of stands from reseeding of initial plants, even in the presence of continued grazing.

Cocksfoot was the second of the two most successful of the sown grasses, reaching a maximum proportion about the end of the first decade but remaining only a small pasture component (Table **2**). The main explanatory variable was its greater proportions from the spring sowing treatments. It had greater proportions in the herbicide treatments, sowing with the experimental drill giving partial cultivation and with starter nitrogen treatments (Table **3**). There was interaction between the nitrogen treatment and previous development with the starter nitrogen increasing cocksfoot proportions in the previous undeveloped block but decreasing it in the previous developed block.

Tall oat grass was the most successful of the sown grasses though having only a very low seeding rate in the initial mixture. It increased from reseeding of established plants in the presence of grazing and possibly from seed dispersion from other trials half a kilometre away. The main explanatory variable was its greater proportions from the summer sown treatments (Table **3**). The proportions were also higher with herbicide, the experimental drill giving partial cultivation, and the intermediate super-phosphate level. Like cocksfoot there was an interaction between starter nitrogen and development with a similar stimulus in the undeveloped block but a decrease in the previous developed block. The species has only moderate stock acceptability, but as the trial shows, establishes and persists under the management and environment used.

The other grass group was of three resident low-moderate fertility adventive grasses of browntop, sweet vernal and kentucky bluegrass (*Poa pratensis* L.) which remained prominent grass components (Table **2**). Sweet vernal and browntop reached a maximum in the 8th-10th year of c 5% and 12% respectively, while kentucky bluegrass rose from rare to c 10% over the period of the trial. The proportions of these grasses were greater from the spring sown treatments and from the highest super-phosphate fertiliser level. They had initially higher proportions in the previous developed block and were considerably reduced then and subsequently by the herbicide treatment.

The slow-growing long-lived native resident fescue tussock remained a component of all treatments (Table **2**). The lower proportions within the experimental drill treatments probably relates to its thinning as a consequence of the initial partial cultivation. There was a response to the nitrogen treatment.

The resident adventive weed hieracium remained a component of all treatments in the ground layer of the vegetation and was higher within the nitrogen treatment (Table **3**).

Of the other sown grasses tall fescue was uncommon (from both the previous trial and current trial), upland brome occasional in sheep camp areas, perennial ryegrass rare, and phalaris absent.

Grazing Capacity

The difference in grazing capacity between the main plot treatments, as measured by sheep grazing-days achieved, were not large with an inversion in effects between the early and later years (2nd to 4th *versus* 6th and beyond) (Table **1**). The grazing days in each year were scaled relative to their grand mean to take account of difference in pasture production between the years.

The grazing advantage in the early years in the prior developed block related more too previous vegetation than the sown species. In hindsight the early grazing of the previously developed plots to similar residuals was probably inappropriate, though at the time it was a compromise between removing the competitive growth of the enhanced previous vegetation and the smaller establishing plants of the present trial.

The perennial lupin had a high novelty factor to sheep while at low densities but was only moderately preferred at higher densities, so may have increased apparent grazing days needed to achieve similar residuals.

One group of six plots in the undeveloped block had a previous lupin component which increased with the drilling of the present trial and had reached very high dominance in the early years. Heavy mob-stocking in the 5th year reduced the perennial lupin and the plots subsequently changed to a large tall oat grass component - in subsequent years an average of 30.6% in those plots compared with 3.5% in the other forty two plots.

Covariates

The trial had 360 adjacent treatment plots dispersed over 4 ha of non-uniform moraine topography, half of which had a similar set of earlier treatments from a prior trial. The site was a low slope of southern aspect ranging from near a drier terrace crest to deeper moister soil at foot of the slope and intersected at one level by a remanent moraine terrace.

The need was to account for this likely source of variation. In a perfect world it would have been done as prior measurement on the same plots of some common treatment over the whole area and used as covariates in the analysis of the present trial.

The suggested alternative here was to establish spatial coordinate for every plot and subplot, to initially treat the dependent variables as if there were no treatment effects, to contour the dependent variables in relations to the coordinates under selected degrees of smoothing and then use those fitted location effect variables as covariates in subsequent analysis for treatment effects. Such an approach could either increase or decrease the treatment effects in the final analysis e.g. if some treatments were in spatial blocks and too finer a smoothing was used the covariates could replace a treatment effect.

For the plots within the previous developed block the previous treatment levels were entered directly in the analysis along with the current treatments.

For the species compositional data the covariate was the proportion averaged for each of main species grouped overall years, standardized, then combined and re-standardized for all groups, with reversing the sign of some species to make the trends similar in all groups.

The plots for the 1st year seedling height measurements for the two different sowing dates were too scattered to determine a location covariate. Stepwise regression, on each separately, with variables for the past and current treatments and proportions of resident species at that time, showed that the most explanatory variable for both sowings was the greater heights in the herbicide treatments. This also in the spring sowing in plots that had previous nitrogen treatments, and in both sowings lower heights in plots with higher proportions of browntop, fescue tussock or hieracium.

In the 2nd and 3rd year establishment phase the inclusion of a location covariate had minimal effect on the analysis of treatment effects. For the treatments within the previous developed block there was a significant effect of higher relative yields from plots which had received superphosphate in the previous trial but with no effect of the different super-phosphate treatments of the current trial.

For species compositional data within the previous developed block, the inclusion of the location and previous treatment covariate effects increased the model's fit for perennial lupin but only marginally for the other species. The location covariate featured more for the resident species components than for the sown species. There was a slight though generally non-significant trend for lupin, cocksfoot and tall oat grass to be greater in previous higher superphosphate and nitrogen plots and the reverse for clovers and previous resident species.

The location covariate was generally the most explanatory variable for the resident species of adventive grasses, fescue tussocks and hieracium, but not significant for most of the sown species. The exception was for cocksfoot in the previously undeveloped block where location covariate was the principal significant explanatory variable.

Within the previously developed block, with the inclusion of previous treatment levels as well as location effects, there was a small trend of slightly greater lupin and adventive grasses in previous lower nitrogen fertiliser rate plots and the reverse for the clovers.

The inclusion of the location covariate greatly increased the model fit to the sheep grazing-day data with it being the main significant response variable in most years, followed by the contrast between the previous developed and undeveloped block. That is partly understandable related to the variation in pasture growth across the site unrelated to the treatments and the grazing management to a common pasture residual.

The earlier presented treatment results included consideration of those location and previous treatment covariates.

Stock Camps

Over the period of the trial there was a noticeable development of a sheep-camp effect within the 5m of the 50 x 8.5m area adjacent to other-plots or alley-ways, more so in the previously undeveloped block. Some of the sown grasses had a high presence and vigour there. In the 12th year cocksfoot, tall-oat grass or tall fescue were within the top two most abundant species in 66%, 62% or 10% respectively in those sections. That probably indicates that soil nitrogen levels in the general plots had still not built up sufficiently for those grasses. Those stock camp areas had been excluded from the general vegetation monitoring.

CONCLUSIONS

The features of the present trial was the contrast between the undeveloped and previous developed treatment blocks with the low medium term establishment of new plants in the previous developed block, the success of the perennial lupin in the previous undeveloped block, and while nitrogen gave initial stimulus to grass establishment the effect was not maintained.

The present trial gave similar results to those in the associated group of trials but extended to a further time scale. Collectively the series of trials show that good establishment of 'improved' pasture grasses remain problematical for over-drilling of tussock grassland. The more successful was cocksfoot (present trial; [2-6]).

The lack of longer term success of perennial ryegrass remains an enigma even though showing early superior seedling vigour [4]. The probable reason is that there is a still insufficient soil nitrogen level, even with starter nitrogen for the species. There also seems to be something related to its poorer performance on greywacke soils but slightly better performance on schist soils. Tall oat grass showed increasing contribution in two of the longer-term trials (present trial; [5].

The pastures have a further legume phase with reseeding even if there had been previous development, as well as a general legume dominant phase if undeveloped (present trial; [4]). Alsike clover is the principal short term successful legume, but in the longer term perennial lupin can be the more persistent and productive legume at moderate fertiliser inputs (present trial; [5, 6, 10]).

There was better establishment of sown grasses and legumes into existing vegetation from a drill type giving partial cultivation from either tyne cultivation (present trial;

[4, 5] or rotary-hoe type cultivation [10] than from a disc drill.

The present trial was the only one which had made a simultaneous comparison of establishment in adjacent undeveloped and previous developed blocks

Prior herbicide treatment was beneficial, but the effects were not large. As noted in the present trial the herbicide treatment had not been visually effective, though the results did show that it had a significant initial beneficial effect on establishment of the newer sown species. Similarly [4, 6] showed little initial effect but subsequent improved legume establishment.

In the present trial there was a positive increase in yield with the use of starter nitrogen in the establishment phase but the measurements had not discriminated between the response of sown grasses and legumes (Table **1**). In the longer term there was little discrimination between the two (Table **2**). For legumes there is a trade-off between possible initial stimulus to legume establishment and a possible adverse effect on the formation of a rhizobia association. Woodman *et al.,* [6] had shown greater initial legume growth with starter nitrogen.

In considering the fertiliser placement in relationship to the seed had shown that placement of nitrogen fertiliser was better below the seed and super-phosphate with the seed [6].

The longer term effects of the difference between early spring or late summer sowing treatments in the present trial showed little difference in the legume component but a large difference between the success of cocksfoot from the spring sowing and tall oat grass from the late summer sowings. There were few differences between spring and late summer sowings results [5].

The analysis of the results has suggested a method for taking account of location effects in a non-uniform environment. It was useful for the grazing capacity data.

CONFLICT OF INTEREST

None declared.

ACKNOWLEDGEMENT

None declared.

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