CONTENIDO DEL INFORME TÉCNICO
CONSULTORES CALIFICADOS

1. Antecedentes de la Propuesta

Título: Determinación de Limitantes de Relación Suelo-Planta en Praderas de Magallanes: Desarrollo de Metodología

Código: CO-V-2003-1-P-14

Entidad Responsable: Eduardo Doberti Guic, Estancia Las Coles

Coordinador: Rodrigo Allende Vargas

Nombre y Especialidad del Consultor: David Scott (Manejo de fertilidad del suelo, praderas)

Lugar de Origen del Consultor (País, Región, Ciudad, Localidad): Nueva Zelanda, Mac Kenzie Country, Lake Tekapo

Lugar (es) donde se desarrolló la Consultoría (Región, Ciudad, Localidad): XII región, estancias en continente e isla Tierra del Fuego

Fecha de Ejecución: 28/11/2003-11/12/2003

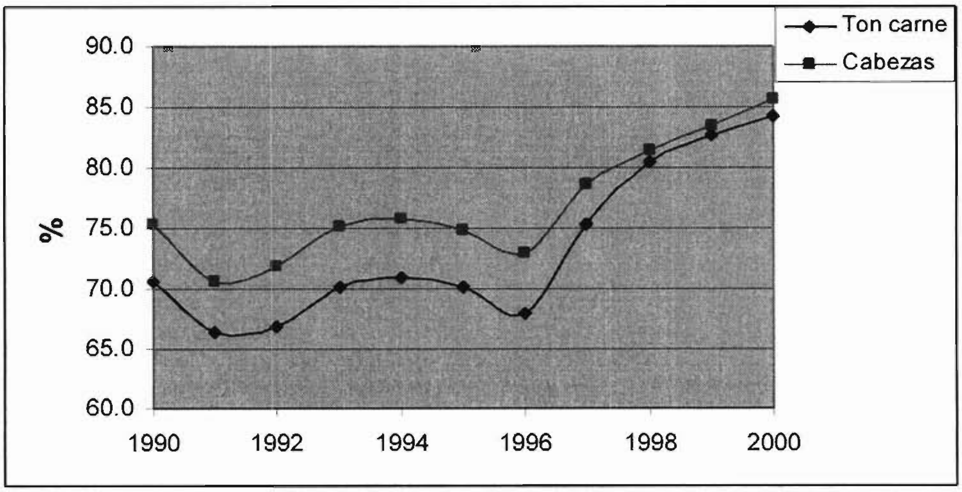
Proponentes: presentación de acuerdo al siguiente cuadro:

Nombre	Institución/Empresa	Cargo/Actividad	Tipo Productor (si corresponde)
Eduardo Doberti Guic	Estancia Las Coles	Propietario/ Ganadera ovina	Mediano
Nicolás Simunovic Vodanovic	Estancia Morro Chico	Propietario/ Ganadera ovina	Grande
Hugo Vera	Estancia La Josefina	Propietario/ Ganadera ovina	Mediano
José Marín	Ganadera Marín	Propietario/ Ganadera ovina	Grande
Sergio Kusanovic	Ganadera Entre Mar	Propietario/ Ganadera ovina	Mediano

Problema a Resolver:

Las existencias ovinas de la XII Región representan el 60% nacional. El sistema tiene por objetivo suministrar proteína animal y lana caracterizándose por ser extractivo, en donde la base de sustentación es el ecosistema pratense. El comportamiento durante la década 1990-2000 demostró una tendencia al alza en la participación regional en la producción nacional de carne de cordero, representando un valor cercano al 85% (Figura 1). Esta tendencia ha mostrado una aceleración en los últimos 5 años a una tasa creciente aproximadamente del 3% anual.

Figura 1. Participación de la XII región en el rubro ovino nacional, 1990-2000.



Fuente: ODEPA,2002

Los ingresos por exportación de carne ovina, también han presentado una tendencia al alza con un valor promedio de US$ 6.428(miles FOB). La importancia del rubro ovino sobre la dinámica económica regional, también se refleja en la absorción de mano de obra que representa entre el 12-15% de la fuerza laboral.

Cuadro 1. Participación de la carne ovina en ingresos por exportación regional

Año % de Participación en Exportaciones regionales (US$ FOB)

Año	% de Participación en Exportaciones regionales (US$ FOB)	% de Variación anual
1995	18	
1996	21	17.6
1997	27	28.0
1998	31	17.8
1999	38	21.6
2000	35	-8.6

Fuente: adaptado de ODEPA, 2002.

El principal mercado de exportación, es la Comunidad Europea, que demanda canales entre 16-18 kg, por lo tanto corderos de un peso vivo entre 35-40 kg. Alrededor del 60% de este peso vivo se obtiene en condiciones de pastoreo, posterior al destete en un período de 90–120 días, entre diciembre-abril, período en el que disminuye sostenidamente la tasa de crecimiento de la pradera. Las iniciativas de innovación del rubro ovino han estado dirigidas principalmente a aumentar el potencial de aumento de peso y rendimiento carnicero de los corderos mediante cruzamiento con líneas paternas carniceras. Este proceso ha generado un biotipo animal más pesado con aumento de los requerimientos nutricionales por efecto de una mayor tasa potencial para aumentar peso vivo.

Este nuevo escenario productivo ha permitido identificar la necesidad de aumentar la eficiencia de uso de la pradera, por lo tanto se demanda incrementar la oferta de nutrientes digestibles, lo que podría estimular corderos más pesados (mayor peso vivo) satisfaciendo las necesidades insatisfecha de una cuota internacional de la Comunidad Europea, destacándose que en un futuro cercano esta cuota aumentará (ASOGAMA, 2002). La producción de materia seca de la pradera presenta una marcada estacionalidad de crecimiento activo en la época estival, dependiente de la temperatura ambiental y humedad del suelo (Cubillos *et al.,* 2001). Esta situación provoca que el mayor crecimiento se produzca entre Octubre-Diciembre. En general, la región de Magallanes desde el punto de vista de praderas naturales y condiciones ambientales se ha dividido en tres zonas: húmeda, transición y estepa, ordenadas decrecientemente considerando la productividad de la pradera por unidad de superficie. El limitante más importante del crecimiento estival de la pradera es el balance hídrico. Aproximadamente, 5-8% de la superficie total dedicada a pastoreo corresponden a zonas de vegas (no limitadas por el efecto de humedad) constituyéndose en sitios importantes dentro de la unidad de producción de corderos.

La información del comportamiento productivo de las vegas en estado natural o manejadas en términos de fertilidad o introducción de nuevas especies pratenses no está disponible para los usuarios del rubro ovino, identificándose falta de innovación en: evaluación de germoplasma forrajero mejorador, determinación de limitaciones de fertilidad y cuantificación bio económica de la vega para la engorda de corderos. Además, 60% de los corderos se obtienen en condiciones de estepa en la Isla de Tierra del Fuego destacándose la necesidad de incorporar y evaluar especies forrajeras resistentes a la sequía y de un período vegetativo más largo (crecimiento tardío) y determinar el potencial del coirón (*Festuca gracillima*) en condiciones de campo y controladas. Por lo tanto, la oportunidad de aumentar el posicionamiento del cordero magallánico en mercados internacionales que demandan canales más pesadas al promedio regional, exige mejoras en la eficiencia de uso de la pradera, principalmente en términos de disponibilidad de la materia seca y digestibilidad de ella. La disminución de los limitantes, anteriormente indicados permitirán aumentar la sustentabilidad del sistema ovino, como unidad ecológica y de negocios y entregar herramientas a los usuarios para potenciar las iniciativas actuales de aumentos en el potencial genético de crecimiento de los corderos.

Objetivos de la Propuesta

Objetivo general técnico y económico de la propuesta

Identificar cuantitativamente y cualitativamente fortalezas y debilidades en el manejo de la relación suelo-planta de la pradera en diferentes zonas agroecológicas de la XII región para aumentar la competitividad del rubro ovino.

Objetivos específicos técnicos y económicos

Técnicos y económicos

a) Capturar la experiencia del consultor en identificación de debilidades en el manejo de la dinámica de nutrientes del suelo para aumentar la producción primaria de materia seca de la pradera bajo un marco de uso racional de los recursos naturales.

b) Desarrollar un marco metodológico para potenciar la relación suelo- planta en diferentes zonas agroecológicas de la XII región.

c) Potenciar las innovaciones de introducción y evaluación de germoplasma forrajero (Proyecto FDI-UMAG) y uso de cero labranza para regenerar la pradera natural (Proyecto FIA-Ganadera Cerro Guido)

2. Antecedentes Generales:

Nueva Zelanda es el principal productor mundial de carne ovina y su industria se encuentra enfocada mayoritariamente a las exportaciones. Principalmente exporta corderos de canales pesadas, destacándose que del total de las importaciones de carne ovina realizadas por la Unión Europea, el 51% proviene de Nueva Zelanda, aunque las posibilidades que tiene para expandirse en la Unión Europea se ven limitadas por las restricciones de cuota de 225.000 toneladas.

Tabla Principales países exportadores de carne de carnero y cordero (2001)

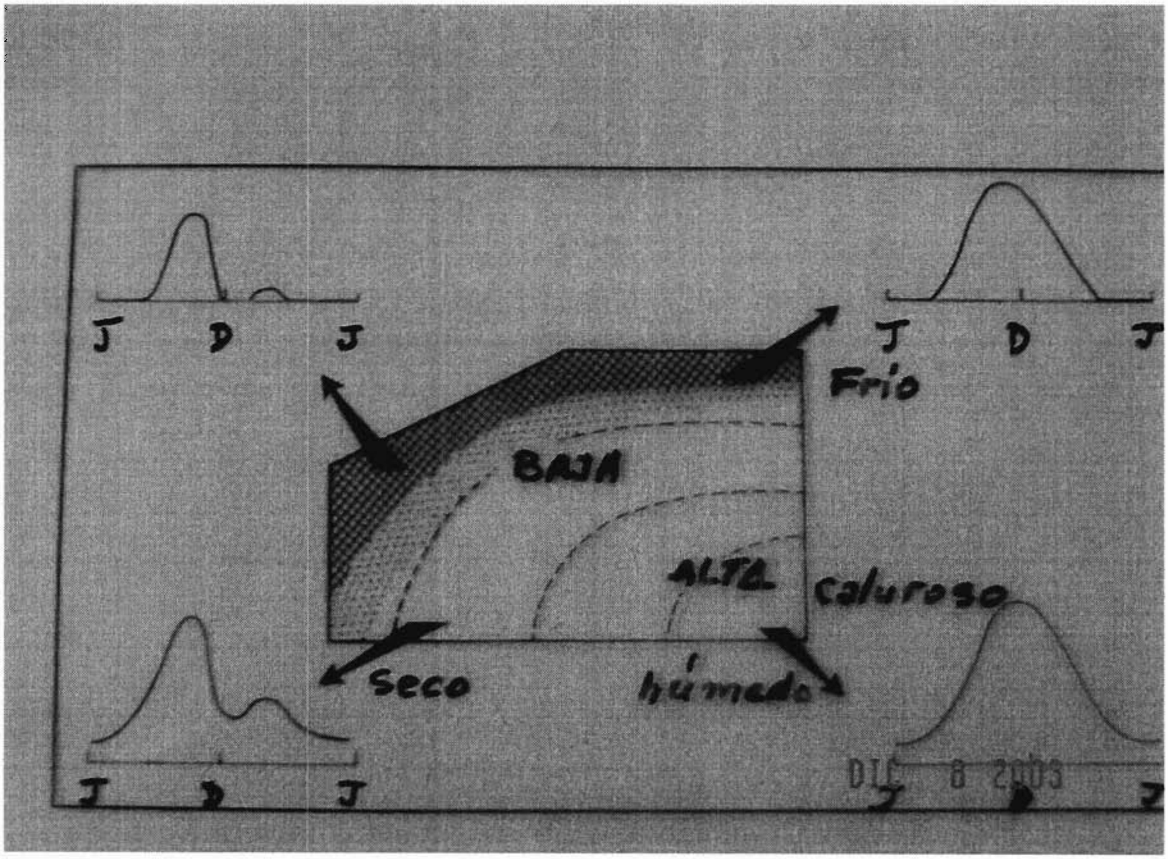
País	Cantidad (Mt)	Miles de U$
Nueva Zelanda	345.475	905.858
Australia	295.924	559.361
Irlanda	67.644	237.369
Reino Unido	30.280	111.541
España	19.505	65.953
Bélgica	16.100	75.718
Uruguay	9.046	23.116
Chile	5.025	10.508

Fuente: FAOSTAT, 2003

El high country de la isla sur de Nueva Zelanda presenta características edáficas y agroclimáticas semejantes a las de la XII región. Posee 3,4 millones de hectáreas representando el 5% de las unidades productivas de Nueva Zelanda, generando aproximadamente un 10% de los ingresos ovinos del país. Las existencias ovinas totales son 2,3 millones de cabezas, destacándose que el 20% de la superficie total del High country ha sido corregida en términos de fertilización y/o resiembra.

La metodología utilizada para la selección de sitios para mejoramiento de praderas se ha basado en la combinación de fertilidad, temperatura y humedad del sitio, elementos fundamentales para la expresión del potencial agronómico de las especies pratenses (Figura 1). Las relaciones implican diferentes ponderaciones que favorecen a ciertas especies y variedades pratenses, por lo tanto la relación sitio-especie pratense es el primer paso lógico para disminuir el riesgo en programas de mejoramiento de praderas.

Figura 1. Comportamiento de la disponibilidad de materia seca de especies pratenses con diferentes combinaciones de temperatura, humedad y fertilidad.



3. Itinerario desarrollado por el Consultor: presentación de acuerdo al siguiente cuadro:

Fecha	Ciudad y/o Localidad	Institución/Empresa	Actividad Programada	Actividad Realizada
Viernes 28 Noviembre 2003	Oficinas del Departamento de Ciencias Animales Facultad de Agronomía e Ingeniería Forestal. P. Universidad Católica de Chile	Llegada Dr. Scott a Santiago de Chile	Reunión de trabajo términos de referencia de visita y coordinación de actividades	●
Domingo 30 Noviembre		Viaje Dr. Scott a Punta Arenas	Inicio de visita a zona de trabajo: Reunión de Grupo de trabajo de visita Dr. Scott	●
Lunes 1 y Martes 2 de Diciembre	Estancia Cerro Guido, Ganadera Complejo de Torres del Paíne, Comuna de Torres del Paíne y Ganadera Morro Chico, Comuna de Laguna Blanca	Visita a zona de transición y estepa	Identificar fortalezas y debilidades del manejo de praderas en zona de estepa: Coirón y Maillin. Identificar fortalezas y debilidades de manejo cero labranza de *Medicago sativa.* Identificar fortalezas y debilidades de especies y variedades sembradas y evaluadas	●
Miércoles 3 de Diciembre	Estancia Cabeza de Mar	Visita a zona de transición	Identificar fortalezas y debilidades del manejo de praderas en zona de transición. Identificar fortalezas y debilidades de especies y variedades sembradas y evaluadas	●
Martes 2 de Diciembre	Ganadera Entre Mar	Visita a Estepa	Identificar fortalezas y debilidades del manejo de praderas en zona de	●

			estepa: Coirón y Maillin.	
Jueves 4 de Diciembre	Estancia Kampenaike Instituto de Investigaciones Agropecuarias Estancia Josefina	Visita a zona de transición	Identificar fortalezas y debilidades del manejo de praderas en zona de estepa: Coirón y Maillin. Identificar fortalezas y debilidades de manejo orgánico de fertilidad fósforada del suelo Identificar fortalezas y debilidades de especies y variedades sembradas y evaluadas	
Viernes 5 y Sábado 6 de Diciembre	Estancia Las Coles Comuna de Río Verde	Visita a zona de transición y zona húmeda	Identificar fortalezas y debilidades del manejo de praderas en zona húmeda. Identificar fortalezas y debilidades de manejo de fertilidad azufrada y fósforada. Identificar fortalezas y debilidades de especies y variedades sembradas y evaluadas	
Domingo 7 de Diciembre	Ganadera Entre Mar, Comuna de Porvenir Isla Tierra del Fuego.	Visita a Estepa	Identificar fortalezas y debilidades del manejo de praderas en zona de estepa: Coirón y Maillin.	
Lunes 8 de Diciembre	Punta Arenas	Sistematización de información	Taller de trabajo	
Martes 9 de Diciembre	Punta Arenas, Servicio Agrícola y Ganadero, Punta Arenas.	Seminario		
Miércoles 10 de Diciembre	Punta Arenas, INIA	Análisis de información de trabajos experimentales	Taller de trabajo	
Jueves 11	Viaje de Regreso a Santiago y			

de Diciembre	Auckland			

4. Resultados Obtenidos:

a) Hipótesis de interrelación entre humedad, fertilidad del suelo y temperatura para predecir la productividad de especies pratenses.
b) Pautas metodológicas para la selección de sitios según la especie pratense a introducir
c) Contactos formales para implementar un sistema de intercambio técnico entre Nueva Zelanda y Chile (Futura gira de captura tecnológica Septiembre 2004)
d) Comportamientos de especies pratenses bajo diferentes combinaciones ambientales. En la práctica se podría sistematizar la información con un ranking pratense en función del sitio, condición y ambiente.

5. Aplicabilidad:

La aplicabilidad de las directrices propuestas por el Dr. Scott en un corto plazo implica establecer 3 a 4 unidades experimentales, en dos sitios contrastantes en zona húmeda y estepa. Las líneas de trabajo propuestas serían:

a) Cuantificación del potencial de producción del coiron y pradera natural con diferentes niveles en cantidad y tipo de fertilización para determinar el potencial de producción de biomasa y su comportamiento temporal. El estudio debe considerar el efecto de la humedad y temperatura, tanto del suelo como del ambiente junto con la evotranspiración.
b) Evaluación de germoplasma forrajeros estratégicos mejoradores: evaluar en condiciones de campo y controladas diferentes especies de forrajes para ser utilizados con fines estratégicos: último mes de gestación y parición, flushing de encaste y engorda post destete de corderos.
c) Diseñar sistemas de pastoreo rotativo para mosaicos prediales mejorados

d) Diseñar modelo matemáticos de evaluación bioeconómica para sistemas integrales de producción de carne y lana ovina
e) Diseñar modelos matemáticos para evaluar balances acuíferos y de nutrientes en diferentes sistemas pratenses y de producción de germoplasmas estratégicos.

Se debe potenciar las capacidades existentes en las unidades experimentales de los proyectos FIA C2002 PI35 y FDI 02 CR AT-02 mediante un proyecto de innovación que complete las líneas generales descritas.

6. Contactos Establecidos: presentación de acuerdo al siguiente cuadro:

Institución/Empresa	Persona de Contacto	Cargo/Actividad	Fono/Fax	Dirección	E-mail

7. Detección de nuevas oportunidades y aspectos que quedan por abordar:

Incorporando las directrices de investigación y desarrollo sugeridas por el Dr. Scott, junto con la evaluación cuantitativa y cualitativa del primer año agronómico de parcelas del proyecto FDI 02 CR AT-02 "Introducción de Germoplasma Forrajeros Mejoradores en la XII Región", adjudicado a la Universidad de Magallanes, se ha generado el siguiente perfil de gira tecnológica para ser evaluada por FIA y que se desarrollaría en la temporada primaveral del 2004 en los estados de Utah y Oregon, USA.

Titulo de gira tecnológica: Forrajes de uso estratégico para la región de Magallanes: identificación de especies, su manejo y utilización en sistemas ovinos.

Objetivos generales (técnicos y económicos):
Capturar información agronómica y comercial de variedades comerciales de forrajes perennes y anuales adaptados a condiciones agroecológicas similares a las de la región de Magallanes considerando el manejo, utilización y potencial en producción animal.
Objetivos específicos (técnicos y económicos)

a. Identificar especies y variedades comerciales de gramíneas, leguminosas y hierbas con potencial de adaptación a las condiciones extremas de la Patagonia, visitando estaciones experimentales donde se han seleccionado las mismas y predios de productores donde se están usando para la producción ovina y carne bovina en sistemas pastoriles
b. Adquirir información publicada, literatura gris e información verbal sobre las prácticas de establecimiento, rango de adaptación, requerimientos nutricionales y de manejo, y prácticas de utilización estratégica, proveniente de productores ovinos, agentes de extensión, investigadores y distribuidores y productores de semilla
c. Adquirir conocimientos sobre la integración de dichas especies con otros recursos forrajeros y pastizales naturales en sistemas de producción de rumiantes, y observar cómo las especies mejoradas se utilizan en forma estratégica en el tiempo y espacio, para diferentes categorías animales
d. Identificar prácticas de conservación, tales como el rezago del pastoreo y otras, usando las especies en cuestión
e. Establecer contactos comerciales con productores y distribuidores de semilla interesados en la exportación de las mismas a Chile, y llegar a acuerdos iniciales para tal fin
f. Gestionar el envío a Chile de cantidades experimentales de semillas de variedades promisorias para prueba en campos de productores de Magallanes
g. Establecer contacto con especialistas en los temas antes mencionados, con la finalidad de continuar intercambiando información y experiencia en el futuro inmediato, así como identificar personas que podrían ser eventualmente invitados a la región como consultores ocasionales

Resultados o productos esperados con la realización de la propuesta

a. Establecimiento de vínculos comerciales con distribuidores y productores de semillas forrajeras de Estados Unidos, resultando en nuevas iniciativas de negocios

b. Aceleramiento del proceso de adquisición e importación de germoplasma forrajero mejorado

c. Nuevas especies forrajeras con capacidad de adaptación a diferentes situaciones en Magallanes, y con mayor potencial de producción animal que las actualmente disponibles, en particular para estepas semiáridas y frías

d. Identificación de prácticas de manejo de forrajes para ovinos que apunten a la resolución de los déficits cuanti y cualitativos en la alimentación

e. Identificación de usos estratégicos de especies forrajeras perennes y anuales para satisfacer requerimientos nutricionales específicos en etapa críticas de la producción ovina

f. Establecimiento de un mecanismo fluido e informal de intercambio de información técnica con el Departamento de Agricultura (USDA), Universidades, productores y semilleristas en Estados Unidos

8. Resultados adicionales:

a) Se presentará una gira tecnológica para identificar potenciales germoplasma forrajeros utilizables en condiciones de estepa magallánica (Fondo FIA 2004).

b) Se presentará proyecto de implementación de estrategias forrajeras para incrementar la productividad de unidades ovinas (Fondo FIA 2004)

c) Se presentará proyecto para caracterizar agronómicamente al trébol asilvestrado de la estepa (Fondo Copec)

9. Material Recopilado:

Tipo de Material	Nº Correlativo (si es necesario)	Caracterización (título)
Presentación power point del consultor		
Invitación a jornada de difusión		
Fotocopias libro		A Guide to Pastures and Pasture Species for The New Zealand Hihg Country
Paper		Sustainability of New Zealand high country pastures under contrasting devolopment inputs.7 Environmental gradients, plants selection and diversity
Fotocopias de mapas agroclimáticos		

10. Aspectos Administrativos

10.1. Organización antes de la llegada del consultor

a. Conformación del grupo proponente

_____ muy dificultosa ___X_ sin problemas _____ algunas dificultades

(Indicar los motivos en caso de dificultades)

b. Apoyo de la Entidad Responsable

__X__ bueno _____ regular _____ malo

c. Trámites de viaje del consultor (visa, pasajes, otros)

X_____ bueno _____ regular _____ malo

d. Recomendaciones

10.2. Organización durante la consultoría (indicar con cruces)

Ítem	Bueno	Regular	Malo
Recepción del consultor en el país o región	X		

Transporte aeropuerto/hotel y viceversa	X		
Reserva en hoteles	X		
Cumplimiento del programa y horarios	X		
Atención en lugares visitados	X		
Intérpretes			

11. Evaluación del consultor:

11. **Informe del Consultor**:

Informe de Consultoría Dr. David Scott

The principal agricultural product of the Magallanes is lamb meat production. In the recent period there is a consumer demand for a heavier lamb carcass than traditionally produced. The main investigative avenue to improving the situation has been cross breeding with Texel and other meat sheep breeds, with a small move towards Merino and Merino cross breeds in an attempt simultaneously improve wool quality and output.

However an old adage says "80% of animal breeding is through the stomach". There thus is a simultaneous need to increase the pasture production systems to release the potential of those cross-breeding programs if lambs are to achieve the growth rates needed within the time available, as well as maintaining the vigour and growth of the base flock.

Because of the similarity in climate, topography and rangeland agriculture between the Magallanes and the New Zealand high country rangeland farming, particularly that of the Mackenzie Country of the inland Basins of the central South Island, I was invited to visit and comment on the concepts and practices which might be transferable to the Magallanes, with particular emphasis on pasture development options with fertiliser.

The visit was sponsored by different farmers with financial support from FIA and took place between 28th Nov. and 12th Dec 2003. In that period there was a rapid visit to properties in several different environmental regions within the Magallanes with discussion with farmers owners, managers, researchers and extension officers. I am conscious that only I visited the area for a short period during maximum summer growth.

Initial resume: The general conclusion/recommendation was the **need to identify the critical feed periods within each farmer operations and to fill it with smaller "special purpose pastures" based on subdivision, fertiliser, and species introduction**. The topography and scale of the Magallanes and its farmer's lends itself to the development of such "special purpose pastures".

The four periods most referred to in discussion were in approximate order of importance:

1. Early spring (Aug.-Sept) at lambing time.
2. Lamb fattening (Jan-March).
3. General winter feed (June-Aug).
4. Flushing feed (March)

People tended to differ in which of the first two they considered the more critical. Suggestion on fertilised pasture species appropriate for each of those 'special purpose pasture' uses is given later.

Concepts (a) 'Special purpose pastures', 'feed bank'

The possible pasture development in the Magallanes was observed from the perspective of a number of concepts developed in New Zealand to understand the relation between pasture performance on different sites and the relationship between natural and improved grasslands (Allan & Scott 1993; Scott et al. 1995). It was considered that aspects of those were transferable to the Magallanes.

World wide, range-land properties, because of the environment in which they operate, are generally large in size. When pasture development is contemplated there is often difficulty in getting the necessary change in perception that these changes need only be small, but incremental, and the changes in management that may be associated with them. By emphasis on identifying what are the critical feed periods and by describing methods for their solution as 'special purpose pastures' assists in this change in perception by almost automatically implying they may be small and requiring specific management.

The other concept to emphasise the dynamic nature of stock feed allowance throughout the year is to envisage where is the rising wave of necessary pasture about a month ahead of where the stock are at present, and how to ensure such an advancing 'feed bank' is there for all periods of the year.

Concepts (b) Environment gradients

The second concept is to see the landscape in terms of four environmental factors or gradients which influence pasture growth. Theses are:

1) Soil moisture as related rainfall, evaporation, drainage (particularly in the present context vegas).
2) Temperature as is indirectly represented in most presentations as latitude, altitude, aspect and slope.
3) Soil fertility either natural or applied.
4) Grazing management in the sense of the interaction of animal treading and grazing with the location of plant growing points.

Collectively these are considered to determine the potential pasture productivity of a site, and for that potential to be unique for each combination of the four environmental factors. The derived concept is that 'potential pasture productivity is determined by environment - not species', and that if we wish to change pasture production it is the environment that has to be modified in some manner, not just the introduction of a new species.

The first two of these factors are particular characteristics of each site, and generally have to be accepted, and not amenable to management change, expect in the very few exceptional cases of drainage or irrigation. The feature of those two factors is the rapid decrease in potential productivity as moisture levels (rainfall) decreases, and as temperature (altitude) decrease, with the decrease tending logarithmic rather than linear.

It is the second two factors of soil fertility and grazing which are most amenable to management. For New Zealand I consider that fertiliser, in the form of P and S fertilisation of legumes can increases potential pasture production by *x*4-5 fold relative to the un-amended natural soils. This compares with the only *x*2-3 fold increase for the water component of irrigation where that is appropriate. The grazing management effect I estimate to be ±*x*2-3 fold, with the deliberate inclusion of the ± to emphasis that while the fertiliser and irrigation response will almost always be positive that the difference between good and bad pasture management can be large.

The Magallanes agriculture operates lesser in the higher rainfall areas, extends further into lower rainfall regions, and operates in a smaller altitudinal range than the concepts were developed for in New Zealand. The likely magnitude of the fertiliser and pasture management effects are considered transferable.

The intention of identifying these factors is to be able to see the relationship between sites and management changes in an environmental domain rather than a geographic domain.

There is also the hope or intention from the all such areas of distinctive environmental combinations would be identified and separately managed for their distinctive characteristics.

Concepts (c) Species niche

The third concept is to see pasture species in the contradictory modes of both being very similar and very different.

They are similar in the sense that they probably all have a similar general response to the four environmental factors of growing best in the wet warm fertile sites, and least in the dry cold infertile environments. I also suspect that most pasture species in their growth reach within 60-70% of the potential pasture production of a site for its particular combination of environmental conditions.

However, I believe, that for each combination of environmental conditions there are only one or two species that can reach the full potential pasture production of the site. In that sense 'each species has its place or niche' where it will be the species that releases the full potential of the site. We have attempted to define what is that niche for a wide range of pasture species for the New Zealand situation, and is the basis for species suggestion made later in the report.

This concept has one of two applications in practice. If we wish to get the best from a particular species e.g. *Medicago sativa* then the environment and management must be changed to suit that species. The alternative is that species selection must correspond to the environment and management conditions that will be applied e.g. possibility of *Lupinus polyphyllus* for vegas areas under zero or low fertiliser applications.

Within general pasture development it is likely that the initial emphasis will be on legume +rhizobia introduction to increase soil nitrogen status and that with that advantage will shift to grasses.

Concepts (d) Grazing management/subdivision

The general concepts of grazing management are a compromise between the animal requirements and the plant requirements. From the animals perspective it is the young regrowth of the plants which is the most digestible, nutritious and hence desirable. From the plants perspective it is being attacked at the very close to the plant parts which are capable of regrowing, and while it is in the process of both trying to make new shoot growth, and replace root reserves depleted since the previous grazing.

The main concept in pasture grazing management was the realization that what made a good pasture species was less to do with its environmental adaptation or growth rate, on more to do with where its new growing points were situated relative to the ground surface and their susceptibility to grazing and treading. Where the new growing points were at or slightly below ground then species had ability to recover and regrow even if periodically grazed to low levels, while other species like *Medicago sativa* with growing points above ground surface were severely damaged by too low grazing. As a plant is started to be grazed, it initiate growth from those lower growing points, and the management skill is in ensuring by the speed of grazing that sufficient material can be taken before it impacts on the upward growing new points.

As a generalisation in a perfect world, no pasture would be grazed for more than a week at one time, and not re-grazed until it had made adequate regrowth.

In extensive range-land systems the compromise is to so reduce the animal grazing intensity that by dilution a sufficient proportion of plants only infrequently encounter the grazing effect and have sufficient time to recover. However, by stock control through subdivision, it is possible control the defoliation intensity /regrowth cycle so that all pasture species can be utilized and thereby increase forage availability.

It is the potential to use all available plants, rather than just a proportion, through control of the defoliation /regrowth cycles which is the basis of the desirability of subdivision.

Again using the generalisation above the desirable level of subdivision would be into weekly feed-allowance areas for the different groups of animals. Because of the differences in potential between land types and seasons of the year it would be desirable that the land subdivisions follow the same differences.

Fertiliser (N, P, K, S)

Some perspectives on fertiliser use for increasing pasture production are suggested. Nitrogen being the one of the main constituents of plant proteins World-wide crop-production, pasture-production, and most fertiliser investigations are towards increasing the nitrogen status of the soil, thereby plant uptake and growth. Where there are natural nitrate deposits (as in Chile in the past), or where countries have an industrial base, then nitrogen fertiliser of various types may be the most efficient fertiliser for increasing pasture production. Direct use of N fertiliser may have a small but much specialised role within Magallanes pasture systems.

The more likely system in the Magallanes, as in Australia, New Zealand, and other parts of the world is indirectly through N fixation of introduced legumes and the appropriate fertilisers for them – "fertilize legumes, to fix N, to grow grass, to feed sheep". As legumes are more coarse rooted than grasses it is generally considered that they are less efficient in nutrient uptake than grasses, that fertiliser levels have to be designed for the legume, and that if they are adequate for the legume they are probably more than adequate for the grass.

For legumes most attention has been focussed on phosphorous, partly I suspect because it was the first discovered in trials, and partly because many of the cropping areas and improved pasture areas of the world are in the higher rainfall where through leaching, P is generally more deficient. The soil tests for the Magallanes suggest that soil P levels are generally moderate to high, though field trials show further response to P fertiliser.

The other main constituent of proteins is sulphur. However in the past it has not been prominent in the fertiliser considerations. This may because many of our results and concepts have come from the Northern Hemisphere, where the Industrial Revolution preceded the Agricultural Revolution, where with emissions from coal burning, S was seldom deficient so not recognized. However in Southern Hemisphere, non-industrial countries and in low rainfall regions S is coming to be recognized as often the most deficient nutrient for legume growth. The trends in the Magallanes are suggesting the same.

Potassium deficiencies are often present in cropping systems, but generally note in grazing agricultural systems.

Chile has its own internal sources of fertiliser materials for P and S in rock phosphate, gypsum and elemental sulphur and is likely to be the basis of further development for the Magallanes. All three have the advantage in being acceptable to the organic movement.

The 'superphosphate' of Chile (high P, low or nil S) is not the same as the 'superphosphate' of Australia and New Zealand (approximately similar S and P levels). The necessary blending technology of elemental sulphur with rock phosphate to get more rapid plant availability is in the literature. My impression is that sulphur fertilisers will become increasingly important in the pasture development of the Magallanes, with the greater solubility of S in gypsum being the more important in the early pasture establishment stages, but the cost efficiencies of elemental S more important in the longer term phases.

Pasture species

The following is an appraisal of the improved pasture species for use in 'special purpose pastures', both those whose potential is established, and those which it is suggested warrant further evaluation.

There are probably two generalities. The first, referring back to the 'species niche' concept is "get the species right" for the particular set of environmental and proposed management conditions before worrying about cultivars. The second would be that in this it is probably going to be "legumes before grasses".

My assessment is that *Medicago sativa* has established its role as likely to be the most suitable and major species throughout the drier zones on moderate to dry sites. But I would emphasise that to get the best performance from the species requires specific management, particularly limiting the grazing duration, and allowing adequate regrowth period, care in the initial years, ensuring initial inoculation, and that it generally performs best in near monoculture. It has to be clearly seen as a "special purpose pasture". With its established wide suitability, it is probably at a suitable stage for investigating whether then can be finer discrimination in site and management suitability by cultivar evaluation.

The improved grass that has shown widest adaptation to a range of Magallanes environments is *Dactylis glomerata*, and is likely to be main successful grass in "special purpose pastures". However, the present form of the species, from introductions several decades ago, is overly 'stalky' or 'stemy' and consideration should be given to evaluating more recent cultivar types which have more leaf. Also in management the guidance would be for lenient grazing in initial years to allow the plant to build up a crown of protective leaf bases. While *Dactylis glomerata* will probably be the most suitable species during an improved pastures moderate fertility phase, it need to be recognised that its feeding quality is only moderate, and that it may be possible to move towards the *Lolium*s as soil fertility increases.

Trifolium repens is already present in the forest zone pastures and is likely to be major legume for that zone and for vegas throughout. However, I had the impression that the full range of environmental sites and management conditions under which it would be suitable has not been established, and warrant further evaluation.

The following two sections refer to other species which I believe warrant further evaluation within the "special purpose pasture" concept. The first section considers alternative species from the perspective of the specific critical feed periods, and the second section from the alternative perspective of suitable species and the role they might fulfil.

Pasture species for critical feed periods

For each of the critical periods the most suitable pasture species are listed in assessed order of suitability. Those in open type are species already in use, while those in brackets are those considered warranting further evaluation.

Lamb finishing feed:
a) drier sites; *Medicago sativa, (Cichorium intybus), (Trifolium pratense), Trifolium repens, (Lolium multiflorum.*
b) moister sites; *Trifolium repens, (Trifolium pratense), (Lotus pedunculatus).*

Early spring: *(Trifolium ambiguum).*

Winter feed: conserved (hay); *Medicago sativa, Dactylis glomerata, (Trifolium hybridum), (Phleum pratense).*
standing pasture; *Dactylis glomerata, (Phleum pratense).*

Flushing: *Medicago sativa*

General grassland development:
a) dry high fertility sites; *Medicago sativa, (Trifolium ambiguum), (Lotus corniculatus).*
b) dry moderate fertility; *(Lotus corniculatus), Medicago sativa.*
c) moist high fertility; *Trifolium repens, (Trifolium pratense), (Trifolium ambiguum), (Lotus pedunculatus).*

d) moist moderate fertility; *(Lupinus polyphyllus), Trifolium repens, (Trifolium pratense), (Lotus pedunculatus).*

Pasture species warranting further evaluation
Legumes: All need consideration of appropriate rhizobia inoculation, summer growers.

Lotus corniculatus: 'poor land *Medicago sativa*', moderate fertility, needs *Medicago sativa* management, late summer feed, ?hay.

Lotus pedunculatus: higher rainfall, vegas, pasture component, lax grazing.

Trifolium ambiguum: as long term pasture component at all fertility levels, particularly high, vegetative spread by rhizomes, slow establishing

Trifolium pratense: 'special purpose pasture', moist sites, good lamb finishing feed, care with formatin levels in relation to flushing.

Trifolium hybridum: i. short term hay crop 1-3yr, potentially good

ii. short term pasture component for high rainfall areas

Lupinus polyphyllus: as pasture component of vegas and higher rainfall areas with zero of low fertiliser, standing winter feed and shelter, already adapted to area.

Coronilla varia: as pasture component for dry areas, slow establishing.

Grasses: Better winter characteristics

Lolium perenne: probably no role at present soil fertility levels, warrant re-evaluation when higher soil fertilities are achieved, high feeding quality and well established knowledge of management systems necessary, has been used in the area in the past.

Phleum pratense: i. as an important but inconspicuous component of grazed pastures over a range of soil fertilities on moderate to higher rainfall sites and vegas

ii. as the grass component of *Trifolium pratense/Phleum pratense* hay.

Secale cereale: as a contender with *Avena sativa* for winter green feed crop at similar

soil fertilities, with the potential advantage of more than one grazing.

Festuca arundinacea: probably superior to *Dactylis glomerata* once higher soil fertility is achieved.

Bromus inermis: possible role similar to *Agropyron elongatum.*

Herbs:

Cichorium intybus: Special purpose lamb finishing feed, tall.

(the high present recent prevailance of *Taraxicum officinale* would suggest suitability)

Infra-structure requirements

In the possible development of 'special purpose pastures' to fill in 'critical feed periods' for greater lamb weights, or for general pasture and grazing management improvements I see the need for infra-structure changes at a number of levels.

For the initial establishment and harvesting of such areas there is a present lack of spraying, cultivation and harvesting machinery. It is suggested that this would be better down by consortiums rather than each land holder acquiring the necessary set. With good will the method works. The advantage of a consortium is the shared expenses and the ability to purchase suitability large equipment, such that site and time factors are not a machinery limitation. The key to the consortium approach is a good machinery manager/operator.

At another level is the within property planning. While initially such 'special purpose pastures' may be small in area and extent, with time hopefully their impact will be to increase general property production, and that they will continue to increase in number and extent. Consideration need to be given to ease of access-way for stock both now and in the future, with the suggestion that they be sufficiently wide so that they can be considered as paddocks in their own right. There is also the need to consider the general property development - with increase in carrying capacity, where may additional staff be located? where will necessary roads and access-ways be?, where will additional yards and buildings be?

At present attempt is being made to accomplish all phase of lamb production within each property, from base flock to fat lamb. Within New Zealand there is the option of subdivision of the different phases, with properties on the more difficult country, trading and transferring lambs to properties on better country and improved pastures for 'finishing' prior to selling to meat-works. The approach warrants consideration. It would involve setting up a suitable trading system. It may well be initiated by the meat-works working back up the production chain rather than the primary producer.

The likely two key elements to development will be fertiliser and subdivision (=fencing). There would need to develop a local fertiliser infra-structure able to supply in greater quantity and bulk than present.

My observation is that fencing in the area is much standardised, from an engineering perspective very good, but I suspect very costly. The topography of the area and the suggested scale of desirable subdivision would be very suited to electric fencing and greatly cheaper. While there is now adequate technology available, the New Zealand experience is that the managers and operators have to fully believe in it for it to work well. It also tends to be slightly less effective for sheep (because of partial insulation of wool) than for cattle.

Fertiliser and sub-division are considered to be equal avenues for development, but differ slightly in short-term risk assessment. Fencing, building, reading, etc. can be regarded as capital items, whose returns may not be immediately obvious in annual balance sheets, but probably have small on-going costs. Fertiliser by contrast could (should) imply an on-going commitment and costs for its continuation, with the hope that the increase in production will more than adequately cover those costs.

Investigation /demonstration areas

In conversation, I was asked how might such developments be initiated, demonstrated, and promoted. The following is a suggested protocol.

An undertaking by a group of land-holders to:

i. Develop a further 10-100ha each year using established pasture development options.

ii. Investigate development options on 1-10ha in new area or type of site.

The yearly protocol for the 1-10ha investigative area might be:
Site preparation in the previous summer/autumn by herbiciding (glyphosate) or cultivation.
Spring sowing (preferably by drilling).

Treatment combinations

Species (1-4) 1. General seed mixture of all possible contending species
2. ?
3. ? (single or specific species of interest)
4. Native (probably not sprayed, or see what volunteers)

Fertiliser levels (2-5)
1. Top control – everything S, P, N, micro at moderate to high level
2. ?
3. ?
4. ? (specific types or levels considered practical)
5. Nil – bottom control

Subsequent pasture management (2)
1. Hay management – tall, single cut
2. Grazing – to moderate height, graze, allow regrowth to moderate before re-graze.

At least visual recording of broad features early summer, once a year. Hold no high expectation for first year.
Maintain for at least 5 years.

The suggested outline or protocol has tried to include a number of features

- That there is already more than enough technology known and in use to continue the development
- An undertaking by the land holders to a continued developing 'special purpose areas' using established methods and species, in return for hopefully some support

for investigating options for different new areas, and thus achieve incremental improvements and understanding.

- The inclusion of a 'top control' in some of the alternatives tried, mainly to change the perception of what might be biologically possible, even if the inputs are not 'practical' at this time. The more 'practical' possibilities can be the intermediate treatments.
- For the exploratory/investigative phase of using of a single seed mixture containing all contending species as a rapid means of finding those most suitable to particular environmental/management combinations. While there may be doubts this approach, my experience is that it works well in practice. Only the more successful species would be carried forward to the large scale developments.
- The need to do things right in the land preparation for the exploratory/investigative phase so that there can be a valid comparison of species suitability.
- The request for relatively large plot areas, by normal pasture research standards, for the exploratory/investigative phase. The scale of the Magallanes allows that. The intent being that what initially look to be request for 'small' experimental areas, are very close in size to what would be ultimately desirable functional 'special purpose pastures'.

Needed investigations: Fertilisers

The comments in the following two sections need to tempered by my only moderate knowledge in soil chemistry. The results of a range of fertiliser response trials from the Magallanes was brought to my attention, but I also obtained the impression that they were not wide-spread, and the many of the recommendations on type and rates came from investigation further north in Chile.

For the particular area there would seem to be a need for further investigation on how the fertiliser rates and type might vary with the rainfall gradient, within the leaching and accumulation areas with a particular landscape. With the principal fertilisers likely to be rock phosphate, gypsum and elemental S, whether the trends in requirements can be accommodated by different blends of those base materials.

Needed investigation: S soil tests

I was left with no clear impression on the utility of soil tests for determining fertiliser requirements.

The soil P tests were indicating that P levels were generally adequate to high for plant growth, though trials and general recommendations were showing continued response to fertiliser application.

Information I was given of fertiliser application trials showing pasture response to sulphur. Soil tests, based on soil solution sulphates, were generally indicating low to deficit levels of S. However, the soil S test were also showing very large differences from deficit to extremely high between land types within the same general area, and a few instances of large difference between successive determinations on the same site.
Assessment of soil S status is known to be difficult – the known small amount is soil solution relative to the total S, its dependence on rate of organic mater mineralization, its sensitivity to rates of plant growth and uptake prior to sampling, and its extreme sensitivity to the moisture status of the sample between collection and analysis. There is also the particular difficulty in drier environments between its presence or possible deficiency in the top soil, versus its possible accumulation in the subsoil. In New Zealand there has been a trend to drop measurement of soil solution sulphate levels as the standard, because of all its sources of potential variability, in favour of a test simulating the mineralization of S from organic matter (extractable organic sulphur). With the likely importance of S for pasture development in the lower rainfall areas, there is probably a need to reassess, or at least give strong guidelines, on how to take and interpret soil S tests.

Needed investigations: Pasture establishment

The prevailing feature of the Magallanes is their low mean temperature, prevailing wind, short slow growing season, with a dominantly perennial vegetation giving competition to establishing species, and often with a high organic matter 'peaty' soil layer overlaying finer loose textured substrata. The prime function in any pasture establishment method is to remove competition from resident vegetation and only secondarily to enhance the soil seed bed for the sown species. On a world scale the two present contrasting methods are either destroying competition by full cultivation or sowing into the prepared seed bed; or, in the present era, herbiciding and direct drilling into the killed sward.

I consider the herbiciding/direct drilling option may be more generally appropriate for the Magallanes, but with a need more investigation of both approaches relevant to other issues. My concern with the cultivation option is the very loose texture of the mix of organic matter and fine textured soil with the high susceptibility to wind erosion. There is probably need to consider heavy rolling following seeding and the inclusion of a low proportion or a cereal species in mixture to provide a quick temporary wind shelter. The dilemma in the herbicide/direct drilling approach is the present concern of the 'organic movement' in the Magallanes where the use of herbicides might not be an option. The merits of the herbicide approach are in removing the competition while retaining a plant cover (dead) against wind erosion. Also I would suggest that the most likely herbicide to be used glyphosate ('Roundup') is a 'safe' herbicide relative to humans and animals and should only need to be used once.

For both the cultivation and herbicide approach the suggestion that the primary stage should be done in the previous summer/autumn.

There is a third option to site preparation in the Magallanes within present farm practices. There are occasions within the year when large mobs are formed as part of stock movement between winter or summer country, or particular activities like shearing. In small pre-fenced proposed "special purpose pastures" these 'over-night' mobs can be used to severely damage existing vegetation and tramp in surface sown seed. Such brief, extremely high stocking rates have been shown to control *Empetrum rubrum*.

Needed investigation: Vegas

It is probable that vegas, making up 5-20% of the properties, already supply much of the forage. They are also likely to the best potential sites for many of the 'special purpose pastures'.

However, at present the term, while implying enhanced moisture status, covers a wide range of site types. There would be usefulness in greater discrimination of the various types and their inherent characteristics, so that investigations of development options and experiences could be more easily extrapolated between different situations. I do not know whether finer discrimination is already present with soil typing, but did not detect it in general conversation.

Their higher moisture, nutrient, and organic matter status make them among best potential sites for 'special purpose pastures'. But I did not detect any body of information other methods for their development through species and fertiliser introduction. The major difficulties are likely to be the competition from existing vegetation, introduction of seed into the often very peaty upper soil layer, and the possibly rapidly changing moisture status of that layer.

Needed investigations: Stock shelter

The prevailing feature of the Magallanes is their low mean temperature, prevailing wind, low stock shelter, few and slow growth of any shelter tree species. The main present shelter in the drier zone is resident shrub species, seen as beneficial at low densities, and detrimental at higher densities. The only observed planted tree species were *Macrocarpa, Sorbus,* occasional *Larix,* and occasional *Salix* in vegas areas.

The only suggestion is towards: deliberate planned retention of parts of the resident shrub areas; perhaps their use as exclosure nurse shelter areas for planted tree species; reappraisal of tree genotypes available from within the forestry industry; and perhaps the use of the native *Nothofagus* species established by cultural methods.

Resume

A fellow New Zealander, Mr Tom Fraser, has also recently visited the Magallanes sponsored by another group of producers, to give comments and suggestions on the particular pastures for lamb finishing. Both reports should be considered in combination.

In conclusion, and to repeat the main recommendation - the need is to identify the critical feed periods within each estancia operations and to fill it with smaller "special purpose pastures" based on subdivision, fertiliser, and species introduction. The topography and scale of the Magallanes and its estancia's lends itself to the development of such "special purpose pastures".

I would particularly like to acknowledge the sponsorship by Mr E. Doberti, and support of Mr R. Allende and Dr. N. Covacevich in understanding the Magallanes.

Reference

Allan, B. E.; Scott, D. 1993: Winter cold temperate rangelands. Improvement strategies for intensive rangeland ecosystems. Invited plenary paper . *Proceedings of the XVII International Grassland Congress 20*: 1701-1704.

Scott, D.; Maunsell, L. A.; Keoghan, J. M.; Allan, B. E.; Lowther, W. L.; Cosssens, G. G. 1995: A guide to pastures and pasture species for the New Zealand high country. Palmerston North, New Zealand Grassland Association.

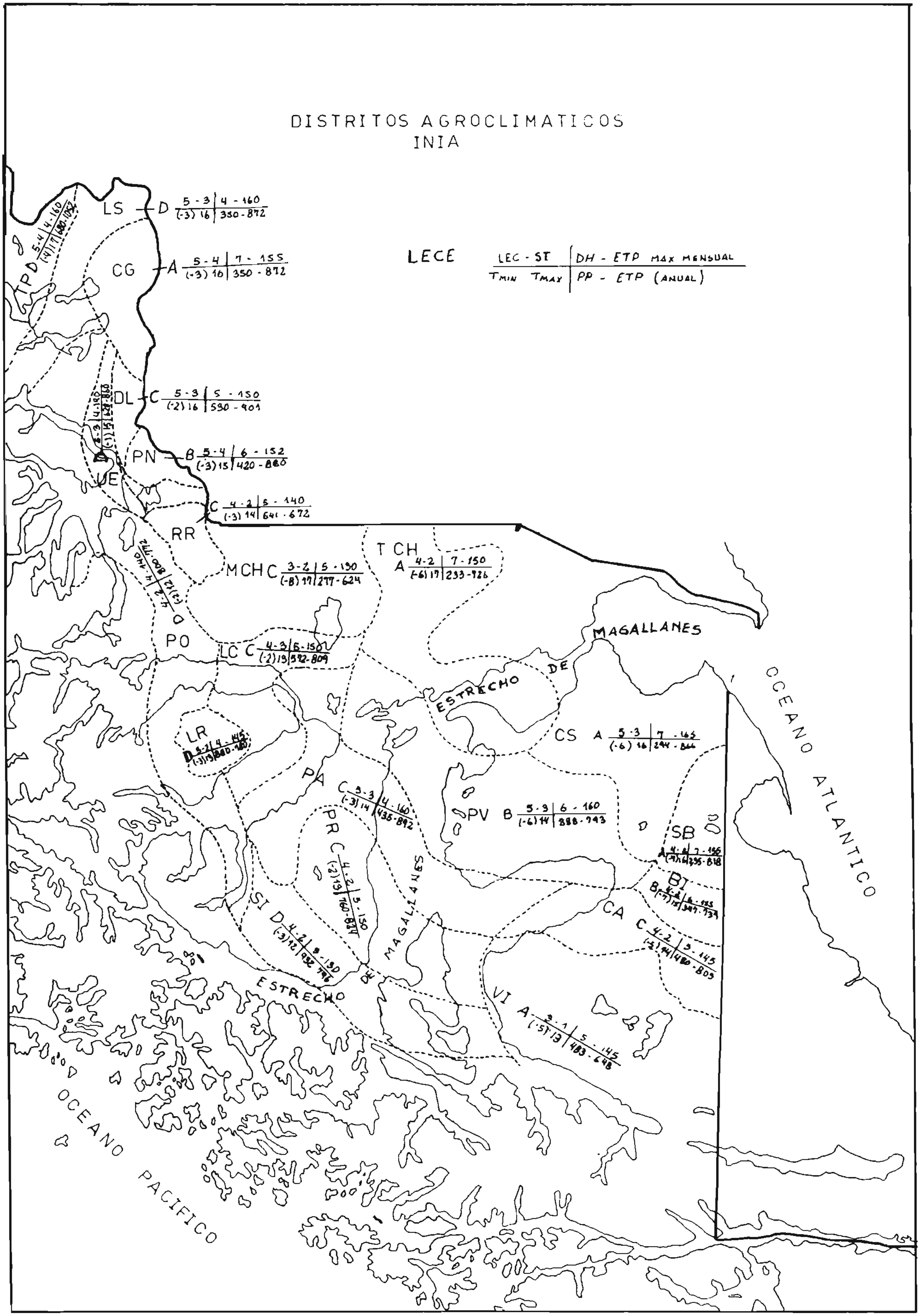
13. Conclusiones Finales

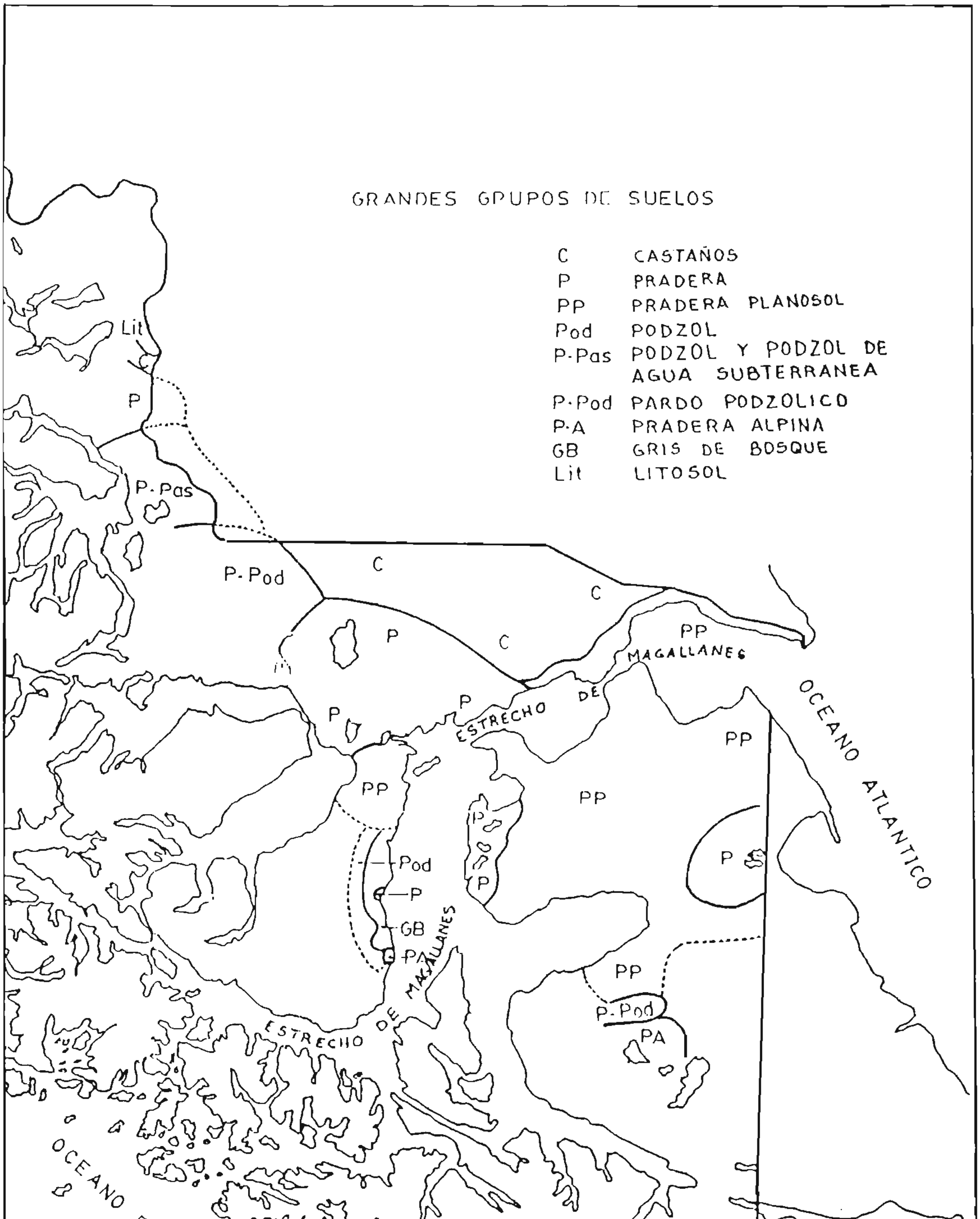
Fecha: 15/10/2003

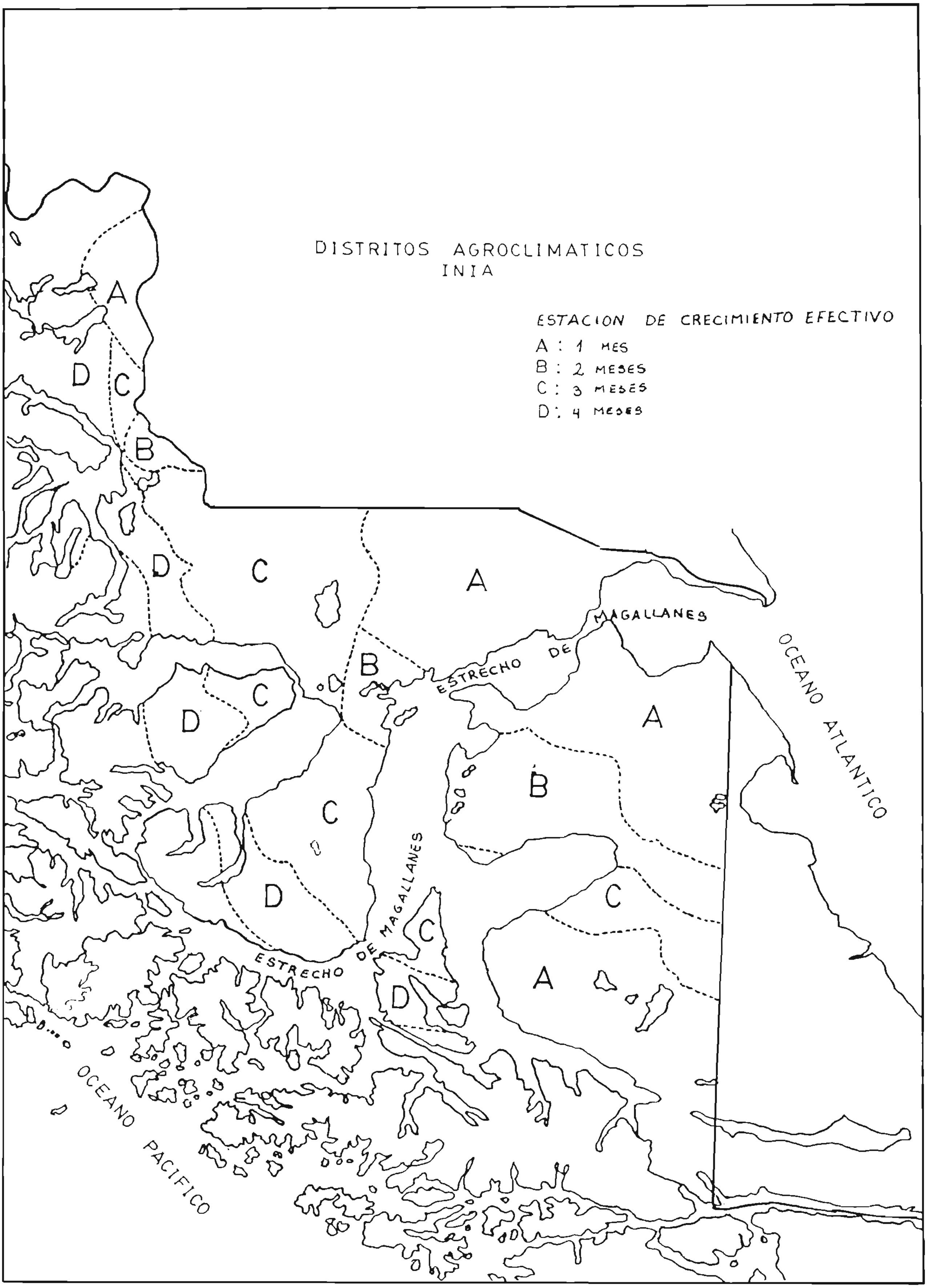
Nombre y Firma coordinador de la ejecución: Rodrigo Allende

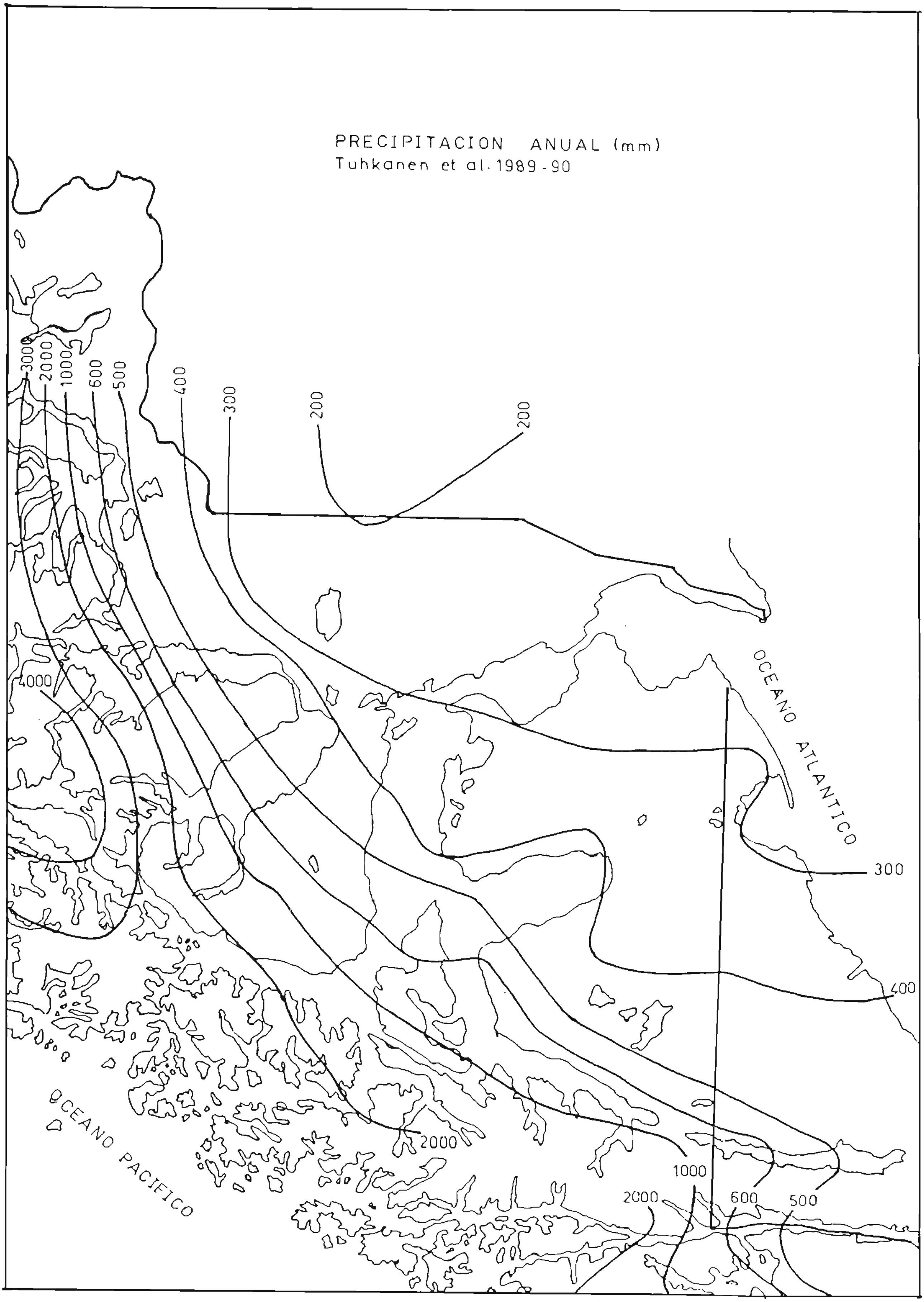
AÑO 2003

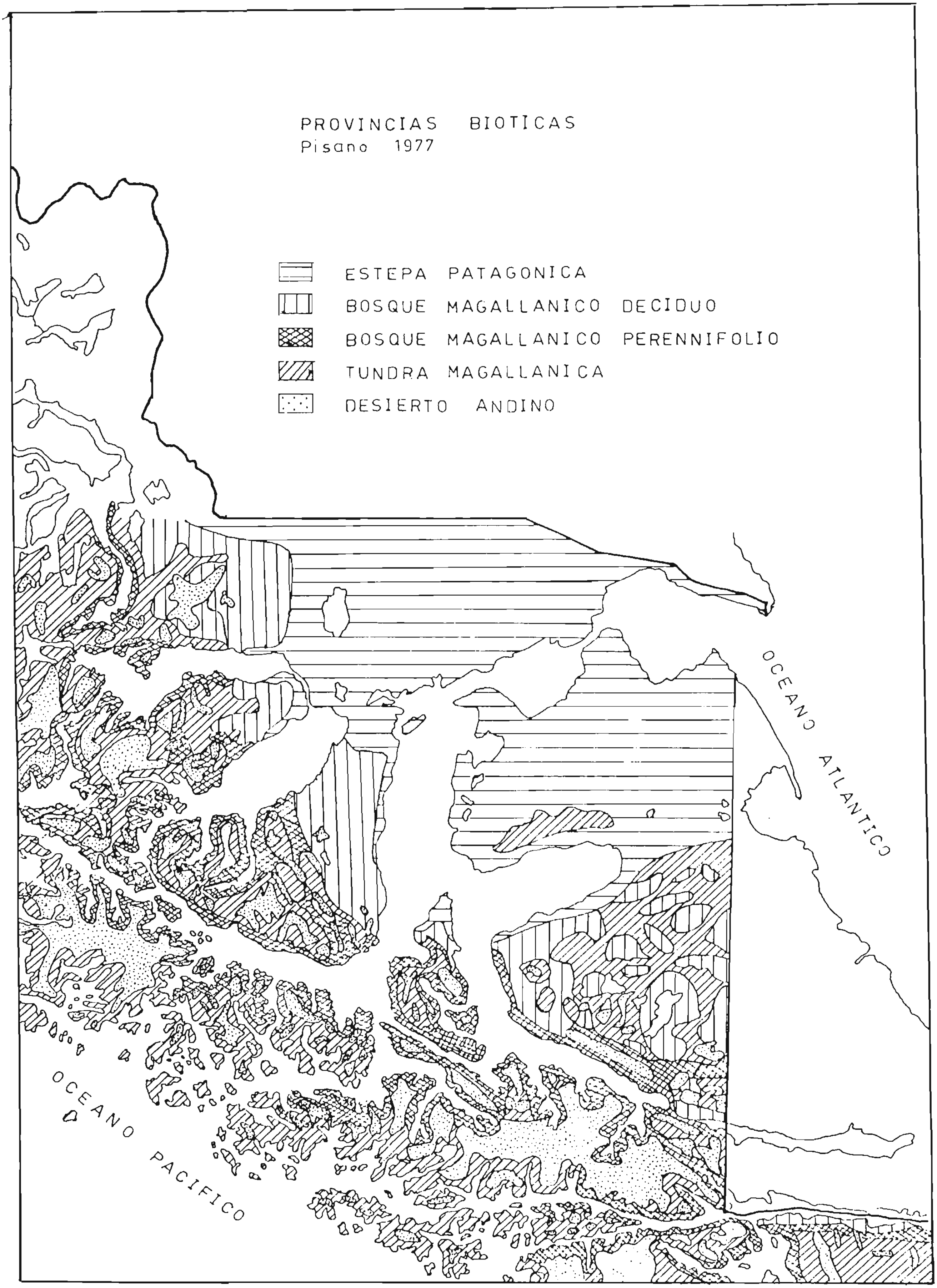
ANEXOS GIRA CONSULTORES
CARACTERIZACION AGROCLIMATICA


DISTRITOS AGROCLIMATICOS
INIA
LECE
LEC - ST | DH - ETP MAX MENSUAL
TMIN TMAX | PP - ETP (ANUAL)
LS
D 5-3 | 4-160
(-3) 16 | 330-872
CG
A 5-4 | 7-155
(-3) 16 | 350-872
TPD
DL
C 5-3 | 5-150
(-2) 16 | 530-901
PN
B 5-4 | 6-152
(-3) 15 | 420-880
UE
C 4-2 | 5-140
(-3) 14 | 641-672
RR
MCH C 3-2 | 5-130
(-8) 17 | 277-624
TCH
A 4-2 | 7-150
(-6) 17 | 233-926
PO
LC C 4-3 | 6-150
(-2) 13 | 592-809
LR
PA
PR
PV B 5-3 | 6-160
(-6) 14 | 388-743
CS A 5-3 | 7-165
(-6) 16 | 294-866
SB
BI
CA
SI
VI A 3-1 | 5-145
(-5) 13 | 483-648
MAGALLANES
ESTRECHO DE MAGALLANES
OCEANO ATLANTICO
OCEANO PACIFICO

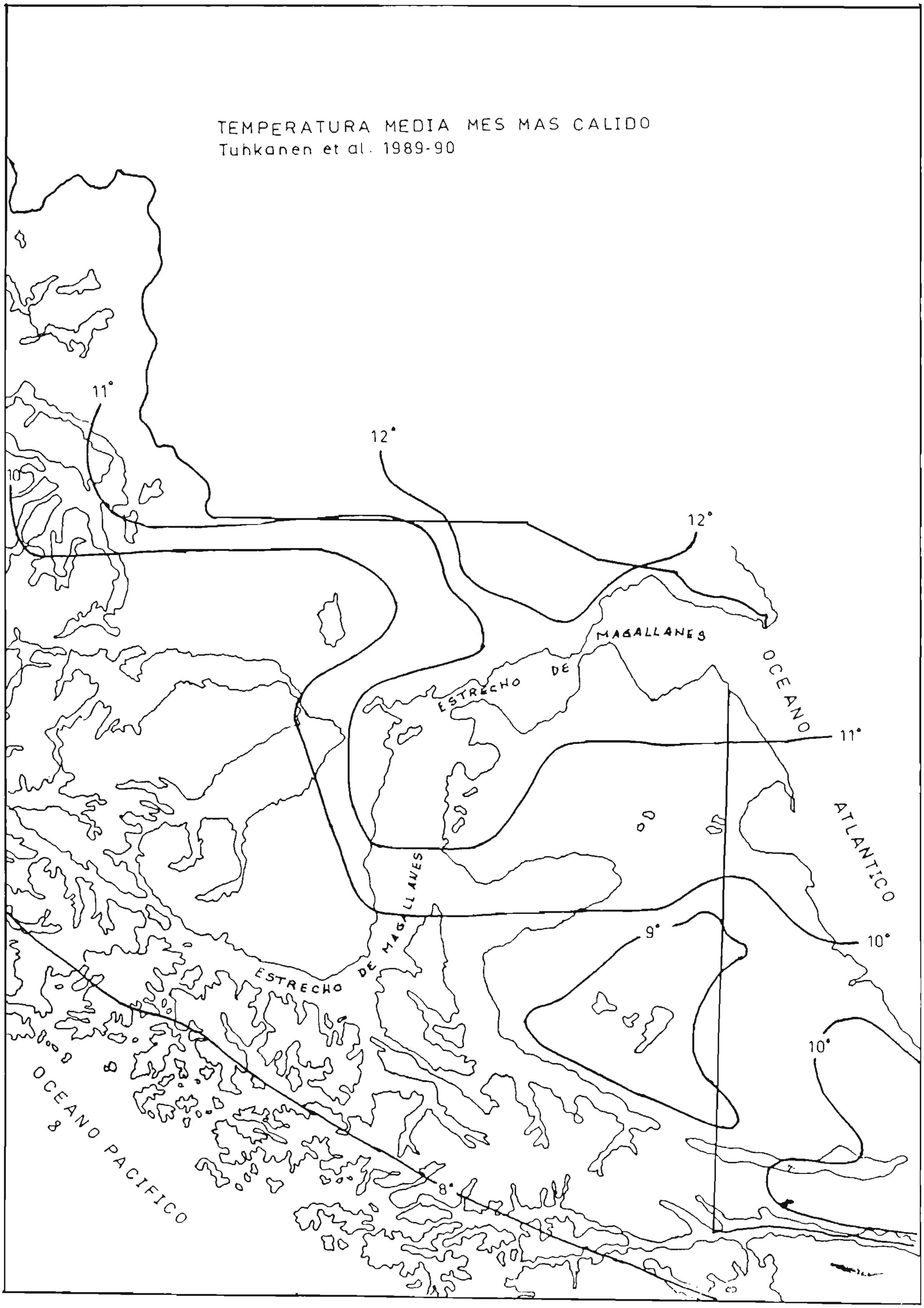

GRANDES GRUPOS DE SUELOS
C CASTAÑOS
P PRADERA
PP PRADERA PLANOSOL
Pod PODZOL
P-Pas PODZOL Y PODZOL DE AGUA SUBTERRANEA
P-Pod PARDO PODZOLICO
P-A PRADERA ALPINA
GB GRIS DE BOSQUE
Lit LITOSOL
Lit
P
P-Pas
P-Pod
C
C
C
P
P
P
PP
ESTRECHO DE MAGALLANES
OCEANO ATLANTICO
PP
PP
PP
P
P
P
Pod
P
GB
PA
PP
P-Pod
PA
ESTRECHO DE MAGALLANES
OCEANO PACIFICO


DISTRITOS AGROCLIMATICOS
INIA
ESTACION DE CRECIMIENTO EFECTIVO
A : 1 MES
B : 2 MESES
C : 3 MESES
D : 4 MESES
ESTRECHO DE MAGALLANES
ESTRECHO DE MAGALLANES
OCEANO ATLANTICO
OCEANO PACIFICO
A
D
C
B
D
C
A
B
D
C
A
B
C
D
C
C
A
D


PRECIPITACION ANUAL (mm)
Tuhkanen et al. 1989-90
3000
2000
1000
600
500
400
300
200
200
4000
OCEANO ATLANTICO
300
400
2000
1000
2000
600
500
OCEANO PACIFICO



PROVINCIAS BIOTICAS
Pisano 1977
ESTEPA PATAGONICA
BOSQUE MAGALLANICO DECIDUO
BOSQUE MAGALLANICO PERENNIFOLIO
TUNDRA MAGALLANICA
DESIERTO ANDINO
OCEANO ATLANTICO
OCEANO PACIFICO



TEMPERATURA MEDIA MES MAS CALIDO
Tuhkanen et al. 1989-90
11°
12°
10°
12°
MAGALLANES
ESTRECHO DE
OCEANO
11°
ATLANTICO
MAGALLANES
ESTRECHO DE
9°
10°
10°
OCEANO PACIFICO
8°

ANEXOS GIRA CONSULTORES
PRESENTACIÓN JORNADA DE DIFUSION

GOBIERNO DE CHILE
FUNDACION PARA LA
INNOVACIÓN AGRARIA

PROGRAMA DE CONSULTORES CALIFICADOS
PROYECTO: " DETERMINACIÓN DE LIMITANTES EN LA REALACION SUELO-PLANTA EN PRADERAS DE MAGALLANES: DESARROLLO DE METODOLOGÍA"

Eduardo Doberti Guic, tiene el agrado de invitarle a participar en las actividades asociadas con la visita del consultor Ph.D. David Scott, experto en suelos e introducción de praderas, proveniente de Nueva Zelanda.

Esperamos contar con su presencia y colaboración. Adjuntamos calendarización de actividades y currículo vitae del experto. Por favor confirmar visitas al 09-6492527.

GOBIERNO DE CHILE
FIA

Programa de Consultores

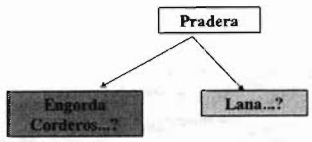
Determinación de Limitantes en Relación Suelo-planta para Praderas de Magallanes: Desarrollo de una Metodología

- Consultor
  - David Scott Ph.D.(AgResearch New Zealand)
- Entidades participantes
  - Estancia Las Coles
  - Ganadera Cerro Guido
  - Ganadera Morro Chico
  - Ganadera Marín
  - Estancia Josefina
  - Ganadera Entre Mar
- Colaboradores
  - INIA Kampenaike
  - Universidad de Magallanes

Objetivos

Identificar cuantitativamente y cualitativamente fortalezas y debilidades en el manejo de la relación suelo-planta de la pradera en diferentes zonas agroecológicas de la XII región para aumentar la competitividad del rubro ovino.

- Aumento de la producción



Períodos críticos de alimentación

[redacted]

- Engorda de corderos (Enero-Marzo)
- Primavera temprana (Agosto-Septiembre)
- Alimentación invernal (Junio-Agosto)
- Flushing de ovejas (Marzo-Abril)

Praderas: Efectos de Manejo

- Fertilizante
  - Produción actual de materia seca x 4- 5 niveles
- Subdivisón (apotreramiento)
  - Producción actual de materia seca x +/- 2-3
    Depende de estrategia de pastoreo

Efecto relativo

- Humedad (lluvia o Vegas) x 2-3 niveles
- Temperatura (Altitud) x ?
- Fertilidad
  - N Natural, P or S x 4-5 niveles
- Manejo del pastoreo: +/- 2-3 niveles...?

Productividad está determinada por ambiente y no por las especies

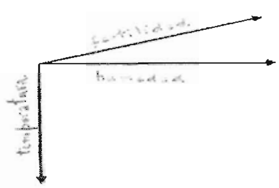
Conceptos de Especies

"Cada especie tiene su lugar"

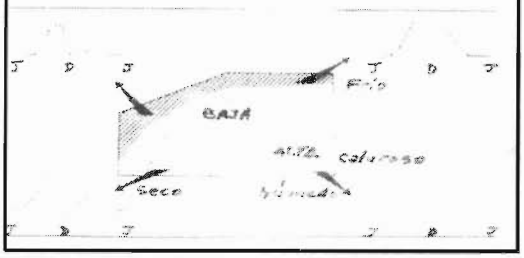
"Solo 1 o 2 especies recepcionarían el potencial de un sitio con una combinación particular de condiciones ambientales"

"Selección de especies se relaciona con las condiciones de manejo (Sitios, Fertilidad, Pastoreo) que existen y se implementarían"

Gradientes ambientales



Humedad y Temperatura



Clima

Fertilidad del suelo

Selección de especies

Fertilizante

- Fertilizante ⟶ Leguminosas ⟶ N ⟶ Grass
- Fósforo: Nivel adecuado...?
- Azúfre: Generalmente deficiente
  - Yeso: Término corto
  - Azúfre elemental: Término largo
  - Análisis del suelo : Azúfre (SO_4, MO)
- Nitrógeno: Altamente especializado
- Infraestructura para fertilizantes

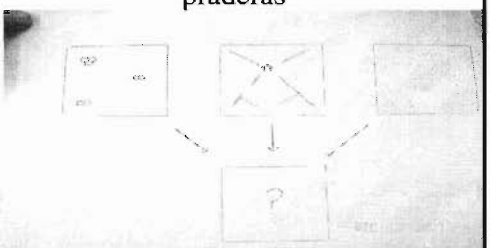
Leguminosas

- Primero leguminosas luego las gramíneas
- Inoculación de Rhizobia
- Azúfre y Fósforo fertilizantes

Subdivisión: Manejo de praderas

- Puntos de crecimiento de la planta
- Ninguna pradera debería ser pastoreada por más de una semana
- Corto/Corte/Recrecimiento

Manejo de la Subdivisión de praderas



Especies de praderas con fertilizantes

- <u>Engorda de corderos</u>:
  - Area secas: Alfalfa (*Medicago sativa*)/ {Chicoria (*Cichorium intybus*)}/ {Trébol rosado }, Trébol blanco (*Trifolium repens*), *{Ballica italiana (<u>Lolium multiflorum</u>)}*
  - Areas humedas: *Trébol blanco/, {Trébol rosado}/, {Lotus pedunculatus}*
- <u>Inicio de primavera</u>
  - Fertilización
  - {Trébol Caucásico (*Trifolium ambiguum*)}
  - Pasto ovillo (*Dactylis glomerata*)

Continuación de especies de praderas con fertilizantes

- Alimentación invernal
  - Conservación: Alfalfa (*Medicago sativa*), Pasto Ovillo (*Dactylis glomerata*), {Pasto Timoteo (*Phleum pratense*)}
  - Standing: Pasto Ovillo (*Dactylis glomerata*), {Pasto Timoteo (*Phleum pratense*)}
- Flushing
  - Desarrollo general de praderas

Continuación de especies de praderas con fertilizantes

- Alta fertilidad.
  - Areas secas: Alfalfa (*Medicago sativa*), {Trébol caucásico (*Trifolium ambiguum*)}, {*Lotus corniculatus*}
  - Areas húmedas: {Pasto timoteo (*Phleum pratense*)}, {Trébol caucásico (*Trifolium ambiguum*)}
- Moderada fertilidad.
  - Areas secas: {*Lotus corniculatus*}, *alfalfa* (*Medicago sativa*) and Trébol blanco (*Trifolium repens*).
  - Areas húmedas: {*Lupin polyphyllus*}, {*Lotus pedunculatus*}, y Trébol blanco (*Trifolium repens*).

Especies Presentes

- "Seleccionar las especies correctas antes de preocuparse de los cultivares"
- Pasto Ovillo (*Dactylis glomerata*) y Alfalfa (*Medicago sativa*)
  - Rol suficientemente definido
  - Se puede partir buscando diferencias en los cultivares
- Trébol blanco (*Trifolium repens*)
  - Others
  - Necesidad de evaluación y rol en diferentes regiones
- Leguminosas primero Pastos contínuan

Posibles especies leguminosas

- *Lotus corniculatus*
  - Tierras pobres
  - Fertilidad moderda en sitios que necesitan manejo para alfalfa management
  - Verano tardío/Otoño alimento como heno...?
- *Lotus pedunculatus*
  - Alta pluviometría, vegas, Componente de pradera, bajo pastoreo
- *Trifolium pratense*
  - Especie para manejo estratégico
  - Humedad
  - Alimento para finalizar corderos
  - Término medio
  - Componente de vegas

Posibles especies leguminosas

- *Trifolium hybridum* (Trébol Alsiker)
  - Período corto para producción de heno: 1-3 años
  - Potencial para heno
  - Como praderas para áreas con altas precipitaciones
- *Trifolium ambiguum* (Trébol caucásico)
  - Se adapta a un amplio espectro de niveles de fertilidad y tiene un período largo de establecimiento
- *Lupinus polyphyllus*
  - Pasto componente de vegas y áreas con alta pluviometría con cero y baja aplicación de fertilizantes
- *Corinilla varia*
  - Pasto para zonas secas
  - Lento establecimiento
- Rhizobia: Muy importante
- Envoltura del azúfre elemental

Posibles Pastos

- *Lolium perenne* (Rye grass)
  - Ningún rol con la fertilidad actual
  - Re evaluación cuando se obtiene alta fertilidad
  - Buen conocimiento para el establecimiento
- *Phleum pratense* (Pasto Timoty)
  - As important but inconspicunoas component of grazed pasture
  - *Phleum pratense/Trifolium pratense* como potreros para henificación
- *Secale cereale*
  - Como componente con *Avena sativa* de aliemntso invernales verdes
  - Su potencial es más que un pastoreo

Continuación de Posibles Pastos

- *Festuca arundinaceae*
  - Necesita alta fertilidad
  - Como componente de la aliemantación verde de invierno
- *Bromus inermis*
  - Rol similar a *Agropyron elongatum*

Posibles Hierbas

- *Cichorium intybus*
  - Pradera especial para engorda de corderos
  - Muy larga (gran suceso of *Taraxacum officinale*)

Estrategia de Desarrollo

- Camino a seguir por las Estancias
  - 10-100 ha/año: Tecnología establecida
  - 1-10 ha/year: Investigación en opciones para nuevas áreas
  - Protocolo para nuevas áreas
    - Pre herbicida para cultivo (año anterior)
    - Especies (1-4)
      - 1. Mezcla general de todas las especies
      - 2. ?
      - 3.?
      - Nativas
- "Necesidad de hacer lo correcto para no conseguir resultados fracasados"

Continuación Estrategia de Desarrollo

- Fertilizantes (2-5)
  1. Control Top con todo S. P. N y microelementos
  2. ?
  3. ?
  4. ?
  5. Nada control
- Manejo
  1. Manejo fuerte - altura de corte
  2. Pastoreo moderado- moderado pastoreo

"Necesidad de hacer lo correcto para no conseguir resultados fracasados"

Subdivision de la cadena de proceso

Investigación: Establecimiento de nuevas plantas

- Corta y lenta temporada de crecimiento
- Competencia
- Viento
- Herbicidas para siembra directa
- Etica por uso de herbicidas
- Cultivo/erosión del viento/cereales de cobertura

Investigación: Azúfre

- Pobablemente el nutriente más deficitario
- Fuentes económicas
- Infraestructura
- Zonas, tasas, frecuencia
- Yeso
- Elemental S
- Análsis de suelo
  - Sulfatos, simple seca
  - Extractable azúfre orgánico

Investigación: vegas

- Mayor productividad
- Areas?
- Tipos: amplia clasificación?
- Opciones de desarrollo?
- Siembra?

Investigacion: Proteccion

- Muy poca investigacion
- Re-evaluacion necesaria

- Macrocarpa, Rowan, broon, larix?
- Nothofagus?

Investigación: Alimento invernal

- Rezago natural de verano
- Alimento conservado
- Cultivos de forrajes
- Establecimiento de leguminosas

Investigación: Infraestuctura

- Subdivision Nalambrado
  - NMaquinaria
  - NConsorcio
  - NCarreteras
  - NTransporte

Investigacion:Relacion ambiente-especies

- Reserva de forraje del verano
- Forrajes conservados
- Cultivos forrajeras
- Conservacin en pie
- Leguminosas mejoradas de ciclo corto

ANEXOS GIRA CONSULTORES
FOTOCOPIAS LIBRO "A GUIDE TO PASTURES AND PASTURE SPECIES FOR THE NEW ZEALAND HIGH COUNTRY"

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Contents

Introduction

The 3.4 million hectares of pastoral high country of the South Island have about 5% of New Zealands stock units, and return about 3 to 8% of New Zealands nett farm income depending on the fluctuating price for fine wool. Hence the high country is not an insignificant part of New Zealand's farming economy. Its productivity is based on pasture.

Over the period of European occupation, the emphasis of this pastoral farming has shifted from the utilisation and modification of the extensive areas of native tussock grassland to the smaller areas of developed, better soils. Thus the present 2.3 million stock units in the high country derive approximately 80% of their feed supply from the 500,000-600,000 hectares that have been fertilised or oversown. These pastures are largely based on introduced species from the United Kingdom or Europe, either consciously introduced and sown, or as accompanying adventive species, which have found a favourable niche in the modified tussock grasslands.

This publication reviews the place of different introduced pasture legumes, grasses and herbs which now have such a dominant role in pastoral farming of the high country, and offer some guidance on their establishment and management. It summarises the collective knowledge of known pasture species relationships at this time, and which were the background to the associated publication Guide to Tussock Grassland Farming outlining their incorporation into farming systems. Both publications represent years of experience by the authors in the South Island high country, along with reference to the published work of many other people in this unique and complex environment.

Because of this wide range of environment and fertility, a greater number of species and cultivars have been considered for high country agriculture than elsewhere in New Zealand. The range of species offers the runholder an opportunity to selectively develop and utilise parts of the property with different species and cultivars for each component of the landscape. Development strategies will be strongly influenced by the land classes on the property, and will be determined by climate, topography, soil type and fertility, vegetation type and cover, and location of buildings and stock handling facilities. Selective development allows the runholder to use the fertiliser application appropriate to each part of the landscape, and allows each landscape class to make its contribution to meeting seasonal animal feed requirements in the most cost-effective way.

The amount of plant introduction, breeding and testing that has been done on behalf of high country agriculture is not fully appreciated. We estimate that, since the 1930s, 30-50 different lines per year have been introduced and tested, but, of these, only a small number have shown potential. In the past decade, these new pasture species and cultivars have become available to the high country farmer, offering more options for pasture improvement programmes.

No apology is made for the emphasis on pasture species. They are the fundamental power house of pastoral farming and along with soils, climate and other physical environmental factors, are the rightful first aspects studied in seeking more productive and sustainable options.

The outlook for future studies of high country pastoral farming will change in emphasis rather than direction. With the availability of component information on species suitability and other aspects of the physical environment, it is now possible to contemplate their integration into total farm systems. This will incorporate the other farm management constraints, and land occupier and community values and aspirations.

The other change will be the increasing emphasis on demonstrating the sustainability of the different practices, as required by the Resource Management Act highlighted by the High Country Review. Sustainability is implicit in the ethos of good husbandry. Certainly in the studies of pasture species there was an implicit assumption that a species or option was not successful unless it was persistent within the management system of its use. The difference in the future is that there will be more requirement to demonstrate this sustainability explicitly, in both persistence of the species and its associated effects on total vegetation and soil nutrients.

This bulletin is probably not the forum to debate whether conservation means preserving or returning the high country to the state as Europeans first saw it; or allowing use of the resource for the betterment of mankind; or only allowing use with replacement. It will be immediately conceded that the past history of the high country has been of allowable use. Our stance for the future is that continued pastoral farming is a land use option for the high country, providing the allowable use ethos is replaced by that of, at least, replacement with particular respect to vegetation bulk, ground cover and soil nutrients. In terms of the topics covered in this publication this will place emphasis on replacing or bettering the nutrient off-take from agricultural products through fertiliser inputs; and matching pasture species to the environmental and management factors required, so that species and vegetation show their sustainability by persistence through time.

It is hoped that this publication will be helpful to runholders and others involved in land management, both in the New Zealand high country and other similar temperate mountain lands of the world.

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The High Country Environment

The most important environmental factors influencing farming and the choice of pasture species are:

- Temperature
- Soil moisture
- Soil fertility
- Pasture management.

Temperature and moisture gradients define the general pattern of soils, original vegetation and present farming systems within New Zealand (Figure 1). With decreasing moisture and temperature, pasture production falls, so pasture yields in the high country are generally much lower than elsewhere. The traditionally large size of both paddocks and runs in the high country was related to the low level of pasture yield from native vegetation.

Temperature

Temperature is a fundamental factor determining potential pasture production and choice of species, so the farming system must be adapted to the natural conditions. Temperature cannot be modified. The high country is characterised by having the lowest mean temperatures, greatest extremes and widest ranges of variation in mean monthly temperature than elsewhere in New Zealand. The annual range is up to 14°C in some inland high country basins, compared with 8°C in coastal areas. The New Zealand average is 10°C.

Local temperature characteristics (means and seasonal ranges) are greatly influenced by altitude, aspect and slope. The high country is on the coldest margin of New Zealand agriculture, for both mean and seasonal temperature, and has the greatest variation with aspect. Even in the lower altitude inland basins there is a period of at least five months when there is little or no pasture growth. Frosts may occur in all seasons, although summer temperatures are good for pasture growth. Because of the temperature differential, and the effect of soil moisture, there may be extreme differences between sunny and shady aspects.

In choosing species for the high country, those which grow at lower temperatures should be preferred. Grasses generally have greater growth at lower temperatures than legumes, although this has not been investigated. For example, winter and spring temperatures are generally too low for adequate growth of subterranean clover in the high country, yet cocksfoot has a long growing season.

Lower temperatures and large annual variation also mean a higher frequency of frost which, in the high country, can occur throughout the year. Frost tolerance is an important characteristic of pasture species, with the grasses generally being more tolerant than legumes. Legumes and grasses are both vulnerable at the seedling stage because they are in the more intense frost zone near ground level and may also be in more open stands. Mature stands of grasses and legumes

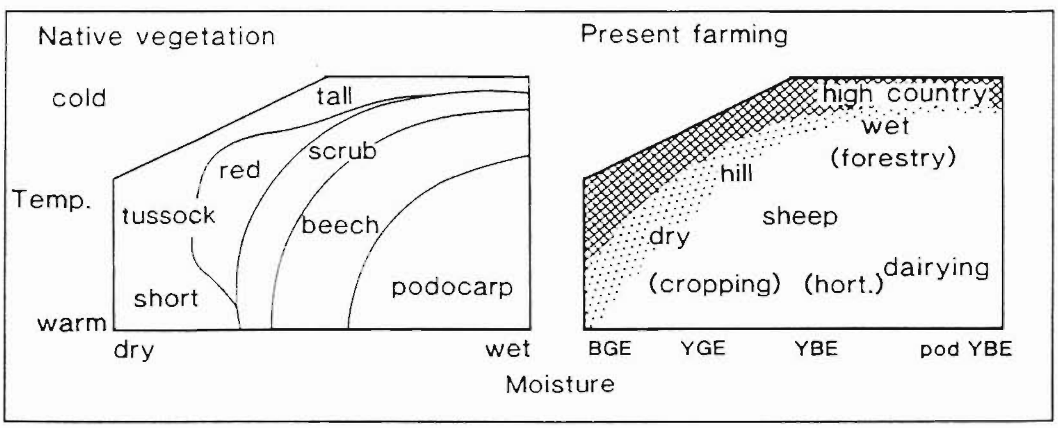

Figure 1: Distribution of original vegetation and present farming practices in New Zealand in relation to the environment gradients of temperature and moisture. The high country is indicated by cross hatching and the hill country by dots.

may be less susceptible to frost damage when there is a large bulk of herbage. However, in this state lucerne, white clover and lotus are all susceptible to foliar frost damage. Alsike clover and tetraploid red clover are more tolerant of winter frost.

The most frost tolerant grasses, in terms of plant survival when mature, are tall fescue, and cocksfoot, followed by ryegrasses, timothy, bromes and phalaris. Species also differ in the extent to which foliage burn-off occurs following frosting. For example, cocksfoot burns off at the tips even though its total bulk is still generally greater than other species. Complete winter kill of plants is not common, though it occurs in white clover and ryegrass in some years, and in some plants from a wide number of species in very cold winters.

Because of the winter no-growth period, saved pasture is needed. Desirable species for this purpose are those which are capable of good autumn growth, are palatable in the rank state, and suffer a minimal loss of feed quality following frosting. Species differ in these attributes. For example, cocksfoot grows well in autumn, is frost-tolerant, but of lower palatability; bromes are palatable but grow poorly in autumn; and ryegrasses produce moderate autumn growth, are highly palatable but relatively intolerant of frost.

Soil Moisture

Moisture is also a fundamental factor controlling potential production, and one which cannot be modified from the natural distribution pattern except, in special cases, by irrigation and drainage. The choice of suitable pasture species is heavily dependent upon soil moisture, which covers a very wide range from the high rainfall areas in the western ranges to the low rainfall in the inland basins. Consequently a wide range of pasture species is required - from those that survive the wet (and frequently colder) conditions of high altitude, to extremes of drought on sunny faces in the inland basins. The amount of soil moisture available for growth also depends on local factors such as altitude, slope and aspect, and on the moisture retention characteristics of the soil.

While the proportion of the high country under irrigation may never be large relative to its total area, it can be very important for filling shortages in critical animal feed periods. Irrigation response will be larger in the low rainfall area and have the effect of changing a site to a moister part of the environmental gradient, though retaining the beneficial effect of higher soil fertility and warmer temperatures often associated with drier zones. Irrigation is also important in taking the risk out of farming in drought-prone areas and in guaranteeing winter feed supply, and this will affect the choice of suitable pasture species.

Patterns Of Soil Distribution

The effects of temperature and moisture interact to produce the range of sites of differing potential pasture production that can be seen in any run or landscape. The high country, and its farming options, has to be seen in the perspective of the total variation within the New Zealand environment (Figure 1). Because temperature and moisture are such important limitations on pasture production, the farming options in the high country are severely constrained by its climate.

The effects of climate are reflected in the soils, so that the interactions between moisture and temperature result in a characteristic pattern of soil types. This is because the breakdown of soil minerals, to release nutrients by weathering, generally increases with temperature, while the loss of nutrients by downward washing through the soil by leaching increases with rainfall. Thus the distribution of soils is related to these topographic variations in temperature and moisture regimes (Figure 2a).

The major soil types are described by the colour of the subsoils, and these show the balance of weathering and leaching. Four major soil groups occur in the high country.

Brown-grey earths (BGE) are weakly weathered and leached because they occur at low altitude in the semi-arid basin areas of Central Otago, the Mackenzie Basin and the upper Waitaki Valley. Pre-European native vegetation was short tussock grassland. Pasture production is severely limited by moisture deficiency.

Yellow-grey earths (YGE) often occur on fans and lower slopes within the high country, and carry short tussock grassland with fescue and some silver tussock. They are more leached than the brown-grey earths. Pasture production is less limited by moisture shortage than on the brown-grey earths.

Upland high country yellow-brown earths (YBE) occur on higher slopes and plateau areas in inland mountain ranges and with increased altitude and rainfall are progressively more leached.

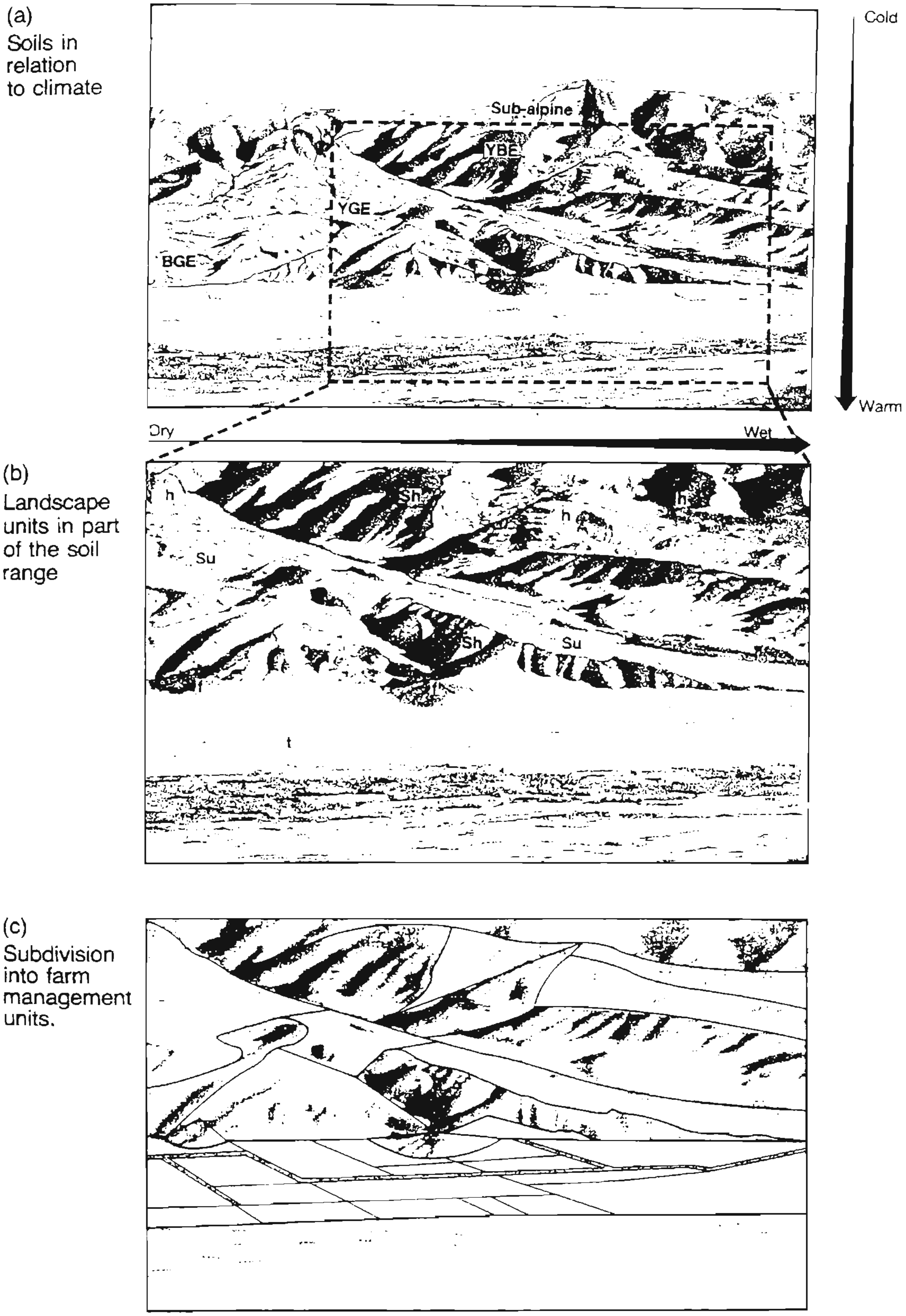

Figure 2: Subdivision of a generalised high country scene according to environmental gradients.

As the release of nutrients by weathering is also slowed down by decreasing temperatures at higher altitudes, soils are increasingly subject to more severe nutrient deficiencies. They characteristically carry tussock grassland species, with greater dominance of snowgrass on the high country soils. On the lower slopes potential pasture production increases with rainfall and altitude but, because of decreasing temperature, the potential production decreases with further increase in elevation in this soil group.

Upland and high country podzolised yellow-brown earths (pod YBE) and podzols are even more strongly leached than the yellow-brown earths. They occur in the higher and wetter areas and grade into the alpine soils of the mountains. The term podzolised refers to the effects of very strong leaching in these groups of soils, with the appearance of a pale layer between the top soil and the yellow-brown subsoil. These soils have very low potential for pastoral agriculture because they suffer from severe nutrient deficiencies as a consequence of the high rainfall and strong leaching, and because lower temperatures at these higher altitudes also restrict pasture growth.

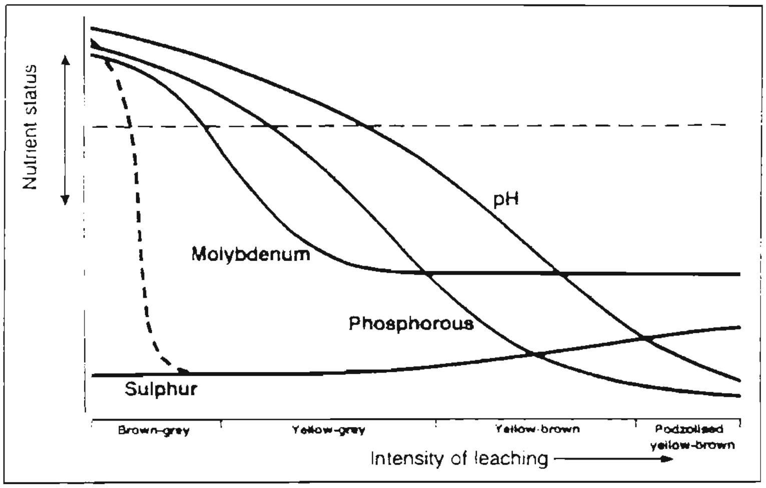

Figure 3: Soils, nutrient status and fertiliser requirements for a series of high country soils is related to rainfall and/or leaching.

Soil Fertility

While temperature and soil moisture have a profound effect on farming options and choice of species, they are generally uncontrollable. The third factor, soil fertility, is the one which, in practice, can be most easily modified - either by the selection of areas of different natural fertility, or by the addition of fertiliser.

The nutrient element which most severely limits pasture production is nitrogen, and it is deficient in most soils. In New Zealand the nitrogen deficiency is usually overcome by growing legumes which, through associated rhizobia in root nodules, fix nitrogen from the air. It is therefore important to satisfy the nutrient requirements of introduced legumes for good pasture production.

Sulphur, phosphorus and molybdenum are the nutrients most commonly deficient for legume plant growth in high country soils. In addition, selenium and, maybe, iodine and sodium will be required for animal health. Adequate calcium levels are required to maintain general soil structure and nutrient exchange characteristics.

The distribution of nutrient deficiencies is not random, but is closely related to the processes of leaching and weathering, and the soil pattern described in the previous section.

The pattern illustrated in Figure 3 shows that, in the semi-arid zone, brown-grey earths usually have sufficient phosphorus and molybdenum, but the topsoils are severely deficient in sulphur. Some deep-rooting plants, like lucerne, may be able to use sulphur from the subsoil. Deficiencies of sulphur and phosphorus occur in yellow-grey earths, and are usually more severe in yellow-brown earths, because these soils are progressively more impoverished by the increasing intensity of leaching. For the same reason, soil acidity also becomes an increasing problem in the most strongly leached soils in the higher and wetter areas. The podzolised soils are so severely leached that their nutrient status is very low and they are strongly acid. Molybdenum deficiency is widespread in yellow-grey and yellow-brown earths, except where rainfall is below 550 mm per year.

This general pattern of soil nutrient status can sometimes be changed by natural factors such as soil rejuvenation by erosion or deposition, and non-uniformity of underlying rock type. Once the land is developed agriculturally, the pattern is further distorted by previous fertiliser applications and nutrient redistribution by stock. Such local variations can be detected by soil testing.

Deficiencies can be corrected by the application of fertilisers to develop and maintain productive pasture. The amounts required are generally related to the soil pattern, and should be greater for initial development than for subsequent maintenance.

Generalised recommendations are given in Table 1, which relates fertiliser rates to the characteristics of each of the four major soil groups. It should be noted that the proportion of sulphur is highest in the fertilisers recommended for the brown-grey earths and that the proportion of phosphorus increases in the fertilisers recommended for those soils where phosphorus deficiency becomes more severe. The podzolised soils are considered uneconomic to develop because of the large amounts of fertiliser required to overcome their natural deficiencies, and because potential pasture production is severely limited by climate in the areas where these soils are found. Molybdenised fertiliser is recommended for initial pasture establishment on soils where molybdenum is likely to be deficient, and it should be used for maintenance about once every four years. Liming is discussed later under the heading Inoculation and coating in the section on pasture establishment.

A different approach to calculating maintenance rates, which allows for the differences in production, utilisation and stocking rate on contrasting soil types, is to allow 25 kg/ha/yr superphosphate for each stock unit. This approach more closely approaches the sustainability concept that fertiliser rate must replace the wool and meat removed.

Both approaches are generalisations and do not allow for the local variations in soil nutrient status which were described earlier.

Good recommendations come from direct soil testing made at regular intervals to determine trends.

Soil tests for P, S and pH have proved to be good indicators of responses to initial applications of fertilisers in tussock grassland development.

Soil sampling and testing should therefore always be carried out before a large development programme is started and regularly thereafter for maintenance purposes.

Table 1: Characteristics of typical high country soils.

	Brown-grey Earths	Yellow-grey Earths	Yellow-brown Earths	Podzolised yellow-brown Earths
Intensity of leaching	Low	Low-medium	Medium-High	Very High
pH	High (>6.0)	Medium (5.2-6.0)	Low (4.6-5.2)	Very Low (<4.6)
Sulphur status	Low *	Low	Low	Low
Phosphorus status	High	Medium	Low	Low
Molybdenum status	Adequate	Deficient	Deficient	Deficient
Optimal fertiliser at present	Sulphur super extra (27% S)	Sulphur super or RPR - S	Super ** or RPR - S	Uneconomic
Establishment fertiliser rate	200 kg/ha sulphur super	200 kg/ha Mo sulphur super	250 kg/ha Mo super	Uneconomic
Maintenance fertiliser rate	200 kg/ha sulphur super extra every 3-4 years	200 kg/ha sulphur super every 2-3 years	250 kg/ha super every 2-3 years	Uneconomic

* Adequate for lucerne in deep (>40cm) soils because of subsoil sulphate.

** Use sulphur super on droughty outwash soils (e.g. Mackenzie soils).

Separate samples should be taken for each distinct area of land which differs in terms of soil type, aspect, slope, vegetation or previous land use, and for which a particular fertiliser treatment could conveniently be applied.

On the moister yellow-grey earths (rainfall >550mm), or where soil pH is <5.5, reactive phosphate rock (RPR) is a cheaper phosphate option. Suppliers offer suitable RPR+S mixtures which supply phosphorus and sulphur in the correct proportion to suit farming on yellow-grey and yellow-brown earths.

Escalating costs of superphosphate transport and application have triggered a move to high analysis phosphorus fertilisers such as ammonium phosphate, triple superphosphate, reactive phosphate rock, and the same rock partially acidulated with phosphoric acid. All of these contain little or no sulphur and will need to be supplemented with sulphur.

Mixtures of elemental sulphur and sodium bentonite offer the possibility of preparing fertilisers to suit different environments, both with respect to proportions of sulphur and phosphorus, and with different degrees of reactivity. Unfortunately, the high cost of their manufacture has, in the meantime, precluded the commercial development of such mixtures by New Zealand fertiliser manufacturers. Manufacturers are now offering instead a greater range of superphosphates enriched with greater quantities of elemental sulphur as standard products, as well as fertiliser mixtures customised to individual client requirements when possible.

There will also be an increasing role for nitrogen fertiliser to increase the initial establishment of grasses, and for special purpose winter grass paddocks.

The general effect of fertiliser application, legume nitrogen fixation and mineral removal will be for the soil to become more acid. One of the trends in pasture evaluation work is to find species which retain their productivity and sustainability in the more acid conditions.

Potential Pasture Production

Variations in temperature and moisture are important in determining the variability of pasture productivity in two ways. Firstly, they will influence the potential productivity, which is greatest in the moist, warm environments and least in the dry cold areas (Figure 4). Secondly, the variation in temperature and moisture will influence the seasonal distribution of potential pasture growth.

In the warm, moist environment enjoyed by much of New Zealand, growth can occur in all seasons, being greatest in spring and summer (Figure 4 lower right). In warm, but drier conditions there is increasing depression of summer pasture growth and hence feed supply - though still with the potential of winter growth (Figure 4 lower left). By contrast, as altitude increases and temperature decreases, the potential for this winter growth decreases. Thus in parts of the high country, there is a non-growth period of five months or more, and standing herbage for the winter has to be carried forward from the previous summer and autumn.

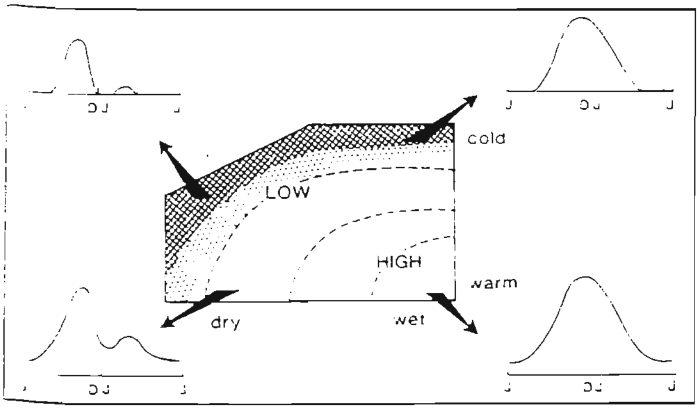

Figure 4: Variation in annual pasture yields and seasonal growth patterns with variation in annual temperature and moisture.

By world agricultural standards, New Zealand is not particularly cold, hot, wet or arid but fluctuations towards these four extremes seem to occur in a matter of days or weeks.

An overview of plant production and breeding of pasture plants for New Zealand would suggest that the species which suit the New Zealand environment, are those which can tolerate, and make an adequate growth contribution under a range of intermediate conditions without having a tendency to go into long term dormancy when they encounter brief periods of adverse temperature or moisture conditions.

Given estimates of the three environmental variables of temperature, moisture and fertility, it is possible to make reasonable estimates of the potential annual average pasture production levels.

This is shown in Figure 5 for three different soil fertility levels (low, moderate and high) and for the same range of temperatures and moisture as in Figure 4.

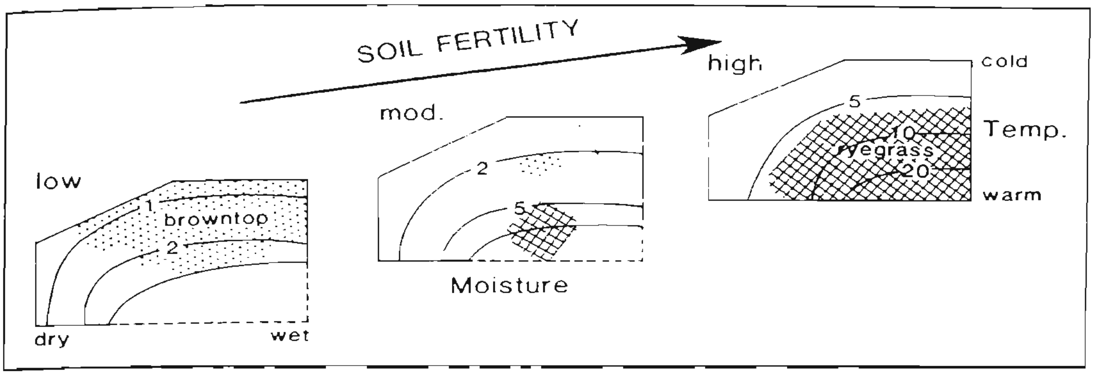

Figure 5: Estimated potential annual pasture yields (t DM/ha/year) in relation to temperature, moisture and three levels of soil fertility. Ranges of temperature and moisture are the same as earlier diagrams. The best zones for two grasses, browntop and perennial ryegrass, are indicated.

The high country will again be represented along the left and upper boundary of each diagram.

Figure 5 illustrates four important points.

- There is a rapid fall-off in potential pasture production as temperatures decrease with altitude and aspect. This decrease is exponential rather than linear.
- Similarly, there is a rapid fall-off in potential pasture production as rainfall and soil moisture decrease; again, it is exponential rather than linear.
- If a site with particular moisture and temperature conditions is transformed from its natural low fertility state to a high fertility state then, in the high country situation, there is about a five-fold increase in potential pasture production.
- If the other input, irrigation, is used it moves a site from the dry to the wet end of the gradient. Responses of potential annual pasture production to water are not large, probably only two-fold. In any irrigation development, both water and fertiliser are applied, to give the often ten-fold increase in potential production.
- These potential ten-fold increases mean suitable sites in the high country have a strong capability for production of winter feed and special purpose pastures.

However, species differ in their environmental needs and tolerances. Our belief is that, while Figure 5 estimates the potential pasture productivity and the general pattern for all species, only one or two species reach the full potential of a particular site as determined by the particular combination of temperature, moisture and fertility.

For example, browntop is probably the grass best adapted to low fertility set stocked sites of moderate temperature and moisture, just as perennial ryegrass is one of the best grass species for high fertility, warm, moderately moist sites.

It is also true that each pasture species can perform adequately in a wide range of conditions, however, the most appropriate place for each of a whole range of species is considered in detail in later sections of the publication.

Characteristics Of Pasture Species

Temperature, soil moisture, soil fertility and pasture management are four important factors which determine the suitability of a pasture species for a particular site. We define the characteristics of a range of species in two alternative ways:

- Diagrammatically in relation to temperature, moisture and fertility for a few species
- In tabular form in more detail for a greater range of species.

Figure 6, in the same manner as earlier figures, places species in the temperature, moisture and fertility environment in which they are likely to have an optimum role. For most of the pasture species (eg perennial ryegrass) this is in a New Zealand environment outside the high country but, by their location in the diagram, the range of adjacent high country environments in which they have a role can be deduced.

Species most suited to lax grazing are printed in capital letters.

The species name is placed in the environment in which it has its optimum role, but there is a range of adjacent environments which are also suitable.

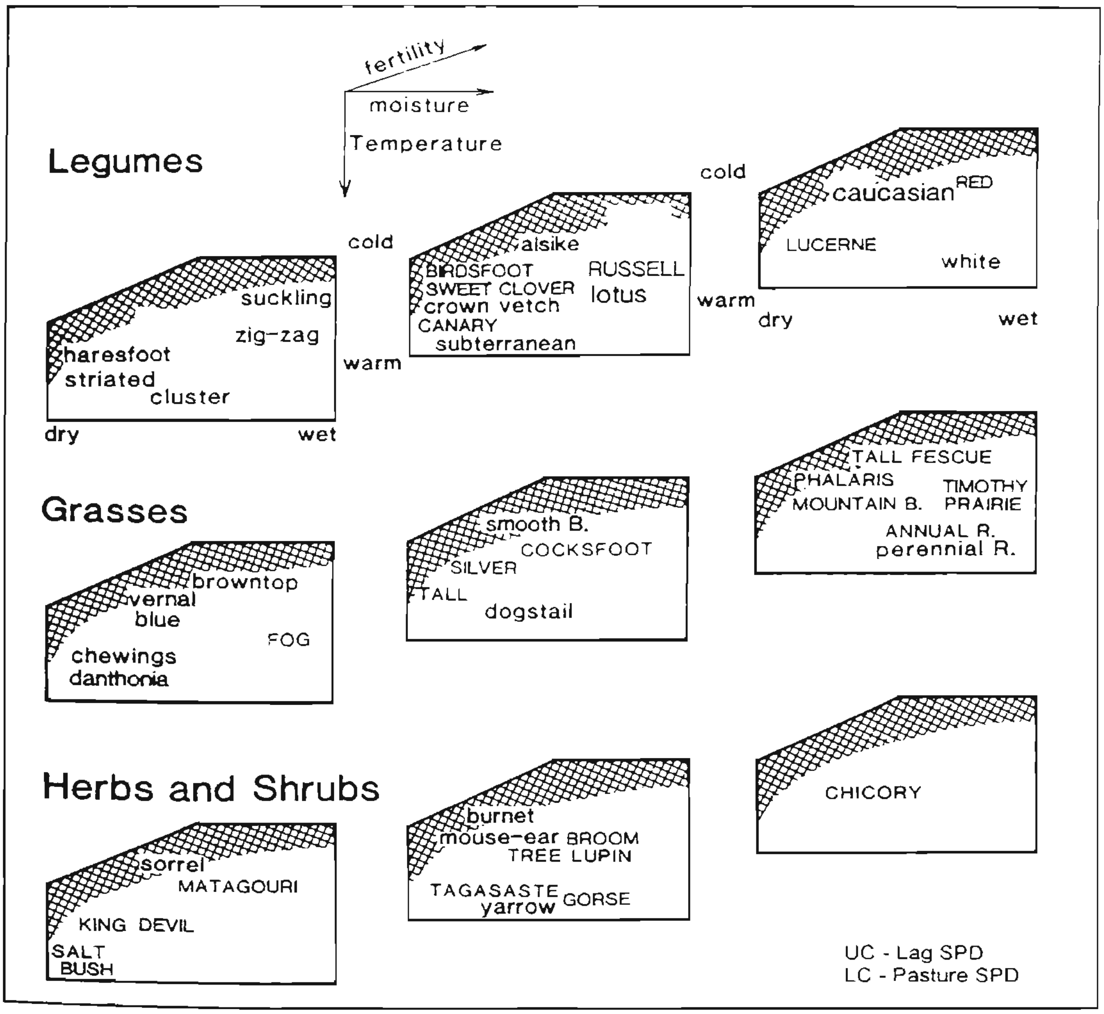

Figure 6: The most suitable role of some pasture species in relation to the environmental factors of temperature, soil moisture and three levels of soil fertility. The name is placed in the environment in which it has its optimum role, but like browntop and perennial ryegrass, there is a range of adjacent environments in which each is also suitable. Species more suited to lax grazing are given capital letters.

Table 2: Species adaptation and tolerances to different high country physical and management environments.

Species	Temp	Moisture 1	Moisture 2	Moisture 3	Soil Fertility 1	Soil Fertility 2	Soil Fertility 3	Grazing Tolerance	Acceptability To Stock	Seeding Rate kg/ha
Legumes										
Alsike clover	A/B	M	M-H	M	M	M	M	B	M	2-4
White clover	B/C	L-M	H	M-H	L	M	H	A	H	2-4
Red clover	A/B	L-M	H	M-H	L	L-M	M-H	C	H	2-4
Lucerne	B/C	H	H	L	L	L	H	C	H	4-10
Lotus	B	L-M	L	M-H	M-H	H	L-M	B	M	3-5
Birdsfoot trefoil	B/C	M-H	M-H	L-M	M	L-M	M	C	H	3-5
Perennial lupin	B	M	M	M	M	L	M	B	M	2-5
Caucasian clover	A/B	M-H	L	M	H	M	L-M	A	H	1-2
Zigzag clover	B	M	L	M-H	H	M	L-M	A	M	1-2
Crown vetch	B/C	H	L	L	H	L	L-M	A	M	1-2
Cicer milk vetch	B	M-H	M	M	M	L	L	B	H	5-10
Suckling clover	A/B	L-M	L	M-H	H	H	L	A	M	0.5-1
Haresfoot clover	B/C	H	L	L	H	L	L	A	L	-
Sweet clover	B	M	L	M	M	M	L-M	B	M	2-5
Subterranean clover	C	M	L	L-M	L	L	H	B	H	5-10
Vetch or tares	C	H	L	L	M	L	M	C	M	5-15
Canary clover	B/C	H	L	L	H	L	L-M	B	L	4
Greenfeed lupin	B	M	L	M	L	M	H	C	H	5-10
Sainfoin	C	M-H	M	M	M	L	L	C	H	5-15
Grasses										
Cocksfoot	ABC	H	M	L-M	M	M	L-M	B	M-H	2-12
Tall fescue	A/B	M	H	M-H	L-M	L	M-H	A	H	2-12
Timothy	B	L	H	H	L-M	M	H	C	H	2-5
Perennial ryegrass	B/C	L-M	H	M-H	L-M	L	M-H	A	H	10-15
Hybrid ryegrass	B/C	L-M	H	M-H	L-M	L	M-H	B	H	10-15
Annual ryegrass	B	M	H	M-H	L	L	H	B	H	15-25
Browntop	A/B	M	L	L-M	M-H	H	L	A	M	0.25-2
Sweet vernal	A/B	M	L	L-M	M	M	L	A	M	-
Yorkshire fog	B	L-M	L	M-H	M	H	L	B	M-H	2-5
Chewings fescue	B	H	L	M	H	H	L	A	L	1-4
Tall oat grass	B	H	L	L-M	H	L	L	C	M	5-10
Fescue or hard tussock	A/B	H	N-A	L	H	M	L	B	L	-
Blue tussock	A	M	N-A	M	H	M	L	B	M	-
Silver tussock	B	M	N-A	N	M	M	M	B	L	-
Snow tussock	A	M	N-A	M-H	H	H	L	B	L	-
Red tussock	A	L	N-A	H	H	H	L	B	L	-
Crested dogstail	C	M	M	M	L-M	L	M	A	M	5
Smooth brome	B	M	L-M	M-H	M	L	M	A	H	10-20
Prairie grass	C	M	M	L-M	L	L	H	C	H	15-25
Kentucky bluegrass	B	M-H	L	M	M-H	L	L	A	L	-
Pubescent wheat grass	C	H	L	L-M	H	L	L	B	M	5
Ryecorn										
Mountain rye	A/B	M	L-M	L-M	M	-	L-M	C	M	30-40
Danthonias	B/C	H	L	H	L	L	L	A	L	-
Phalaris	B/C	H	L-M	M-H	H	M	L	B	L-H	1-3
Herbs										
Sheeps burnet	B	H	-	L	M	L	L	B	M	
Sheeps sorrel	A	H	-	L	H	H	L	A	L	
Mouse-ear hawkweed	B	M	L-M	M	L	L	A	M	-	
King devil hawkweed	B	M	-	L-M	H	M	L	B	M	-
Yarrow	B	M	-	L	M	M	M	B	M	2-5
Chicory	C	M	-	M	L	L	H	C	H	2-5
Plantain	B	M	-	L-M	M	M	M	B	H	1-2

Species	Temp	Moisture			Soil Fertility			Grazing Tolerance	Acceptability To Stock	Seeding Rate kg/ha
		1	2	3	1	2	3			
Shrubs										
Matagouri	A	L	-	L-M	H	H	L	A	L	-
Briar	B	H	-	L-M	M	M	L	A	L	-
Gorse	B	L	-	M	M	H	M	A	L	-
Brome	B	M	-	M	M	H	L	A	L	-
Saltbush	C	L	L	L	M	L	L	C	M	10
Tagasaste	C	L	M	L-M	L-M	L	M	C	M	2-5
Mountain mahogany	C	L	L	L	M	L	L	B	L	10
Bluebush	C	L	L	L	M	L	L	C	M	10
Tree lupin	C	L	L	M	M	M	L	B	L	5-15
Tree medic	C	L	L	L	M	L	L	C	M	5

Temperature (zone of greatest value)
A Cool temperature
B Moderate temperatures and altitudes
C Warm temperatures, low altitudes, sunny faces
Moisture (L=Low, M=Medium, H=High)
1 Tolerance to prolonged moisture stress (drought)
2 Suitability for intensive irrigated pastures
3 Rainfall at which species is most useful or prevalent
Acceptability To Stock
L=Low, M=Medium, H=High

Soil Fertility (L=Low, M=Medium, H=High)
1 Adaptation to low soil fertility
2 Suitability for wet, acid and infertile soils
3 Fertility levels where species is of greatest value
Grazing Tolerance
A Tolerates intensive set stocking at least moderately well
B Intermediate
C Requires lax grazing or long regrowth periods
Seeding Rate (kg/ha)
Legume seed inoculated and coated

This is not where each species grows best (nearly always in a warm, wet, high fertility environment) but rather where each species would be more productive and persistent than other species that might be considered. The second approach (Table 2) gives detailed information on a greater range of species. It discriminates between different degrees of temperature, moisture and fertility adaptation and gives information on grazing tolerance, palatability, and seed rates. A general theme of this guide is to get the right species for the actual conditions experienced on each site.

The relative importance of the plant attributes which determine the level of success or suitability of specific pasture species will vary with environment, type of management, and expected performance. In difficult environments, traits which determine long-term persistence, survival and sustainability are given more weight than production potential and level of animal acceptability.

To appreciate how a plant species will respond to grazing, cutting or trampling, we need some understanding of its actual growth habit or morphology, i.e. the type of shoots and process of shoot development; the location of growing points and their level of vulnerability to removal and damage. For example, lucerne starts producing new shoots from the plant crown at or slightly below ground level following first defoliation. These grow into zones where they can be eaten within 7-10 days. Thus lucerne can be grazed very hard, but only for a short period (7-10 days). Red clover produces its new shoots at or just above ground level and should not be grazed as close as lucerne. Ryegrass produces its new shoots at or below ground level, whereas cocksfoot shoots originate above ground level.

These morphological differences allow hard grazing of ryegrass on one hand, but dictate lax grazing or brief intense grazing of cocksfoot on the other.

Interaction between where the new shoots are produced and how quickly they grow leads to a contrast of species tolerance to closeness and frequency of grazing. Species like lucerne and prairie grass are intolerant of frequent grazing. Subterranean clover is the other extreme, intolerant of close but tolerant of frequent grazing. Others range from those intolerant of close and frequent grazing, like red clover and annual ryegrass, through cocksfoot, biennial and hybrid ryegrasses, white clover and tall fescue, to perennial ryegrass and phalaris which are tolerant of close and frequent grazing.

Widespread occurrence of browntop, sweet vernal and haresfoot clover in the high country shows that spread of species by volunteer reseeding is effective. The occasional occurrence of white clover, red clover, cocksfoot, yorkshire fog and tall oat grass in many unimproved parts of the high country also indicates that volunteer reseeding can occur in these species. However, seed set and spread should not be assumed. For instance, cool temperatures and high altitudes can lead to frost damage during flowering. Establishment of legumes by reseeding can be restricted by lack of rhizobia spread.

Pasture species, particularly legumes, can spread vegetatively also. White clover is the prime example. Research has shown that seasonal variation in soil moisture levels has a far greater influence on the vegetative spread of white clover on tussock country than grazing management. Other spreading legumes are lotus, caucasian clover, zigzag clover and crown vetch. Most grasses have very slow vegetative spread.

General Development Strategies

Having briefly described the high country in terms of its environment, potential pasture production, and suitability of particular pasture species, we need to consider development strategies for sustainable animal production. Important points are:

- Type of animal
- Provision of winter feed
- Land and management requirements to grow young stock
- Subdivision of land into its various natural units to fulfil the year round stock feed requirements
- Efficient use of fertilisers
- General strategies of pasture development using legumes, grasses and nutrient cycling.

Type Of Animal

At present the options for the type of domesticated herbivorous animal to farm in the high country are sheep, cattle, deer or goats. There is also the unwelcome competition from feral herbivores such as rabbits, hares, deer, goats, chamois and thar. Each of the domesticated and feral species has environmental preferences and constraints, similar to those described for pasture species.

Sheep are suited to the widest range of conditions from the high alpine areas to the undeveloped low altitude semi-arid zones, and to developed pastures in all areas. The average high country run has about 8,700 sheep. At the environmental extreme of both the cold, wet higher altitudes, and the semi-arid areas, the merino is the best adapted of the sheep breeds. Wool is the main source of income for runs in those zones. It is fortunate that the breed that is adapted to these environments is the one producing the more profitable fine wool. In the high rainfall and snow risk zones, particularly the gorge runs, a Merino with clean face and legs and a dense, fleece is preferred. By contrast, in the drier zones a well covered higher yielding Merino has advantages.

With the higher pasture production from developed areas, there are the options of wool, store sheep, and even fat lamb production using Merino, crossbred and other breeds. This has the advantage of diversifying run income.

Most runs have some cattle. Their grazing is generally associated with low altitude moist terrain or swampy areas. Winter feed is more critical for cattle than sheep. Farm economics have generally favoured sheep production over beef production. There was a period in the 1950s when cattle production was encouraged relative to sheep production for soil conservation reasons. This was later revised when it was realised that cattle damage to the wetlands and the stream edges had a greater effect on flooding than the sheep grazing on vegetation at a higher altitude. Cattle have a role for scrub, bracken and silver tussock control in some of the higher rainfall areas.

The main pest scourge of the high country is the feral rabbit as shown by their most recent plague and the associated Rabbit and Land Management Programme over the last decade. Feral rabbits are the main source of feed competition with domestic stock, with the competition being greatest in the warm, moderate to semi-arid undeveloped zone. The rabbit problem clearly illustrates the point that vegetation and nutrient sustainability is determined by the total grazing pressure, not just that of domestic stock, and that as a consequence, if pests increase, domestic stock have to be decreased.

Red deer in their feral state were most prevalent in the higher rainfall areas in the transition zone between forest, scrublands and tussock grasslands. However, during the initial decade of their domestication, their high economic value and legal fencing requirement resulted in their being concentrated on a few runs, generally on developed pastures on easy terrain.

Feral goats are relatively rare in the high country now, but there was a brief period of domestication, primarily for control of briar and for fibre production. The trend is for their use in the moderate to low rainfall undeveloped pastures.

Hares give some competition over a wide range of environments; deer near the scrub and forest margins; and chamois and thar give slight competition only at the highest altitudes.

Winter Feed

Lack of winter feed for stock is the main constraint to pastoral farming in the high country. The management of a high country run revolves around the extent and management of areas suitable for providing winter feed.

Various winter feed options include summer saved native pasture, summer saved legume pasture; summer saved grass/legume mixtures, nitrogen fertilised grass; hay or silage, and special purpose winter crops. Except for the native pasture, the other options imply pasture development to different levels of intensity. All are special purpose pastures.

The traditional summer saved native country for wintering stock was low altitude sunny country, sloping rather than flat, from which snow would clear first following a storm. The same type of country would be preferred also for winter feeding-out when using the other options. The winter country, because of its topography and aspect, will tend to have good spring pasture growth but be summer dry.

The various pasture options for providing winter feed differ in their cost. While the hay or silage options from spring and early summer harvests, will be the most expensive generally, they do have the advantage that for winter feed their quantities are known well in advance of their time of use. All the other options are very dependant on growth conditions in the autumn only shortly before their requirement time.

Young stock and rams have priority for winter feed. Many runs will supplement ewes, and only a small proportion of runs will supplement wethers. In the high country, winter feeding can only hope to maintain animal body weights or minimise losses. Stock weight gains are unlikely over winter.

Young Stock

A major consideration in management of a high country run is whether the land and its pasture is suitable for breeding replacements and growing young stock. A few runs have to buy in all their replacement stock.

Wool is the major produce of most runs, and there may be a need to only carry sufficient ewes to breed for replacement. Autumn flushing of ewes, while desirable, is not as prominent as in lowland fat lamb producing areas. There is a desirable trend towards providing better winter nutrition of ewes, particularly towards the later stages of pregnancy. Lambing generally takes place in September - October to coincide with spring growth.

Young stock should have feed priority from lambing to weaning in January or February and during their first winter. Special purpose blocks and pastures are needed to feed young stock. Runholders value the lower, warm or sweet country for this purpose. It is this country that generally has drier recent soils which are less weathered than those which are wetter or at higher altitudes. There are many similarities between winter country and lambing or hogget country. Where such land is limited, careful planning and management is needed to get the best use, rather than abuse, of this land.

Subdivision

Ideally, the different landscape units within a run should be managed separately, for they will differ in potential pasture growth, in the ideal spelling time to allow adequate regrowth, and in the stocking rates needed to ensure sustainable use. However, in practice, for both physical and financial reasons, this ideal is generally not achievable. The following approach to subdivision is suggested.

First, mark in the boundaries between landscape units of different types e.g. on a land capability map or aerial photograph (Figure 2, page 5). If any of these units are still greater than 100ha, then consider further subdivision, preferably along the contour, as animals tend to move and graze horizontally rather than up and down the hill. Some adjacent areas may need to be combined if they are less than 20ha each. Next, mark out possible access lanes. These should be at least 50-100m wide and should be regarded as narrow paddocks. Make line adjustments if necessary to facilitate easy stock movement and to prevent acute corners to paddocks.

The result is a map of potential fence lines that may be achieved at some time in the future (Figure 2c). Using this map, start subdivision in blocks needed for special purpose pastures, or where development is intended, or where present utilisation is most uneven. This is where grazing control is most needed. Clearly, the ideal block size will vary according to the intended size of the mob and its specific feed requirements.

It may not always be necessary to use fencing to manage utilisation. Recent work has indicated that partial development of large blocks can alter the use of the whole block. In particular, the development of lower slopes and valley bottoms can lessen the grazing pressure on the high slopes.

There are divergent views on the need for stock water. Some insist on a continuous supply of clean water in all paddocks. While others consider water unnecessary so long as adequate feed is available. They point to third generation flocks that have never seen water, or animal behaviour studies where sheep were observed not to drink on dry tussock country in mid-summer even though water was available. Lack of stock water should not be regarded as a constraint in high country development and subdivision.

Pasture Development

One of the main avenues for improving animal production in the high country is pasture development. The large holding and block sizes have traditionally encouraged large scale development. There are numerous examples of areas which have been oversown at great cost but never effectively used or maintained - let alone ever paid for themselves. Oversowing tends to increase the difference between summer and winter feed supply.

Clearly, individual runholders must identify the periods when feed is most limiting to their stock and act accordingly. Each piece of development should be considered as a special purpose pasture, done to satisfy particular stock feed requirements. This approach has the advantage that one will then consider smaller areas, and the consequent fencing, ground preparation and management that should go with them. A large number of such special purpose paddocks may be needed.

If additional feed is required for winter and spring, then lower, sunny slopes or flats should be considered for development because of their warmer temperatures. By contrast, if more autumn feed is required, it will be necessary to choose sites which still have adequate moisture at that time of the year. Note that in dry areas shady aspects are generally more productive than sunny aspects, while in higher and wetter areas, where temperature is the major limitation to pasture growth, sunny faces are more productive.

Fertilisers

The main input needed in pasture development is fertiliser. For the high country it is always likely to be costly because of the high transport component. Against this disadvantage, is the advantage that because much of the developable high country is in the moderate to low rainfall zone, that the rates required are not as high as in the higher rainfall areas elsewhere in New Zealand.

Fertiliser responses show a diminishing return with application rate, with the greatest response at low application rates. Taken in conjunction with the fact that developable land as such is seldom a limiting factor in the high country, then a better development strategy may be to use a given affordable amount of fertiliser at a lower rate over a larger area. The associated requirement is that the legume and grass species used in the development should be matched closely with the actual fertiliser rates used, and that there needs to be the associated subdivision or animal control to efficiently use the resulting enhanced pasture growth.

Legumes

For most of the high country, pasture legumes have a major competitive advantage over grasses through their capability to fix their own nitrogen. Fixation should not be assumed. Nitrogen fixation is totally dependent on rhizobia bacteria associated with the roots of legumes, so inoculation of legume seed with an effective rhizobia strain is as important as sowing the seed. The rate of nitrogen fixation under adequate phosphorus and sulphur fertiliser levels is determined mostly by legume growth and is largely independent of species. Thus the choice of legume should be determined largely by the species which grows best in the particular situation.

Because of the low growth rates of plants and slow mineralisation of organic matter due to the low mean temperature, the build up of total soil organic matter and nitrogen is slow. It may be many years before the stage is reached where the introduced grasses have both the necessary nitrogen levels and competitive advantage. Improved high country pastures can therefore remain legume dominant for many years.

Even under high fertiliser levels, for high growth rates of alsike, white, and red clover, or lucerne, typically 4-5 years may elapse after initial development before introduced grasses make a significant contribution to the pasture. For moderate fertiliser inputs and associated legumes, like alsike clover, lotus, birdsfoot trefoil and perennial lupin, it may be many years before soil nitrogen levels are adequate for grasses like cocksfoot, timothy, tall oat grass or tall fescue. The period may be of the order of 20 years or more for low fertiliser input and low production legumes like zigzag clover.

The volunteer grasses like browntop and sweet vernal usually make up the major proportion of the grass component in many development situations. These are all valid options, but in high country farming, as in life in general, you only get what you are willing to pay for. In pasture production terms, this generally means the amount of fertiliser used to grow legumes.

Grasses

The low initial fertility, and the long clover dominant stage of many grassland developments, leads to a debate on whether to include grasses in the initial sowings. Even though grasses should ultimately be more important because of their greater winter feeding quality and cold tolerance, their initial establishment is variable.

They can be sown successfully in the fully cultivated situation, though, even there, their contribution can be low for several years. The establishment of grasses by aerial oversowing is difficult, especially if there are constraints of limited moisture or excessive competition.

Cocksfoot and ryegrass can be established if conditions are favourable and, given time, may dominate feed production on drier country where browntop is absent and once soil nitrogen levels have been increased.

Nutrient Cycling

Grazing animals derive their mineral mainly from the pasture, though some can come from direct ingestion of soil.

Pasture plants derive their nutrients from the soil solution, which in turn, can come from direct fertiliser application, weathering of rocks, or more usually from the mineralisation of litter and soil organic matters. This soil organic matter is the main nutrient reserve and buffer in the nutrient cycle.

Like a bank, the release or payout can be of capital, or the more sustainable method as interest, so that the return from either at least equals that used to achieve the initial pasture growth.

Nitrogen is generally the most deficient nutrient for pastures. In New Zealand this deficit is rectified by growing legumes to fix nitrogen. Nitrogen release to the soil is achieved through the rapid animal excreta pathway, or more slowly through mineralisation of organic matter. While the former pathway is faster, the return of nutrients is not so even and they tend to be concentrated in stock camp areas.

By the analogy of a bank and a commercial economy, as used above, it is not clear whether it is better to leave all the nutrients locked up in organic matter, or have all the nutrients in circulation, with a consequent buoyant economy of plant growth, but the associated risk of reserves being lost in the system, and outbreaks of bankruptcy!

The original tussock grasslands were a good example of a very conservative economy, with the large capital of nutrients locked up, like trees, in large amounts of standing dead biomass, which was released only slowly.

The grazing and burning of the past pastoral phase mainly used that capital, though to put it in the total New Zealand context, that use lasted a century and a half in the high country, as compared with only half a century following pastoral development on burnt forest areas of the North Island.

High country pastoral farming is now reaching the stage, as elsewhere in New Zealand, that for sustainability, the mineral removal in products must be more than balanced by added fertiliser.

In the management of nutrient cycling, there are a number of compromises between the safe but slow release characteristics of nutrients stored in organic matter; versus the more rapid turnover and availability of nutrients, through release by animal dung and urine into soil solution. There is potentially a risk of loss with the latter method too. The general trend is that as productivity and nutrient turnover increase, the risk of loss increases.

Pasture Establishment

Pasture establishment involves considerations such as site preparation, time of sowing, seed mixtures, seed coating, method of sowing and subsequent management. The recommendations which follow relate mostly to the initial development of native tussock grassland.

Site Preparation

In much of the tussock grasslands, existing tussocks provide favourable microclimates for the establishment of oversown seedlings. However, dense resident vegetation can reduce both germination and survival of seedlings. This may be reduced by using large mobs of sheep or cattle or, if necessary, by burning. Complete removal of cover can expose oversown seed on the soil surface to severe environmental conditions and can result in germination failure, particularly when dry conditions follow oversowing.

In the drier environments, competition from the natural vegetation can restrict seedling survival. It may be necessary to use a herbicide to reduce competition during the establishment phase for successful establishment of species by oversowing or overdrilling.

Where danthonia (*Rytidosperma* species) are present, nodulation of lucerne is suppressed by toxic exudates. The effect is most severe in drier environments (<650 mm rainfall), where it is necessary to kill the danthonia several months prior to oversowing.

Another consideration is the effect of soil disturbance by cultivation or earth movement for border-dyke irrigation. High country soils, at least in most potentially irrigable areas, are generally low in organic matter. Machinery movement during preparation can cause subsoil compaction, although this seems to have only a small, direct, adverse affect on pasture production. More importantly compaction limits water holding capacity during the early years until the increase of organic matter improves the soil porosity.

Time Of Sowing

Throughout most of the high country only spring sowings should be considered because of the variable nature of autumn rainfall. With the additional hazard of loss by winter frost, establishment and growth can be severely restricted. In the lower, dry high country, autumn sowing may be an option particularly if irrigation is available.

In spring a compromise has to be struck between waiting for adequate temperature, and yet sowing sufficiently early before moisture supplies decrease later in the spring. But, again, one has to compromise between the higher temperatures desirable for seedling establishment, and higher temperature as an indicator of impending drought conditions. The optimum sowing dates will therefore range from mid-August to October, with the earliest sowing dates on those lower sunny faces most prone to early drought. Most legumes appear to have similar moderate initial germination in the various micro-sites available, but then undergo selective mortality as stresses develop in late spring and summer. By contrast, once grasses get through the seedling stage they generally survive.

Seed Mixtures

Where sites can be fully cultivated and drilled, seed mixtures and seeding rates need be no different in the high country than elsewhere.

Initial aerial oversowing of tussock blocks should be based on clover or other legume seed at 4-6 kg/ha. Opinion is somewhat divided as to the desirable species composition. A common compromise is alsike, white clover and red clover at 2+2+2 kg/ha. Where higher fertiliser rates are used and subdivision for subsequent grazing control is good, a higher proportion of white clover can be used, especially in areas not prone to severe summer droughts. Alsike clover is more suitable for large areas of moderate fertility under extensive grazing management. Red clover has the highest establishment vigour and early productivity but often does not persist if grazed heavily by sheep.

Grass is usually included in the mixtures, but the proportion of seed that establishes is generally very low. Establishment rates of 1% or less are common. The use of mob stocking to open up existing vegetation and then to tread the seed into the soil is recommended. Consideration should be given to leaving the grass introduction for several years because, unless there is adequate nitrogen being transferred from legumes to the grasses, the oversowing of grasses will often be a waste of time and money. Plants which do establish will be nitrogen deficient and will contribute little to pasture quality and production. Consequently, sufficient S, P and Mo must be present in the soil to ensure that the legumes are fixing adequate amounts of nitrogen.

The establishment of pasture grasses in special purpose pastures by cultivation of tussock grassland can be enhanced by the strategic use of nitrogen fertiliser. Establishment may start with nitrogen fertiliser drilled with the grass seed. Only low rates (5-10 kg N/ha) should be used. Also, as nitrogen fertiliser restricts legume nodulation, the legume seed should be cross drilled in a separate operation. Following seedling establishment, further nitrogen, up to 50 kg N/ha in the later summer/early autumn, will further increase grass establishment. However, the main response in grass establishment gained with nitrogen application is achieved in the second year by using up to 150 kg N/ha in split applications during growth periods in the spring and autumn. The use of nitrogen ensures both good grass establishment and production.

Inoculation And Coating

Each legume species generally needs specific rhizobia to form nitrogen fixing nodules. The exception is that most of the common clovers are nodulated by the same *Rhizobium* species.

Rhizobia are absent from large areas of undeveloped tussock grassland and, in areas where they do occur, their distribution is often irregular, so inoculation of legume seed with the correct strain of rhizobia is recommended. In the absence of existing soil rhizobia, inoculation of seed with rhizobia is essential for legume establishment because, without it, seedlings fail to nodulate and will die from nitrogen deficiency.

Areas of the tussock grasslands where clover rhizobia are present have been developed by oversowing un-inoculated seed. However, the rhizobia present may be poor nitrogen fixers and inoculation is still recommended because, if the inoculant strain displaces the existing population and forms nodules, increased nitrogen fixation can occur. Rhizobia which form nodules on lucerne and those which form nodules on lotus are rare in the tussock grasslands, so these species should always be inoculated.

Rhizobia on oversown seed are exposed to severe environmental and soil conditions between inoculation and penetration of the seedling root into the soil. Rapid death of rhizobia can occur with conventional inoculation, so techniques have been developed to improve survival of rhizobia and hence increase nodulation and establishment of seedlings.

Coating of inoculated clover and lucerne seed is recommended to increase establishment and growth. Seed coating with lime reduces the death of rhizobia on the seed and raises the pH in the vicinity of the seedling root. Soil pH is critical during the brief period of nodule formation on seedlings. On the more acid tussock grassland soils (pH less than 5.0), lime coating is essential for nodulation of legumes unless the more expensive broadcast lime is applied.

Runholders can inoculate and coat seed themselves in a concrete mixer, using gum arabic as adhesive and microfine lime as coating material. However, it is difficult to produce consistent, high quality coated seed by this method, so it is advisable to use effective commercially coated seed.

It is considered better to use lime coating of seed to achieve the higher pH required for initial inoculation than the high transport and spreading cost in the high country of general liming. In the long term, it is probably more sustainable to find acid tolerant rhizobia and legume species than general liming.

In New Zealand, coating, or pelleting grass seed is worth considering for surface sown seed. The effect of coating on grass establishment can be large on occasions (up to six times greater establishment), but results are highly inconsistent between sowings, sites and seasons. Coating probably only doubles establishment on average, and this must be discounted against the cost. The coating is effective at the early germination and seedling establishment stage and is related to moisture contact between seed and soil. In this sense, it is the physical presence of a coat and not its composition which is important, and relatively inert coating materials are suitable.

When oversowing by air, the heavier weight of coated seed will not significantly increase seed penetration through resident vegetation. Large multi-seed pellets are generally ineffective. The present lighter commercial coating of legume seed, and the heavier coating of grass seed, decreases the drift separation of the two components in aerial oversowing.

The use of commercially coated legume seed would seem to provide an opportunity to supply nutrients in the immediate vicinity of the establishing seedling. This could be important in the tussock grasslands because of the difficulty in obtaining uniform distribution of seed and fertiliser with aerial oversowing in steep high country. The standard coating for legumes is finely ground limestone to which sulphur and molybdenum can be added on request.

The largest response is to the addition of sulphur, which can increase both establishment and vigour of legume seedlings. It is recommended for use on the low rainfall sulphur-deficient tussock grassland soils in combination with the normal sulphur topdressing.

On molybdenum-deficient soil, addition of Mo to coated seed is recommended as an alternative to Mo application in fertiliser. However, maintenance Mo application should commence with the first maintenance fertiliser dressing, and be repeated every four years thereafter.

Coating seed with insecticides is a means of limiting early loss of legume seedlings due to attacks by weevils and grasshoppers following oversowing in tussock grasslands. In lowland pasture, coating seed with fungicides can also have beneficial effects, so this practice could be worthy of further investigation in the tussock grasslands. Coating with phosphorous or nitrogen fertiliser has not been successful to date.

Method Of Sowing

Again, there is the dilemma of compromise between the relatively low cost but often poor reliability of broadcast or aerial sowing, suitable for large areas and irregular topography, and the moderate reliability of overdrilling, or the even greater reliability of full cultivation with drilling.

Where broadcast or aerial sowing is used the seed should be trampled by using heavy stocking for a short period following sowing.

With rhizobia inoculation and coating, and sulphur and phosphorus fertiliser, the establishment of clovers is now reasonably reliable from surface sowings - except for the drier areas, where it will always be chancy.

The generally very low establishment of grasses is a concern, and the question has already been raised whether it is worth including grasses in initial sowing mixtures.

Direct drilling into tussock vegetation is generally superior to broadcast sowings, particularly in the drier areas. Over recent years, results from a comparison of the different types of drill, particularly as they influence grass establishment, have been recorded. The ranking of drills from worst to best in terms of plant establishment is: hoe coulter, till seeder, single disk, triple disc, rotadrill and single pass strip seeder.. Unfortunately, operating costs probably increase in the same order.

The limitations of the different drills appear to relate to the bulk of the resident vegetation that is being overdrilled and the uniformity in sowing depth of the individual coulter when traversing irregular topography. The cultivation action of hoe coulter and till seeder drills leaves chunks of turf which do not settle back uniformly over the seed.

This effect is minimised by the greater cutting action of the rotadrill or the removal of a turf strip as done by the single pass strip seeder under development. The cultivation action of the rotadrill or the single pass strip seeder temporarily reduces the competition from the surrounding resident vegetation. The effect of closing the drill slot over the seed, or covering of the seed, is probably best with the triple disc and rotadrill or single pass strip seeder drill.

However, in dense vegetation the triple disc tends to drag plant material down into the slot, limiting contact between seed and soil. There have also been cases, when herbicides have been used on dense vegetation, where the dragging action of the disc has brought this herbicide treated vegetation into contact with the seed. Herbicide should be applied well in advance of drilling to avoid this problem.

Post-Sowing Management

The success of any oversowing or overdrilling will depend considerably on how it is managed after sowing. With broadcast oversowing, the present recommendation is to stock it very heavily immediately for up to five days following sowing, to both dislodge any seed from the vegetation and to trample it into the ground.

There is a general underestimation of the time for which a pasture requires specific spelling and other management to enhance its establishment, vigour and spread as opposed to its long-term role in livestock feeding systems.

The decision on when and how to use new pastures should be based on the actual stage of growth and development they have reached, rather than time as such. As a very broad generalisation, plants should be allowed to grow to at least 10cm before grazing.

Figure 5 (page 9) was presented to show the production of an establishing pasture. It can also be used to estimate the establishing time.

In a warm, moist, highly fertile site of high potential production (e.g. 8-12t DM/ha) it is possible to establish a stand producing substantial (e.g. 2t DM/ha) yields in a few months.

However, in a dry site of low fertility, with 1t/ha potential, satisfactory establishment will probably take several years.

Young stock should be used to graze young pastures. The animal husbandry requirements of young stock will ensure that young pastures are leniently grazed at this stage.

Most of the initial oversowing in the high country will be very legume dominant. If grass seed has been sown, and established successfully, then periodic, brief, hard grazing will be necessary to reduce competition and to cycle nitrogen to the grasses to enhance their growth and development.

Pasture Management And Winter Feed

One of the main objectives of pasture management is to meet the annual feed demand of stock by manipulating the annual feed supply from pasture. This challenge is probably greatest for high country runholders because long cold winters and often dry summers severely disrupt the continuity of pasture growth and create a mismatch between supply and demand. Within each high country run there is generally a diverse range of landscapes environments whose integration with planning, and an appropriate choice of pasture species. and selective management, can help overcome this mismatch.

Pasture growth is very tightly controlled by climate. In that sense animals may be more flexible than plants in that, because of their fat reserves, they can tolerate some management variation in feed intake and body weight. For example, winter hay feeding can be reduced by building up extra body weight in late autumn/early winter on standing alsike before it loses its feeding value by frosting, instead of trying to maintain or build acceptable body weights in winter with extra hay.

Good management in pastoral farming is working out a compromise between the conflicting requirements of animals and pastures.

The ideal management from the point of view of the pasture would be to allow it to grow to approximately three quarters of its maximum height or bulk, then to graze or cut it within a very short time (hours rather than weeks), and then allow it to regrow to the same level again before repeating the cycle. While impractical in most grazing systems, it illustrates the three desirable principles of pasture management which should be aimed for:

- Very quick removal
- Minimal treading
- Uninterrupted regrowth back to near maximum bulk or height.

In contrast, the ideal management from an animal viewpoint would be a constant and adequate supply of quality feed.

The important principle in management is not that pastures are grazed in a regular sequence, but rather that they are grazed intensively for a short period and then allowed to regrow uninterrupted until adequate bulk is achieved (e.g. 10-20cm high). These management principles encourage non-selective grazing and good utilisation, and favour the regrowth patterns of desired pasture species. Note that the period required for regrowth may differ widely between pastures on different sites, and between pastures grazed at different times of the year.

Utilisation

Pasture utilisation refers to the consumption of pasture by the grazing animal. All pasture not consumed must eventually die and decay, and therefore, while not directly contributing to animal production in the short term, will add to the soil organic matter and fertility in the longer term. The more consumed relative to that grown, the greater the efficiency of utilisation.

Generally the aim should be to achieve 60-70% utilisation of available inter-tussock herbage in no more than 10 days. On more extreme dry sites, particularly where ground cover conservation has priority, the utilisation should be less, with the rule-of-thumb being take half and leave half. This allows the maintenance of a greater root mass and reserves for regrowth, and protects the soil surface from wind erosion.

Special purpose pastures convey the desirable concept of each area or paddock being managed to fulfil feed requirements at a certain stage of each year. The runholder should aim for the integration of a sequence of special purpose paddocks rather than rotational grazing. On better sites, the same paddock could fulfil feed requirements many times during the year, thus approaching the concept of rotational grazing.

In addition to providing the immediate feed requirements for animals, and growth requirements for pastures, successful grazing management involves continual forward planning to help balance the known stock feed demand with the expected feed supply. Subdivision provides the means to control utilisation, allowing a bank of feed to build up ahead of stock when pasture growth is good (e.g. spring and autumn). This feed bank can then be carried over and effectively used during periods of feed deficit.

It may take up to 10 years to realise the full potential from topdressing, intensive grazing and adequate spelling for regrowth. However, with such management, up to an 8-fold increase in carrying capacity over that in the native state can be achieved.

Pasture utilisation is a stock numbers game. If stocking rate is increased, so is efficiency of utilisation - but herbage allowance will decrease and so eventually will individual animal performance. The ideal stocking rate obviously depends on farmer objectives, but grazing research on oversown tussock country has shown that optimum liveweights per hectare are achieved when pasture utilisation per grazing is about 60-70%. For optimum wool production per hectare, even higher levels of utilisation are required. The greater the stocking rate the greater the efficiency of utilisation, but the more difficult it is to match annual feed demand to annual feed supply.

Subdivision fencing provides the essential key to control utilisation. Increased subdivision allows even and non-selective grazing, gives increased flexibility when carrying pasture from the periods of plenty to periods of deficit, and promotes more efficient re-cycling and spread of nutrients.

Winter Feed

To balance the highly seasonal nature of pasture growth with the more constant feed requirements of stock, feed has to be transferred from one period of a year to another, principally between spring and the following winter. The greater the overall stocking rate relative to the overall feed supply, the more difficult it is to overcome any imbalance.

Gains in stock liveweight should not be expected during winter. The best that can be hoped for is maintaining or having only slight losses in liveweights. Weight losses during the winter are generally compensated for by greater weight gains during the following spring. The exception to this is the breeding stock. High weights are advantageous for flushing during the autumn. There is some evidence that low weights during early pregnancy (early winter) are not detrimental, but the evidence is unanimous that feeding must be more than adequate during late pregnancy, particularly in the last few weeks.

Special winter feed paddocks will generally be used in conjunction with other undeveloped or developed paddocks. Stock take some time to adapt to new types of feed because of changes in the rumen micro-organisms. Hence, different feeds should be introduced slowly over several weeks prior to their real need.

Conserved Feed

One option is to conserve feed, usually as hay. The common hay mixtures are based on combinations of red clover, alsike, cocksfoot or timothy in the mid to high rainfall area and lucerne in the drier zone. There is also a tendency to prefer alsike rather than red clover in the highest rainfall zone, both for its better performance at moderate levels of soil fertility, and its hollow stem which cures more rapidly than the solid stem of red clover.

Under dryland conditions, only one hay cut can be assured in many areas, with perhaps a second in good years. With irrigation, two or more cuts can be expected, increasing the reliability of winter feed. This may justify irrigation in many of the moderate and lower rainfall areas where there are limited winter feed options.

Hay is the usual form of conserved feed, principally because of its straightforward preparation (subject to the normal vagaries of weather) and its flexibility when feeding out during winter. It is generally only of maintenance feed value, and in most situations winter liveweight gains of stock cannot be expected. The allowance rate is commonly 0.8kg/sheep/day, though for ewes in lamb it should be increased to 1kg/ewe/day in early winter and 1.5kg/ewe/day in late winter.

Good quality silage can be made more consistently than good quality hay because silage making does not need long periods of fine weather. Unlike hay, silage retains its quality for many years if properly made. Silage requires more machinery though, particularly when feeding out. Haylage, or wilted silage, is a possible compromise. The pasture species recommended for hay making are also ideal for silage and haylage, but should be cut at an earlier stage of growth to ensure the best quality.

Hay or silage paddocks are good examples of special purpose pastures, having specific fencing, fertiliser, species and often irrigation requirements. They are the most expensive of the winter feed options but have the advantage that the reserves available are known well before the winter period.

To maintain density of hay paddocks, a hay cut may have to be replaced periodically with grazing to clean out the bottom of stands and promote tillering of grasses.

To compensate for nutrient transfer when conserved feed is fed out on areas other than those on which it was made, fertiliser application rates on hay paddocks will need to be higher than elsewhere. Also, when the feed out areas are different, care is needed to ensure that the resident vegetation does not become overgrazed because of the higher stocking rates.

Autumn Saved Pasture

An attractive and now widespread alternative to hay or silage making is to close up improved hill blocks at some stage during the growing season to provide winter grazing. Success depends largely on the ability to maintain pasture with reasonable bulk and acceptability into the winter. Pasture species differ in this respect. For instance, browntop and haresfoot clover are virtually unacceptable to stock once they have developed seed heads, while timothy, perennial bromes, and most legumes are quite acceptable even when rank. Legume quantity and quality deteriorates rapidly when subjected to frosting. Introduced grasses are clearly a desirable component of autumn saved pastures.

Pasture growth in the high country is negligible during winter, so management of autumn saved pasture becomes a feed budgeting exercise.

Autumn saved pastures and their use on hill blocks take two forms. Blocks at the highest altitudes, or legume dominant pastures, are used in late autumn or early winter. The objective is to eat the herbage before it loses feed quality by frosting, or disappears under snow, and to put on animal body weight to tolerate lower feeding levels later in the winter. Alsike and red clover are important in this approach. The other approach is to exploit the greater frost tolerance of grasses as direct standing feed in mid and late winter. Grass dominant blocks, particularly those on sunny faces, can be used in this manner.

The closing of those sown grass/legume pastures for winter feed may be as early as the previous November. However, close grazing, then closing in December greatly reduces the less acceptable species like browntop. Cocksfoot is the most useful sown grass. There is a trade-off between bulk and feeding quality in such autumn saved pasture.

An example of all-grass wintering on hill country would be ten saved blocks to ration out over June, July and August, with stock shifts every 5-15 days depending on size of block, amount of feed, aspect, and other factors which might determine the duration of grazing.

Most high country all-grass wintering is achieved on large sunny hill blocks. It is possible to intensively break feed special purpose pasture grown on the flat, throughout the winter. Areas may be used strategically in late winter, allowing spelling of the lower sunny faces, which provide early spring feed.

Grasses for such pastures ranked for suitability according to a combination of both autumn productivity and winter quality are as follows: cocksfoot, ryegrass, tall fescue and bromes.

Autumn regrowth from hay paddocks can be used in the same manner. These special purpose pastures could be grass, using nitrogen fertiliser at 150-300kgN/ha in split applications. One method used irrigated tall fescue, nitrogen fertiliser, with 1-2 hay cuts, allowing autumn regrowth, and winter feeding out in that area with sheep receiving standing forage and hay.

Annual Crops

Greenfeed crops produce well on select areas of high fertility, but must be sown earlier than they would be on down country. The bulbs of swedes and turnips, with their high water content, can freeze, leaving only their tops edible. Rapes and kales do not suffer the same disadvantage.

Ryecorn and, to a lesser extent, oats and barley are the main greenfeed cereals, indicating their adaptation to both cooler temperatures and moderate soil fertility. Some varieties of triticale and wheat are also suitable as greenfeed crops but have less regrowth following grazing and generally require higher soil fertility than ryecorn, oats, or barley.

Annual greenfeed ryegrasses are generally not suitable in the high country because they need more fertile soil and early sowing to express their growth potential. However, there are occasionally very good crops of these species.

All annual crops require sites of high soil fertility. The exception may be the common practice of taking an oat crop following initial cultivation of tussock grasslands using the consequent mineralisation of soil organic matter. It may be economically justifiable in the short term, but it must be followed by fertiliser input for sustainability.

Supplements

Supplements or concentrates in the form of grain (ryecorn, wheat, oats, barley), molasses or bone meal are used on some developed runs during times of critical feed shortage.

Species For Particular Uses

A theme of this publication is that each pasture species occupies a particular niche where it does better than others which might be used. In so doing each also fills a particular role in the juggling act between feed supply and animal requirements. We have stressed the need to identify the critical stock feed periods, and then to establish special purpose pastures to satisfy these requirements.

In Table 3 we group pasture species according to their value for particular critical feed periods. This includes a judgement on ranking of what are considered to be the best species for that use, based on our present knowledge. A more detailed description of each species is given in the last section.

Table 3: Most suitable farm management role for species and cultivars in South Island hill and high country. Species and cultivars are ranked approximately in order of merit within each group

Autumn Saved Standing Winter Feed

Low To Moderate Soil Fertility
Grasses>legumes

Cocksfoot>browntop>sweet vernal> tall oat grass

Perennial lupin>alsike clover

High Soil Fertility
Grasses>legumes

Cocksfoot > tall fescue > perennial ryegrass > timothy > prairie grass > phalaris

Red clover > alsike > (lotus, lucerne, birdsfoot trefoil and white clover, seldom suitable in this role past May)

Late Summer/Autumn

Low Soil Fertility
Perennial lupin > suckling clover

Chewings fescue > blue tussock > native tussocks > danthonia > sheeps sorrel > yarrow.

High Soil Fertility
Lucerne > red clover > white clover

Cocksfoot > tall oat grass > tall fescue > perennial ryegrass > timothy > smooth brome > prairie grass

Hay or Silage - Dryland

Moderate To High Soil Fertility
Lucerne > red clover > alsike clover and possibly birdsfoot trefoil > timothy > cocksfoot > mountain brome > prairie grass > tall fescue > phalaris

Special Purpose Lamb Fattening Feed

High Soil Fertility
Red clover > lucerne > white clover > chicory > mountain brome > prairie grass > hybrid ryegrass > timothy

Spring/Early Summer

Low Soil Fertility
Perennial lupin>suckling clover>haresfoot clover>red clover>zigzag clover.

Browntop>sweet vernal>chewings fescue> blue tussock >timothy>yorkshire fog>native tussocks>danthonia>sheeps sorrel

Moderate Soil Fertility
Alsike clover > red clover > birdsfoot trefoil > perennial lupin > sweet clover > lotus - moist acid soil > caucasian clover > crown vetch > subterranean clover

Cocksfoot > tall oat grass > smooth brome > yorkshire fog > crested dogstail > silver tussock > pubescent wheat grass.

High Soil Fertility
White clover > lucerne > alsike clover > red clover

Cocksfoot > perennial ryegrass (endophytic) > tall fescue > phalaris > hybrid ryegrass > mountain brome > prairie grass

Special Purpose Winter Crops

Moderate Soil Fertility
Ryecorn > oats

High Soil Fertility
Turnip>swede>kale>greenfeed lupin

Annual ryegrass > barley (Claremont)

Late/Winter/Early Spring Special Purpose Feed

Ryecorn>annual ryegrass>short rotation ryegrasses

Lucerne, for high soil fertility (needs long spelling).
Sheeps burnet (low to moderate soil fertility).

Subterranean clover and tares (lowest altitude warm country)

Description Of Species

The attributes of each species are described in turn, starting with the legume, followed by grasses, and then herbs and shrubs. Within each of these main groups the species are listed in approximate order of their importance within the high country. Where several cultivars of a particular species are available, the most suitable ones are mentioned. With less emphasis on cultivar testing in recent years, some of the recommendations are becoming somewhat dated.

Legumes

Alsike Clover (*Trifolium hybridum*)

Alsike clover, along with white clover, is among the most important pasture legumes in the high country. It grows in a wide range of conditions and is used as both a grazing and hay species. It is a short-lived perennial under most conditions.

Alsike establishes and yields better under moderate soil fertility and moderate stocking rates than does white clover. However, it does have a period of low acceptability to stock in late spring/early summer. It is more frost tolerant than white clover and is often preferred to red clover for hay as its hollow stems cure more rapidly. Alsike is a stronger competitor against mouse-ear hawkweed than white clover. It is a prolific seeder, so seed is cheap and, once established, much of the further seed supply can come from on-farm harvesting. The rhizobia are the same as for white and red clover. It should be the main clover in mixtures for large scale initial oversowing of moderate rainfall high country.

Alsike is advocated and used more in Marlborough and Canterbury than Otago, though whether this difference is related to human preference or the differences between greywacke and schist soils is not known. Alsike use is mainly a high country phenomenon. It is little tested or advocated in other warmer regions of New Zealand, where virus diseases associated with higher temperature limit its use.

Initial clover oversowings in the high country generally go through a spectacular clover-dominant phase lasting for 2-4 years before falling back to low levels. The reasons for this are not fully understood, but it is particularly notable in alsike and white clover.

Most of the presently available alsike seed is uncertified, locally grown material of Canadian origin. Testing of many lines and cultivars done in the last decade has shown less variation between lines than in other clovers. Results indicate New Zealand and Canadian uncertified seed and Tetra, are the best commercially available seed at present. Canadian, Finnish and Russian material perform better in New Zealand than Swedish or Danish material. A New Zealand cultivar (G50), based on a decade of selection, is due for release.

White Clover (*Trifolium repens*)

The great virtues of white clover, are its: tolerance to close grazing once closed swards are obtained high growth rates when soil fertility is high and moisture stress low and its ability to spread by both vegetative propagation and seed. However, white clover does have limitations in the high country and these are over-emphasised in order to draw attention to the possible role of other legume species.

White clover is not as important in the high country as it is in the rest of New Zealand. It is important in the highly fertilised, intensive or semi-intensive developed paddocks but is replaced by alsike and red clover under more extensive, moderate fertility conditions. It requires high fertility to express its high growth rates and makes only a limited contribution when sown into low or moderate soil fertility conditions. However, it is persistent, particularly in the moderate rainfall zone.

Currently available material has low tolerance of moisture stress and therefore makes a limited contribution in the very low rainfall zone. White clover is also very palatable and therefore tends to be selectively grazed. It has the least frost tolerant leaves of the pasture legumes and disappears as a useful diet component after a few severe winter frosts.

Grasslands Huia is currently the most productive available cultivar for the high country but may be replaced by Grasslands Tahora and Grasslands Demand. Grasslands Pitau is slightly less suitable. Grasslands Prestige and Prop have not yet been sufficiently tested for high country use.

These recommendations for pastoral use in the high country are not to be confused with use for commercial seed production. The previous absence of legumes from many regions of the high country often make them potential areas for nucleus production of new cultivars - as was the case for Grasslands Pitau -though the frequency of summer frosts makes consistent year to year seed production problematical.

Red Clover (*Trifolium pratense*)

As one of the three main clover species in the high country, red clover is a tap-rooted perennial which, although relatively short-lived in mixed swards, establishes and produces well under a wide range of conditions. It is most productive under fertile, moist (natural or irrigated) conditions and is used for hay or grazing. With alsike and timothy, it becomes the main component of hay mixtures in the high rainfall/lower temperature zones where lucerne does not persist.

Red clover is also suitable as an oversown species even where soil fertility is low, providing the stocking rate also remains low. It is the most frost tolerant of the common legumes, particularly the tetraploid Pawera. It is not tolerant of prolonged close grazing and is best used for hay or lax grazing.

Red clover-dominant stands can cause bloat in cattle, and contain oestrogens which have a short-term effect of reducing ovulation in ewes if grazed immediately prior to tupping. However, the same feature promotes high growth rates in wethers.

Besides being used for hay, the main virtue of red clover is its ability to produce well in late summer/early autumn, which can be one of the critical feed periods in high country farming. In the high country, with the emphasis on wool and store sheep, the high feeding value of red clover for non-breeding ewes should be promoted.

Of the red clover cultivars commercially available, the tetraploid red clover Grasslands Pawera is the best for the high country, in terms of both production and frost tolerance. It is followed by Grasslands Hamua (cow grass) and then by Grasslands Turoa (Montgomery red clover). The new cultivars Grasslands Colenso, Enterprise and G27 have been little tested yet.

Central Otago and the Mackenzie Country, because of their populations of long-tongued bumble bees, are suitable areas in New Zealand for seed production of tetraploid red clovers.

Red clover is one of a group of three species, including the grasses Yorkshire fog and timothy, normally associated with high fertility moist conditions but which are also suitable for dry, low fertility conditions.

Lucerne (*Medicago sativa*)

The prime role of lucerne in the high country is as pure hay stands in the moderate to low rainfall zone (350-550 mm) and secondly as a potential overdrilled species in the low rainfall, (<450mm) high base soils zone. It requires moderate to high soil fertility and high moisture to express its high growth rate.

There is a definite soil limitation precluding its use in the moderate to high rainfall zone and in the older soils in the low rainfall zone. This limitation is soluble aluminium in the soil, which may be present in soils below pH 5.8 and which can be tested for.

If the soil aluminium test is above 5 units then lucerne is unsuitable and more aluminium tolerant legumes like alsike, perennial lupin, red clover and birdsfoot trefoil should be used.

The best sites for lucerne are the young outwash soils of the fans, recent river terraces, or lower hill soils. There, in the high fertility intensive paddock situation, lucerne will be the most productive species, under both dryland or irrigation, for use as hay or short duration rotational mob stocking. The recommendation for establishment in a cultivated paddock is:

- Check aluminium levels by soil analysis
- Pre-spray with glyphosate if any weeds are present
- Drill with inoculated pelleted seed and lime reverted superphosphate plus molybdenum in the late winter-early spring
- Use insecticide to control grass grub.

The deep rooted lucerne will be able to use subsoil sources of sulphur when present.

Trial results have also demonstrated that lucerne has good potential as an overdrilled species on the low altitude dry slopes in the dry zone. However, in practice there is seldom adequate subdivision to give it proper subsequent grazing control (i.e. short term grazing, even if hard, followed by adequate uninterrupted regrowth periods). Establishment from oversowing is generally poor.

Among the best available cultivars for dryland high country conditions are Grasslands Otaio, Grasslands Oranga, Deseret and Wairau. For irrigated conditions the best are Saranac and Washoe.

Lotus (*Lotus pedunculatus* or *L. uliginosus*)

Lotus is establishing its role as a pasture legume for the Otago uplands and high rainfall zones on soils too acid (pH < 5) for good white clover growth. Thus it can be used in preference to white clover when oversowing such areas. These areas are likely to be wet, or of initially low soil fertility and, because of moderate fertiliser rates and continued leaching, will rise to only moderate soil fertility. However, in spite of misleading information to the contrary, lotus grows very poorly without fertiliser on acid and infertile soils but can survive and continue to grow under these conditions because of its superior ability to compete with resident vegetation for limited nutrients. Its response to sulphur and phosphate is very similar to that of other clovers on such soils. It spreads vegetatively by underground rhizomes. It tolerates close grazing, but should be rotationally grazed to provide the spelling it needs to achieve its full potential production.

Elsewhere in New Zealand it also has a role as a special-purpose pasture for non-bloating feed, or where some degree of resistance to insect attack is required.

Lotus establishes slowly because of its small seed, low germination at low temperatures, and poor seedling vigour. Establishment is best if seed is applied to an open sward and not onto bare soil or dense vegetation. Dense resident vegetation should be opened up prior to oversowing by either burning or hoof and tooth. Use high rates of inoculation, and give it two full growing seasons to establish. There is almost no spread from reseeding at higher altitudes and the sparse stands can be encouraged to thicken up by vegetative spread if spelled completely in the January to March period.

When grown on acid and infertile soils, lotus contains high levels of condensed tannins, which may restrict voluntary intake by grazing animals and result in lower animal growth rates. This should not be viewed as a deterrent to its use on such soils. On most runs, lotus is grown, not as a specific fattening feed, but as a summer-country feed for ewes to allow spelling of intensive, lower altitude, clover-based pastures. Stock may need a fortnight adjustment period to lotus.

Grassland Maku and Grasslands Sunrise are similar in performance, though there is much more experience with the former. Seed can have a high hard seed content requiring scarification. This should be checked by germination tests.

Birdsfoot Trefoil (*Lotus corniculatus*)

This is a relatively new species on the New Zealand farming scene. Trials over the last two decades show that birdsfoot trefoil has the particular characteristics of high persistence and continued production under moderate soil fertility conditions in the drier high country regions. It is probably best described as a poor land lucerne. Its probable role is as a grazing species for late summer to autumn feed, on country which, if more fertiliser or subdivision were available, would be considered for lucerne. Overseas it is used primarily as a hay species. Its grazing tolerance is similar to lucerne in requiring a short grazing period followed by adequate regrowth time. One disadvantage is likely to be its slow establishment from seed, but once established it is very persistent. The best guidance on grazing management is to treat it as lucerne should be treated, as it is very similar in growth form and other characteristics.

Birdsfoot trefoil requires a specific rhizobial inoculant at a high rate and, for the type of site for which it is most appropriate, sulphur coated seed should be considered. The seed can have a high hard seed content so scarifying it before inoculating may be advantageous.

About 300 lines and cultivars have been tested in New Zealand and about 200 in the high country. Breeding from these, two New Zealand cultivars have been developed, Grasslands Goldie - selected for the North Island - and one selected for the high country conditions. The best performing overseas cultivars are: Franco, Tana, Cascade, Granger, San Gabriel, El Boyero, Ginestrino and Maitland. Two or three of these are commercially available in New Zealand. Continued farmer experience over the next decade should define the best cultivars of birdsfoot trefoil and their role in the New Zealand high country.

Perennial Lupin (*Lupinus polyphyllus*)

While originally a garden flower, perennial or Russell lupin was sown initially in the Tekapo area along a newly formed road. It has subsequently spread along many roadsides and other areas, indicating that it is adapted to the high country environment.

Lupin grows best in loose textured soils with reliable moisture. A decade of research has indicated that it has the potential to become a major pasture legume for the moister regions of the high country. It considerably out yields other legumes under low fertiliser inputs. Its role appears to be as a grazing legume for loose textured soils at 600mm or greater rainfall where only low fertiliser inputs can be afforded. It is particularly tolerant of acid, high aluminium soils. It is proving somewhat difficult to establish. While germinating at much lower temperatures than other legumes it is very sensitive to drought and competition during the first years. Thereafter, it is very persistent, productive and tolerant of periodic hard grazing, with stands thickening up by reseeding. While like alsike it has lower stock summer acceptability, and hence per animal performance, than red clover, it more than compensates with its total feed production.

Seed is becoming commercially available.

The next four species to be discussed, caucasian clover, zigzag clover, crown vetch and milk vetch, have many features in common: all spread extensively by underground rhizomes or stolons; they are very slow to establish (commonly one or more years before they are seen and four or more years before becoming productive); they need specific rhizobia (except for zigzag, which requires the same as white clover); they are winter dormant; they have moderate spring/early summer growth; and they are generally very poor seeders so seed costs are likely to be high. It may be necessary to contemplate vegetative propagation. Their virtue is their underground spread and persistence once established.

Caucasian Clover (*Trifolium ambiguum*)

The initial New Zealand and Australian interest and testing of caucasian clover was for high altitude revegetation. However, research over the last decade indicates that it has greater potential of becoming a major pasture legume for the high country because of its productivity and long term spread and persistence, giving sustainability in a range of environments. Its main role will probably be as the long term legume component of grazed pastures under moderate to high fertiliser inputs. There are current studies to improve its slow rate of establishment.

Caucasian clover is suitable for its early spring growth. It is similar to other legumes during the summer and with some enhanced autumn growth. It is similar to alsike in frost tolerance. Initially, it is a species which is likely to be included as a small component in seeding mixtures to ultimately replace the more rapidly establishing but more transient legumes like alsike.

The hexaploid lines, Monaro and Prairie of caucasian clover are better suited for pastoral agricultural purposes, than the tetraploid and diploid cultivars, Treeline and Alpine. New Zealand cultivars based on hexaploids are being developed.

Zigzag Clover (*Trifolium medium*)

Zigzag clover is often the only introduced legume surviving in old high country trial areas, with some 30 or 50-year-old stands being present. In relation to the other species in the group, zigzag clover is the best option for lower soil fertilities. Seed is not commercially available at present, though there has been some plant breeding in New Zealand.

Crown Vetch (*Coronilla varia*)

Overseas, crown vetch is used primarily for roadside stabilisation, and has been evaluated in New Zealand for that purpose. It has also been evaluated as a grazing legume, and its role is likely to be in the higher pH and moderate fertility soils of the low rainfall zones under continuing low, or nil fertiliser input. It is slow to establish but then spreads extensively. Yields can be expected only to reflect the lower to moderate fertility of the sites on which it would be used.

A New Zealand line, G34, may soon be available.

Cicer Milk Vetch (*Astragalus cicer*)

A species little tested in New Zealand. Indications are that it is more suited than crown vetch to loose textured soils towards the mid rainfall area, though requiring moderate soil fertility.

Suckling Clover (*Trifolium dubium*)

This introduced annual clover has become widespread, but only locally dense, throughout the unfertilised mid altitudes. It gives some spring growth but is of unknown nitrogen fixing ability. It is only mentioned because it may represent the best legume that could be hoped for under continued low soil fertility and moist conditions.

It is unlikely to be sown in pasture mixtures, though it is used in some soil conservation mixtures for disturbed sites. Its presence in other legume seed lines would be of no concern.

Haresfoot Clover (*Trifolium arvense*)

Haresfoot clover is an introduced tap rooted annual which can form dense swards. It has become widespread throughout the unfertilised dry high country. It produces spring and early summer growth, but its nitrogen fixing ability and feed value is unknown. It probably only has grazing value in the spring. It responds to superphosphate. Resident plants can give severe competition to oversown. more productive legumes and grasses, though conversely give a useful vegetation response if sown species have failed for other reasons. It has the same rhizobia as the common clovers, so rhizobia coating of these other clovers may be dispensed with when sowing into areas known to have had dense haresfoot clover. The plant flowers and goes to seed early in the season and becomes unpalatable in the rank state.

It would not be deliberately sown. Haresfoot clover is mentioned because it is an introduced clover which may represent the best that can be hoped for under continued low soil fertility and dry conditions.

Sweet Clover (*Melilotus alba* and *M. officinalis*)

Based on natural spread in Otago, these biennial legumes could have an agricultural place in the dry zone at low to moderate soil fertility. Their role could be as a short term lucerne, to be used as a nitrogen fixer and bee or sheep feed while other, simultaneously sown but more permanent, species are establishing. It makes some growth in the first year and yields similar to lucerne in the second year prior to dying off. The bred cultivars are more palatable than the wild form which occurs in many areas. It could be used for a hay crop following initial cultivation of tussock country, but resulting hay must be well cured prior to baling.

Yukon is the preferred cultivar because of its higher yield, low coumarin content, and some ability to re-establish from seed. Other cultivars which have been tested are Polara, Arctic, Denta and Goldtop.

Subterranean Clover (*Trifolium subterraneum*)

This species is of doubtful relevance to the high country because of its limited tolerance to low temperature and frost. A winter annual, it was once used extensively in the lowlands as the initial legume on moderately fertile soils, and used for winter and spring feed for fat lamb production. It must be spelled from grazing from mid-spring to allow flowering and seed set. High country trials indicate that it produces only in the warm, moist years when all legumes produce well and, unless the first seasons after sowing are like this so that a store of seed can build up, it soon dies out. If it has a high country role then it would be on the lower altitude sunny faces of the dry zone, merging into the dry hill country.

The few trials have indicated that Mt Barker and Woogenellup are still the best cultivars for the high country.

Vetch or Tares (*Vicia sativa*)

This legume is a large seeded, spring annual. Like sweet clover, it could be used as a temporary oversowing species on the lower altitude, warm sunny faces for spring feed. Alternatively, it could be used in a mixed sowing with oats for hay, though it probably would not increase the nett yield. It needs specific rhizobia. Like subterranean clover, grazing would need to cease in mid-spring if reseeding is to occur.

Uncertified lines are commercially available in Canterbury.

Greenfeed Lupin (*Lupinus angustifolius*)

In other regions of New Zealand, this was one of the main greenfeed annuals grown in earlier decades. Greenfeed lupins are used spasmodically in the high country, and deserve further consideration because of the adaptation of lupins to moderate fertility acid conditions.

Uncertified seed is commercially available.

Sainfoin (*Onobrychis viciifolia*)

A species little seen in New Zealand outside research stations. Its use is as a special purpose pasture of very high feeding value, which, in the case of cattle, is also non-bloating. The very limited high country experience suggests that it falls between lucerne and sheeps burnet in site, management requirements and growth characteristics.

Of the cultivars tested, the preferred order is Krasnodar, Melrose and Fakin.

Grasses

Cocksfoot (*Dactylis glomerata*)

At present this is the best of the higher producing pasture grasses for the high country because of its tolerance of a wide range of temperature, moisture and soil fertility conditions. Cocksfoot grows well under moderate to high fertility conditions. It is the common grass accompanying clover and fertiliser oversowing of tussock grassland, where its suitability to the environment, and often low stocking pressure, allow it to express its growth potential. It will spread slowly under low stocking pressure.

Cocksfoot performs best during early development, but becomes less prominent with increasing grazing pressure and subdivision unless there is a corresponding change towards rotational mob grazing. The generally better autumn growth of cocksfoot compared with other grasses has often made it the basis for autumn saved winter pastures. It is slow to establish relative to ryegrass in high fertility (nitrogen) situations. Cocksfoot is one of the principal species for pasture hay paddocks.

Four cultivars are commercially available - Grasslands Kara, Grasslands Wana, Saborto and the older Grasslands Apanui - and high country trials show some differences between them. The more erect cultivars appear to suit the high country best. Grasslands Kara, followed by Saboto, is the most productive under cutting or autumn spelling for accumulating winter feed in the high country. Grasslands Wana is considered to be the best cultivar for sheep grazing in lower altitude, improved pasture grazed throughout the year. It is slightly more productive, but less digestible than Grasslands Apanui or Grasslands Kara.

A large number of overseas cultivars have been tested over many years in the high country, but none have shown consistent superiority over New Zealand material bred basically for lowland areas. However, a related species, *Dactylis woronowii*, has shown up well in many trials in dry areas over the years and should be considered as an oversowing species if seed ever became available.

Tall Fescue (*Festuca arundinacea*)

Trial results have indicated that, under high fertility conditions, tall fescue could be a contender with cocksfoot and perennial ryegrass as a principal grazing grass of the high country. It will outyield both species and has a greater frost tolerance than ryegrass. However, most high country areas do not have the necessary soil fertility for it to do well. Tall fescue grows very well in spring, is tolerant of summer drought, grows reasonably well in autumn, and retains its feed quality well in the winter.

It is slower to establish than ryegrass and performs best under high soil fertility. Its main role is in developed, cultivated, moderate to high fertility grazing paddocks rather than general oversowing. Management is similar to cocksfoot. It forms tight swards with periodic close grazing, and a large root mass. Like cocksfoot, it grows better under laxer grazing followed by long regrowth periods. It is not as persistent as cocksfoot.

Trial results have not shown consistent differences between Grasslands Roa tall fescue and the older S170 of the commercially available lines. The other available cultivars Au Triumph and Johnson have not been sufficiently tested in the high country. The cause of tall fescue-induced animal disorder problems (fescue foot), similar to the ryegrass fungal endophyte and common in wild tall fescues, is not present in these bred cultivars.

Timothy (*Phleum pratense*)

This is a much under-rated species in the high country because it is seldom noticed, except when flowering. Timothy is the main grass component, along with cocksfoot, in moist or irrigated high country pasture hay paddocks. The accompanying legumes are red clover and/or alsike clover. Timothy is best suited to high fertility and the long regrowth periods associated with hay production. It is tolerant of low to moderate soil fertility conditions, and has been used as a grass component of oversowing mixtures for high rainfall tussock grasslands. Timothy is highly palatable even in the rank state, is small seeded, and slow to establish.

There has been little plant breeding on timothy either in New Zealand or overseas in recent decades, with Grasslands Kahu being the best commercially available cultivar. There have been very few comparative studies of timothy lines in the high country.

Perennial Ryegrass (*Lolium perenne*)

Under high fertility grazing situations, perennial ryegrass can be the main grass, as it is elsewhere in New Zealand. However, it must have moderate to high fertility to perform well, so is of major value only in developed pasture paddocks and not as a component of general oversowings without adequate legume and fertility base. It does not persist in less favourable conditions. Its main virtues are its rapid establishment, production, and tolerance to close grazing and treading under high stocking rates.

Of the commercially available lines, Grasslands Nui is probably better than Ellets and Grasslands Ruanui for the high country because of its slightly greater production and drought tolerance. But the whole perennial ryegrass scene is in a state of flux with the discovery of the relationship between fungal endophytic infection, ryegrass staggers, and resistance to insect attack, and persistence. It is almost certain that the reputation of local lines for greater persistence than bred lines is related to their drought tolerance through endophytic infection and the consequent lower feed value.

Hybrid Ryegrasses (*Lolium hybridum*)

The role of the hybrid ryegrasses like Grasslands Ariki, Grasslands Greenstone, Grasslands Marsden and Grasslands Manawa in the high country is not clear. Under high soil fertility and irrigation, they can out-yield the other ryegrasses. It is doubtful if dryland soil fertility conditions will be high enough for their yield advantage to compensate for their lower tolerance of lower moisture.

Annual Ryegrass (*Lolium multiflorum*)

In other parts of New Zealand, the annual ryegrasses are used as autumn and winter growing species, requiring high soil fertility to produce winter and spring feed, either in rotation with crops or overdrilled into lucerne or existing old pasture. Because of the dearth of sufficiently high soil fertility conditions and because low temperatures greatly limit any winter growth, annual ryegrasses are seldom a useful option in the high country.

There is insufficient simultaneous testing of Grasslands Tama, Grasslands Paroa, Grasslands Moata and Corvette to differentiate between them for possible high country use, but Paroa and Moata are likely to perform better than Tama under the generally lower fertility levels of the high country.

Browntop (*Agrostis capillaris*)

An adventive, sward forming grass, browntop is abundant in most grazed, unimproved country of the moderate to high rainfall zone. Browntop probably represents the most suitable grass for such lower fertility grazed conditions. It is acceptable to stock when well grazed, but becomes less acceptable when rank, or in seed. Other uses include long-term revegetation and slope stabilisation, and as an amenity grass for lawns and playing fields. A lot of tussock country, originally developed in earlier times, reverts to browntop, probably through lack of adequate fertiliser and grazing management necessary to retain more productive species.

It is occasionally included in oversowing mixtures. Uncertified seed of browntop is freely available. A grazing cultivar Grasslands Muster has been released, and has had limited testing in the high country.

Sweet Vernal (*Anthoxanthum odoratum*)

This is an adventive grass already widespread in areas of dry to moderate moisture and low to moderate fertility. Sweet vernal seldom forms dense swards as does browntop. It is a useful grazing grass where soil fertility is low to moderate and it tends to increase in frequency and growth with increasing fertility. Sweet vernal is slightly less tolerant of close grazing than browntop. It is slightly more acceptable than browntop in the rank state.

It is unlikely to be sown even if seed were available.

Yorkshire Fog (*Holcus lanatus*)

This grass is suited to moderate to moist soils of low to moderate fertility. It is probably the easiest and most rapidly establishing grass in the high country, where trials show it to be a productive grass with proper management. Elsewhere in New Zealand, it is nearly always regarded as a weed under high fertility where other more palatable species could be grown. Its peak growth is in the summer. Feed quality is greatly reduced by frosting. Yorkshire fog requires lax grazing and is intolerant of heavy trampling. It can also be used for first year grass cover in revegetation oversowings.

The cultivar Massey Basyn is available, as is uncertified seed.

Chewings Fescue (*Festuca rubra ssp. commutata*)

This fine-leafed introduced grass is suitable for low to moderate fertility soils in the low to mid rainfall zone. It is adapted to close grazing. Chewings fescue, while widely sown in the past, has been under-used in the high country in recent decades because there are better pasture grasses if soil fertility conditions are improved. Its role is probably best in the low fertility, thin outwash soils. In comparison with browntop it is more suited to drier conditions, is faster establishing, and about as productive, and persistent.

Uncertified seed lines are available. As with browntop, perennial ryegrass and tall fescue, there are a number of Chewings fescue cultivars available bred specifically as lawn or amenity grasses. These should all be treated with caution for grazing purposes.

Tall Oat Grass (*Arrhenatherum elatius*)

Tall oat grass is an introduced grass occurring in the moderately fertile low rainfall zone, where it has been slowly spreading under lax grazing. A tall, stalky grass of moderate acceptability. Opinion is divided on its value as a herbage species with the reactions becoming more favourable as investigation continue. It is an extreme drought tolerant grass giving the potential of feed in all seasons. Small quantities of seed have been taken. A comparison of the various more leafy cultivars and lines available from elsewhere in the world is underway from which selections will be released.

Fescue or Hard Tussock (*Festuca novae-zelandiae* and *F. mathewsii*)

For most of this century, Fescue tussock was the most predominant and characteristic native species of the lower altitude, lower fertility, tussock grasslands. Historically it is now thought to have been originally a minor species and only increased in early years of European occupation to replace tall tussock or other sward forming grasses. It is presently decreasing rapidly throughout its range because of both pasture development and the spread of hieracium.

Fescue tussock has a slow growth rate, is probably a long lived perennial, with limited acceptability to stock. It increases in vigour with increased fertility, but is often eaten out under the increased set stocked grazing pressure that accompanies development.

However, fescue tussock declines in vigour in completely ungrazed situations, although *F. mathewsii* appears to be the more vigorous of the two species with slight winter or early spring grazing. In the drier area, fescue tussock shelter increases the establishment of oversown legumes. The loss of fescue tussock, and its consequences, in undeveloped areas is of concern.

Fescue tussock, like most of the following native grasses, would probably not be sown in grazing pastures even if seed were available, though they are starting to be sown for natural conservation plantings.

Blue Tussock (*Poa colensoi*)

Historically, all native tussock species, except for blue tussock, were burnt as they were unpalatable when mature. This burning encouraged palatable early regrowth. Blue tussock occurs throughout the lower altitude short tussock grassland, is found in the snow tussock grassland, and extends into the high altitude herb fields as well. It occurs on both low and moderate fertility sites and is moderately responsive to increased fertility. As a herbage species, it is the most desirable of the native tussocks for stock acceptability, because of its growth rate and response to grazing. Grazing trials at 700-900m show that blue tussock becomes the major native grass component of rotationally grazed hill blocks.

This species might be sown in oversowing mixtures for tussock grasslands if seed were available, though little is known of its establishment characteristics.

Silver Tussock (*Poa cita*)

One of the lower altitude native tussock grasses of the warmer, more fertile soils of river beds, stream edges and other areas of moderate to high fertility soils. As the most fertiliser responsive of all the native tussocks, silver tussock, has the highest growth rate, and tends to increase in frequency of occurrence with development. Like most of the native tussocks, its rank herbage is not very acceptable, and it is not tolerant of hard grazing. Its main value is as an indicator of areas which can be expected to give large production responses if developed. It provides a good shelter for the protection of oversown legumes, which generally do well on the soils favoured by silver tussock.

It can increase to troublesome density in moist, fertile, laxly grazed foothill country.

Snow Tussock (*Chionochloa rigida*)

C. rigida is one of several species called snow grass which, in early European times, would have been the dominant vegetation on the low fertility soils from mid to high altitudes (400-1200 m) in the mid to high rainfall zone. Like most of the tussocks, it is of limited acceptability to stock except for the regrowth immediately following fire. It is very long lived if not burnt, with indications of only limited re-establishment from seed. It is the dominant vegetation of all high altitude undeveloped land, though most of the forage for stock comes from associated smaller species.

Red Tussock (*Chionochloa rubra*)

Red tussock is a tall native now generally only occurring on moderately fertile swampy sites. There is evidence that in early European times it was much more widespread on the lower country, especially in the mid-rainfall zone, where it was replaced by fescue tussock following burning during the first century of occupation, or by improved pastures (e.g. in Southland).

Crested Dogstail (*Cynosurus cristatus*)

A tufted perennial grass which is best suited to moderately fertile and moderately moist to dry soils. It is extensively but sparingly used on sheep properties in the hill country where it can tolerate hard grazing.

Smooth Brome (*Bromus inermis*)

This is a new perennial grass for the high country, whose role will probably be as a spring/early summer grazing species of dryland of moderate soil fertility, and on moderate to low rainfall high country sites. It is an erect broad-leaved species with high spring production, and some summer and autumn production in dry environments. It is winter dormant in the high country situation and has good digestibility. While swards are slow to establish compared to other improved grasses, over time its vegetative spread thickens up stands, which are then highly persistent. It is palatable in the rank state. Smooth brome is tolerant of occasional hard grazing.

A cultivar, Grasslands Tiki, is now available.

The place of grazing brome (*B. stamineus*, Grasslands Gala) in the high country is being assessed.

Upland Brome (*Bromus sitchensis*)

A species similar to prairie grass but more suited to cooler, drier conditions. It is erect, and broad-leaved, and can be used as a pasture for high spring production under fertile dryland conditions, where it produces highly digestible material. One of its roles, like prairie grass, is likely to be as special purpose lamb finishing feed under lax grazing. It is palatable in the rank state. It is a short lived perennial.

A cultivar, Grasslands Hakari, is now available. While much of the testing and development of the species within New Zealand was done in the high country, its probable greater role is in the downland and hill country.

Prairie Grass (*Bromus wildenowii or B. catharticus*)

An upright short term perennial grass, it is usually used on high fertility, moist soils under rotational grazing, lowland conditions, where it produces throughout the year, with particularly good winter growth. Grazing should be of short duration, though it can be hard. Adequate regrowth periods are required. It is susceptible to grass grub attack.

At present there is only limited experience with it in the high country, where it could be used as a special purpose pasture. Like all species in these hard inland areas, it has no winter growth here, but it is productive in other seasons on high fertility soils under both irrigation and dryland. Its role is likely to be as a high quality spring/early summer/autumn feed. Seed requires de-awning, and it should be considered only for sowing into fully cultivated land of high fertility. It is very palatable at all stages of growth and is highly digestible.

Grasslands Matua is the recommended cultivar. Seed of all bromes should be fungicide treated before sowing to prevent ergot development on seed heads.

Kentucky Bluegrass (*Poa pratensis*)

Another fine-leafed adventive grass, this rhizomatous species occurs abundantly in the dry to moderately moist high country, where it forms swards and is adapted to close grazing. Kentucky bluegrass has some spring production, which browns off very rapidly in summer, and is often rust infected. It has no advantage over other grasses under moderate or high fertility conditions.

While an important forage grass in other parts of the world, it has shown no potential in any New Zealand trials and is generally regarded as a weed due to its competitive effect on more productive species.

Pubescent Wheat Grass (*Elytrigia intermedia*)

An introduced grass under trial for the dry, moderately fertile areas where its sod-forming growth habit make it suited for disturbed and eroded soils. It would need to be drilled and given time to establish. Yields are moderate. The cultivars tested are Mandan, Luna and Greenleaf. These along with other related North American wheat grasses tested have the common features of good vegetative spread but low forage production relative to cocksfoot and tall fescue.

Adventive Annual Grasses

A number of introduced annual grasses have spread through the moderate to low rainfall regions of the high country. These include cheat grass (*Bromus tectorum*), goose grass or soft brome (*B. mollis*), hair grass (*Vulpia myuros*), rats tail fescue (*V. bromoides*), silvery hair grass (*Aira caryophyllea*), and barley grass (*Hordeum* spp.).

All would be regarded as weeds in moderate or high fertility pastures, but probably make a contribution in the low fertility dry areas where they commonly occur. The young foliage of late winter and early spring is acceptable to stock, but all become highly unacceptable with the advent of flowering from mid spring on. Cheat grass has the greatest growth and is widespread in the high country. It is regarded as a weed here as in other range pastures of the world and indications are that it is increasing in New Zealand. Cheat grass and barley grass respond to increased soil fertility, with barley grass often being a good indicator of high fertility soils.

All these species are undesirable contaminants in pasture seed.

There are very few native annual grasses. The success of the adventive annual grasses, and the annual legumes like haresfoot clover and suckling clover, in the lower rainfall areas of low to moderate fertility high country suggests that other, more productive annual species should be investigated for moderate to high soil fertility sites during development.

Ryecorn (*Secale cereale*)

This is an annual cereal used both as a cereal crop and in the high country as a special purpose winter greenfeed crop. As such, it is better suited to the moderate fertility conditions likely in the high country than the other greenfeed cereals, with their higher fertility requirements. Ryecorn, like some of the oat and barley varieties, can be fed off in early or mid winter after autumn establishment and growth; it holds or makes some further growth in milder winter conditions; and gives good growth for feeding off in late winter and spring.

Grain cultivars are available and used, but there are local selections which, from long use, have a more prostrate leafy habit.

Mountain Rye (*Secale montanum*)

Black Mountain mountain rye is a new species under evaluation and is best described as a perennial ryecorn. Like ryecorn, it has good autumn and early spring growth and is best used under occasional mob stocking.

Danthonias (*Rytidosperma spp.*)

These are a group of several native and introduced species which have shown good adaptation to low to moderate soil fertility, and close grazing. They occur widely in the drier regions of hill and high country. The country on which they occur is difficult to develop, because of the poor environment for legumes and other oversown species. At least some of the danthonias have a strong chemical inhibitory effect on sown legumes. They do show some response to increased fertility.

Phalaris (*Phalaris aquatica*)

A perennial grass, which has good autumn/winter growth where milder temperatures permit, and a reputation overseas for very good drought tolerance. Many old high country trials showed that phalaris should have a role in the drier high country because of this drought tolerance and persistence. Phalaris requires moderate to high soil fertility, performs well in irrigated and dryland conditions and is superior to cocksfoot in spring production. Summer growth is low. Its potential role should be in the semi-improved low rainfall zone but there are few recent trial results and some of these have been disappointing.

Like lucerne it is sensitive to soil aluminium. This could explain why it has not done as well in the high country as might be expected. In other areas it combines well with lucerne, and as a component of other mixtures, to give both grass grub resistance and winter growth where temperatures are favourable.

In recent times a new cultivar, Grasslands Maru, has been tested and found to be superior to other lines in developed cultivated pastures.

Herbs

Sheeps Burnet (*Sanguisorba minor*)

Sheeps burnet is a herb introduced into early high country trials in the Mackenzie Country. It has been notable for its persistence (along with zigzag clover), and early spring growth in the lower rainfall areas. It is a large seeded species with slow initial establishment. It has a deep taproot. While spring and autumn growth is good, it has only limited summer production. Sheeps burnets probable role is for early spring feed under moderate soil fertility, or as standing summer feed. Lucerne is more productive if high fertility conditions exist. Sheeps burnet is moderately palatable at all stages. While it grows in the same conditions as hieracium, there is no evidence that it has particular competitive abilities against hieracium. It does not grow successfully in the mid to high rainfall zone of more leached soils.

Seed from some of the more productive lines of Spanish origin is commercially available.

Sheeps Sorrel (*Rumex acetosella*)

One of the most widespread adventive species, sheeps sorrel is now found from the highest, wettest areas to the lowest, driest areas. It is eaten by stock if little else is available, so is often a common part of their diet, though not by choice. There is a general belief that it indicates acid soils, which may well be true, but measurements show that it makes soils more alkaline.

Sheeps sorrel would not be sown and its seed should be regarded as an unacceptable contaminant in other pasture seed.

Broadleaf Species

A number of dandelion-like plants have come into New Zealand and spread throughout the high country. They are generally acceptable and preferred by stock under low to moderate fertility conditions and are notable for their high mineral content. The variety and success of such adventive species, including the hieraciums, suggests that the high country environments suit this type of plant. Catsear (*Hypochoeris radicata*) is the most widespread of these next to the hieraciums, but they also include hawksbeard (*Crepis capillaris*), hawkbit (*Leontodon taraxocoides*) and dandelion (*Taraxacum officinale*).

While none of these species would be deliberately sown, their occurrence (other than hieracium) as contaminants of other pasture seed should be of no concern.

Hieracium or Hawkweeds

Ten hawkweed species have been inadvertently introduced into New Zealand and some have reached epidemic weed proportions in the high country. The worst of these is mouse-ear hawkweed (*Hieracium pilosella*) followed by king devil (*H. praealtum*), tussock hawkweed (*H. lepidulum*) and field hawkweed (*H. caespitosum*).

Mouse-ear hawkweed is a major weed which has spread extensively in recent decades, reducing pasture production in the moderate to low rainfall zone. It establishes on moderately fertile undisturbed topsoil, in over-grazed short tussock grasslands. The species is regarded as a weed, not because of its unacceptability or low feed quality but because its low stature makes it low producing, and its competitive exclusion of other species limits the total feed available.

King devil is a coloniser of disturbed, low to moderately fertile soils in open situations, where it can increase under nil or low grazing pressure, either as open mats, or in combination with other species. It is moderately productive and is more accessible to stock than is mouse-ear. It is acceptable to sheep so it is doubtful whether it has a weed status under sufficient grazing pressure.

Tussock hawkweed and other single stemmed hieracium species occur in scrub and rubbly grassland soils in Otago and along boundaries of grasslands, shrublands and forests.

All hawkweeds should be regarded as undesirable contaminants of any pasture seed used in the high country because of their competitive growth habit.

Yarrow (*Achillea millifolium*)

Yarrow is an adventive herb occurring spasmodically throughout the high country. While it is regarded as a weed in lower altitude cropping land, its palatability, moderate growth, and vegetative spread make it a suitable grazing plant in the high country. It is more prevalent in moderate soil fertility conditions and little is known about its management requirements as a grazing species or the most suitable conditions for its use. Small quantities of yarrow are used in revegetation. It survives well under dry conditions. Rabbits have a preference for yarrow.

This species is being reassessed as a desirable grazing species in other areas of New Zealand. Its presence in other seed lines would be an advantage. Selections of it are being developed.

Chicory (*Cichorium intybus*)

Chicory, a herb now used in lowland pastures, may have a place as a special purpose spring feed on high fertility soils in the high country. On moderate or low fertility soils its production and persistence is unknown at this stage.

Grasslands Puna is the only available cultivar.

Plantain (*Plantago lanceolata*)

Like chicory, this is a herb which is starting to be reassessed for use in the lowlands. Its potential in the high country is under consideration.

Forage Shrubs

A number of trials have looked at the possibility of introduced shrub species as potential forage plants for the high country. In general, very few species have shown any great potential. The difficulty appears to be the lack of high growing season temperatures and the frequency of growing season frosts in New Zealand, which preclude most of the forage shrubs from overseas continental areas being suitable here.

The few species which have shown limited potential are tagasaste or tree lucerne, (*Chamaecytisus palmensis*); tree saltbush, (*Atriplex halimus*, *A. nummularia*); mountain mahogany, (*Cercocarpus montanus*); bluebush, (*Kochia prostrata*); and tree medic, (*Medicago arborea*).

Tagasaste can be established from either seed or transplants and has its major growth in summer.

Two slow establishing, small shrub canary clovers, (*Dorycnium hirsutum*, *D. pentaphyllum*), are showing promise for medium fertility, low rainfall country of near neutral soil pH. These clovers will nodulate with *Lotus corniculatus* inoculum. Shrubs can be established from seed.

A number of shrubs which are regarded as weeds in other parts of New Zealand, and in any sheep farming area, are worthy of a second thought as forage shrubs in the high country if diversification into goats is seriously considered. It has already been demonstrated in the high country that briar, *Rosa rubiginosa*, is a preferred species, and can be controlled, by goats. Similarly, gorse, *Ulex europeus*, is not a vigorous shrub in the high country and it has been demonstrated that goats prefer, and can control, gorse in the hill country zone where it is much more vigorous. However, neither briar nor gorse are likely to be acceptable species to sow, either by farmers or conservationists. Tree lupin, *Lupinus arboreus*, does occur in the high country, is a legume, and wilted foliage is eaten.

Summary

Good planning well in advance of the need is the key to successful pasture systems. Each system must be individualised in accordance with the particular farm enterprise.

Species and cultivars must be selected according to their likely management use (and abuse), as well as their soil and climate suitability. High country properties are commonly run as large, set stocked paddocks. This should be regarded as an accident of history rather than a desirable situation.

The need for improved grazing management through subdivision in the marginal environments of the high country is as great as, or greater than, it is elsewhere in New Zealand. When pastures are used during the growing season, grazing management must take into consideration the differences in species tolerances to grazing intensity and duration, and regrowth interval. The most marked distinction is between species that are tolerant of close grazing/set stocking, and those requiring long regrowth periods after grazing.

The farmers in the high country, like those elsewhere, have to reach a compromise between five general requirements:

- The feeding requirements of the particular type of animal they choose to farm
- The range of land classes within their particular farm boundary
- Selection of suitable fertiliser strategies
- The suitability of the different pasture species for those different land classes
- The demonstration of the sustainability of the options by persistence through time.

Temperature and moisture are characteristic of each site and cannot be changed, except for the special cases of irrigation and drainage. Thus, major changes in farm productivity depend on improvements in soil fertility and pasture management to enhance the growth, utilisation and persistence of resident and introduced pasture species, and a better appreciation of the optimum roles of different landscape units.

The future of high country farming lies increasingly with strategies of selective development and pasture utilisation, based on different combinations of introduced species and cultivars as well as resident species. The off-take from agricultural products of wool and stock, must be balanced by inputs, particularly fertiliser, to balance the vegetation and nutrient pools. Such strategies will be strongly influenced by the different combinations of slope, aspect and altitude (and therefore climate), soil type and fertility, and vegetation type, cover and location in relation to the desired stock management policy. Selective development will mean more selective fertiliser application both in quantity and type, the range again reflecting the diversity of soils and landscape units, and the role that is decided on for each to meet seasonal feed requirements in the most cost effective way.

We hope this guide will help high country runholders and farmers of other temperate mountain lands to achieve these objectives.

ANEXOS GIRA CONSULTORES
FOTOCOPIAS PAPER "SUSTAINABILITY OF NEW ZEALAND HIGH COUNTRY PASTURES UNDER CONTRASTING DEVELOPMENT INPUTS.7 ENVIRONMENTAL GRADIENTS, PLANTS SELECTION AND DIVERSITY"

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Sustainability of New Zealand high-country pastures under contrasting development inputs. 7. Environmental gradients, plant species selection, and diversity

D. SCOTT
AgResearch
P.O. Box 60
Lincoln, New Zealand

Abstract The change in plant species relative abundance under different fertiliser and management inputs over 19 years is reported for two grazed multiple-species trials on a Pukaki/Tekapo high-country soil. One trial was 30 combinations of 5 superphosphate rates (0–500 kg ha^{-1} yr^{-1}) × 3 stocking rates × 2 stocking methods, and the second was 31 combinations of S, P (0–100 kg ha^{-1} yr^{-1}), and micronutrient fertilisers. Both were overdrilled with a 25-species pasture mixture. There was rapid initial separation in relative abundance of species, principally according to fertiliser level. Main features were *Hieracium pilosella* remaining dominant in the absence of fertiliser; the initial success of *Trifolium hybridum*; the dominance and long-term persistence of *Lupinus polyphyllus* at low fertiliser inputs; the transition to *Dactylis glomerata* dominance at high fertiliser inputs following a legume phase, in the middle years; the slow vegetative increase of *Trifolium ambiguum* to become dominant in most of the moderate and high fertiliser treatments in the second decade; and the increase of *Bromus tectorum* in later years. Species distributions were predominately determined by P fertiliser rates, or P by S fertiliser interactions. The effects of different grazing managements on late spring pasture composition were small during the first decade but increased over time, with the principal changes under moderate to high rate set-stocking. Diversity considerations showed that the number of vascular plants in a plot (n), or their proportional distribution in biomass (k diversity), gave only a weak and inconsistent correlation with secondary production (mean sheep carrying capacity), or its stability (CV of annual grazing capacity), after fertiliser and grazing management treatment effects were considered. The only significant trend was in one trial where production tended to be inversely related to the number of plant species (2.2% decrease per species).

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Keywords New Zealand; high-country; species selection; sustainability; biodiversity; *Lupinus polyphyllus*; *Trifolium ambiguum*; *T. hybridum*; *T. repens*; *T. pratense*; *Hieracium pilosella*; *Festuca rubra*; *Dactylis glomerata*; *Bromus tectorum*

INTRODUCTION

Environmental gradients and species niches

The high-country rangelands of the mountains and basins of the eastern side of the Southern Alps occupy about a tenth of the land area of New Zealand and, depending on fine wool prices, produce 3–8% of New Zealand's farm income (Anon. 1996). They cover a wide range of topographic and climatic environments that are marginal for pastoral agriculture. Because their original vegetation was mainly indigenous grassland, they can be farmed under both their natural low fertility conditions and by development through over-sowing and top-dressing through to high fertility conditions.

In establishing an overview of earlier trial work and farmer experience on the role of different pasture species in the high country and elsewhere, a concept of environmental gradients and species niches was developed (Scott 1979a, 1979b; Scott & Groves 1982; Scott et al. 1995). This concept defines a site by its position on four environmental gradients: available moisture, as determined by rainfall, drainage, and evaporation; temperature, as determined by latitude, altitude, aspect, and slope; soil fertility, either natural or applied; and the interaction of animals with plant growing points, as determined by grazing and treading. Potential pasture production was considered to be determined by these four environmental factors.

The second part of the concept was that while all pasture species may have a similar general response to each of these environmental factors, for each particular combination of environmental factors only one or two species have the combination of characters enabling them to out-perform all other species in establishment, productivity, and persistence. Thus, they would be the preferred species for the site and also the species that defined the potential for that particular combination of environmental conditions. An attempt was made to make a provisional assessment of the optimum niche for a wide range of pasture species (Scott et al. 1995).

Although the concept was developed from an overview of many few-species trials, it should also be experimentally verifiable in observing the response of multiple-species seeding mixtures in different environments or treatment combinations. Therefore, the two trials described in this series of papers were established. This paper describes the relative success of a 25-species seeding mixture overdrilled into a hieracium-infested fescue tussock grassland site, onto which 61 different fertiliser and grazing management environments were imposed. The relative success of different species under the different environmental combinations has been followed for 19 years to date. Besides the evaluation of the concept, the trials had the practical objective of determining which species thrive best and persist under particular levels of fertiliser and grazing management on one class of high-country sites.

The historical context of the site and the general description of the trial have been given by Scott (1999). Subsequent papers have described the effect of fertiliser treatments on the soil inorganic (Scott 2000a) and organic components (Scott 2000b), sheep carrying capacities (Scott 2000c), nutrient balances (Scott 2000d), and fertiliser efficiency (Scott 2000e).

Plant species diversity

Biodiversity has become one of the concerns of the recent decade, prompted by the belief that in some manner the resilience, sustainability, and productivity of a biological or agricultural system is proportional to the number of different species it contains. There has been a further suggestion that productivity may be more related to dominance by a few species, with stability more related to diversity of species (McNaughton 1968), although others have observed the reverse (e.g., Singh & Misra 1969). From those perspectives, the monoculture or few-species pasture-mixtures of developed agriculture are regarded as suspect. The United Nations has recently sponsored a state-of-the-art review of biodiversity and its tenets (UNEP 1995). However, a close reading of that document and references cited therein indicates that these beliefs in the relationship between biodiversity and resilience, productivity, or sustainability are not well founded on empirical or theoretical studies.

For pastoral agriculture there is particular interest in how plant diversity may interact with secondary animal production. A recent review on the interactions between plant diversity and herbivores indicated that the question has shifted from "do herbivores have an effect?", to "why do the effects differ in different situations?" (Olff & Ritchie 1998). Herbivores affect plant diversity through their influences on plant species colonisation and extinction, and this depends on the size and type of herbivores, types of habitat, and spatial and temporal scales considered. As a provisional generalisation, Olff & Ritchie (1998) concluded that large herbivores, such as sheep, would decrease diversity in dry fertile environments and increase diversity in wet infertile environments, principally through the effect of the herbivores on the taller dominant plant species. However, the effect in dry infertile environments may range from neutral to decreasing diversity, while in a wet, fertile environment effects can range across the whole spectrum from increasing to decreasing diversity.

The multi-species nature of the vegetation of the two trials involved in this series of papers under contrasting management regimes gave an opportunity to investigate empirically the diversity relationships. In particular, the second part of the present paper considers the possible correlation between pasture plant diversity parameters and production and/or stability of secondary production (sheep) in an agricultural context, using annual measurements of vegetation and sheep grazing capacity (Scott 2000c).

Two measures of plant diversity were available. The first was the number of different plant species in each plot after they had had 12 years to adjust from an initial common species pool. The second was the distribution of biomass between the plant species in each plot, as estimated from the gradient coefficient (k) giving the proportional reduction in abundance between successively ranked species in the log/linear relationship between species abundance and the rank of a species within the vegetation, as

$$P = (1-k)\,k^{R-1} \qquad (1)$$

where P = proportional contribution of the Rth ranked species (Preston 1948). The k coefficient can range from c. 0.2 in vegetation very dominated by one species, to c. 0.8 to vegetation in which biomass is relatively more evenly distributed between species. Grasslands characteristically have values of about 0.32 (Hargreaves & Kerr 1978; Scott 1986).

MATERIALS AND METHODS

Design

Two adjacent trials at the AgResearch Mt John trial site, Lake Tekapo, were established by partial over-drilling of hieracium (*Hieracium pilosella*)-infested fescue tussock (*Festuca novae-zelandiae*) grassland in 1982 (Scott 1999).

The first trial was a response surface design of 27 combinations of S fertiliser (as elemental sulphur) and P fertiliser (as triple superphosphate of 20% P) of nominally 0, 5, 10, 20, 50, or 100 kg element ha^{-1} yr^{-1} (hereafter referred to as the PxS trial). Four of the combinations were repeated with the addition of potassium and micronutrients (40 kg K ha^{-1} yr^{-1} as potassium chloride, and 4 kg ha^{-1} yr^{-1} "BASF Fertilon" containing the micronutrients Mo, B, Co, Zn, Co, and Fe). Each fenced treatment combination was 12.5 m × 12.5 m. The fertiliser rates were doubled in the initial sowing year with half the sulphur applied as gypsum.

In the second trial the main treatment blocks were two spatial replications of 5 fertiliser/growth regimes of nominally 0, 50, 100, 250, or 500 kg superphosphate ha^{-1} yr^{-1} (hereafter referred to as the Graze/fert trial). The superphosphate was sulphur-fortified to 20–50% S at the 50 and 100 kg ha^{-1} yr^{-1} superphosphate rate. The fertiliser rates were doubled in the first year. The 500 kg ha^{-1} yr^{-1} treatment also received fortnightly spray irrigation from late spring to autumn. Within those main treatment blocks were further grazing treatments of 3 stocking rates (low, moderate, or high in ratio of 1:2:4 sheep grazing days in Years 2–4, and 2:3:4 in subsequent years), by 2 stocking methods (high sheep numbers for 5–7 days, i.e., mob-stocking; or few sheep for longer periods, i.e., sustained or set-stocking). Each fenced treatment combination was 8 m × 50 m.

The fertiliser was applied annually in early spring. Annual variations in the proximate analysis of P and S contents of the superphosphate were taken into account. The actual mean fertiliser rates for the PxS trial were given in Scott (1999, fig. 4). For the Graze/fert trial they were 0 + 0, 4.1 + 17.6, 8.9 + 26.0, 22.7 + 54.5, and 46.8 kg ha^{-1} yr^{-1} P and 114.8 kg ha^{-1} yr^{-1} S for the zero, low, moderate, high, and high + irrigation treatments, respectively.

Both trials were sown with a common complex mixture of 25 different legumes and grasses, using a rotary hoe drill which cultivated and sowed into about a third of the area over which it passed (Scott & Covacevich 1987; Scott 1999). The plots were given nearly two growing seasons to establish.

After two years, plots were grazed by sheep from November to May as required (Scott 2000c). For the PxS trial this involved mob-stocking on two or three common occasions each year for 4–8 days each. For the Graze/fert trial the number of grazings varied with fertiliser treatment. The plots were grazed in groups of three for each of the different fertiliser, stocking-method, and replication combinations. The plots were grazed as judged from the moderate stocking-rate plot, with the other two plots receiving their differential stocking-rate for the same period. For the moderate stocking-rate treatments (and all the PxS trial) this was when feed on offer was 1–2 t DM ha^{-1} and ceased when plots were grazed to a residual 1–2-cm height.

Pasture composition

In both trials vegetation was monitored each November from the second year, after a common ungrazed regrowth period from mid winter. Relative species contribution and pasture composition was determined by the ranking technique (Scott 1989) in which species in each plot were visually ranked in order of their contribution to herbage bulk within that plot. For the ranked species, there was simultaneous visual estimate of the ratio of the relative contribution of two of the species (usually the 1st and 5th ranked species) from which the proportional contribution of each of the species and the diversity coefficient (k) were determined (Scott 1989, 1993a). In the 12th year all species present in each plot of the Graze/fert trial were recorded. Three observers made the annual assessments concurrently but separately during the first decade; the same single observer made annual assessments on three successive days subsequently. The diversity coefficient and the number of plant species were the two measures of diversity used. It was considered that the plot size within the PxS trial was not large enough to give a fair estimate of the total number of species.

Interpretation of species measurements

For the purposes of analysis the 1st ranked species in each plot was given the value of 1, the 2nd ranked a value of 2, etc., to the 10th ranked a value of 10, and lower ranked or absent species a value of 11. These values were treated as continuous quantitative variables, and were meaned and analysed for the different treatment comparisons, even though such rank data were amenable to direct analysis by ordinal regression techniques (SAS 1989; Scott 1989).

The semi-quantitative treatment of the ranked data is partly justified by the frequently observed near-linear relationship between logarithm of species abundance and species rank within vegetation (Preston 1948; Whittaker 1972; May 1979). A visual estimate of the ratio of herbage bulk of the 5th to 1st ranked species in each plot was made to estimate a biodiversity index (k) and the consequent percentage contribution of each species to herbage bulk. The mean value of k was 0.45. From this, the mean contribution of the 1st to 10th ranked species were 54.8%, 24.8%, 11.2%, 5.1%, 2.3%, 1.0%, 0.5%, 0.2%, 0.1%, and 0.04%, respectively. These percentages are used as a secondary axis on the graphs presented. For the three top-ranked species these percentages would give weighting coefficients of 0.60, 0.27, and 0.12, respectively, in the Australian dry-weight-rank technique compared with the values of 0.71, 0.21, and 0.09, respectively, advocated ('t Mannetje 1963; Scott 1986).

It is emphasised that the species ranking technique gives a relative contribution, not an absolute contribution, of species within each plot. Similarly, in comparing or combining measurements between treatments, these ordinal ranking data give changes in relative contribution of species.

Data analysis and presentation

The relationship between variables was determined by covariance ANOVA and multiple regression analysis. The results have been presented in graphical and tabular form. The individual species rank data (Fig. 2–15) are as 3D plots using a bivariate spline fitting (SAS 1990, proc g3d). The left-hand vertical axis is the mean rank of the species from being the 1st ranked (most abundant) to being the 10th or unranked. The right-hand vertical axis gives the same results in terms of the percentage contribution of the species to the total herbage bulk of the treatment.

For the PxS trial the right-hand base scale is for S fertiliser rates of 0–196 kg S ha^{-1} yr^{-1} (= 0–14 on square root scale), and the left-hand base scale for P fertiliser rate of 0–121 kg P ha^{-1} yr^{-1} (0–11 on square root scale). A square root transformation of the fertiliser levels was used because of the approximately geometric increase in rates applied at successive levels.

For the Graze/fert trial the left-hand base scale is for the fertiliser rate expressed in terms of the P component of 0–64 kg P ha^{-1} yr^{-1} (0–8 on square root scale), with irrigation at the highest fertiliser rate. There was very little difference between alternative descriptors of the fertility gradient using either average fertiliser P or S application rates, or whether expressed as a linear response or square root of the rate (range of $r = 0.52$–0.53). The right-hand base scale is a gradient expressing the relationship between the six grazing treatments and is common for all species. This was determined from the first component of a principal component analysis (SAS 1989, proc factor) of the rank data for a group of the principal species to show best dispersion of the data, after adjustment for their fertiliser response. The axis for grazing treatment combinations are coded as L = low stocking-rate, M = moderate stocking-rate, H = high stocking-rate, s = set-stocked, and m = mob-stocked. The shading of the response surface on the graphs is confined to the proximity of the sample points.

Fitting the fertiliser to species ranking relationship was done independently for each 3-year time period, so that the consistency of pattern and trends between diagrams is partly a measure of the reliability of those trends. The standard viewing angle used for all figures tends to mask patterns of species with maximum abundance at low fertiliser rates.

RESULTS

Principal species and time trend

Of the 81 vascular plant species within the two trial areas, only some reached appreciable mean ranking, indicating either a moderate relative abundance in many treatment combinations or high abundance in a proportion of the plots (Table 1). The highest mean relative abundance was recorded for the

Table 1 Mean and highest rank abundance of principal species in the two trials in annual spring measurements over Years 2–19. Species ranked according to contribution to herbage bulk in each plot with most abundant 1st ranked species = 1, 2nd ranked = 2, to 10th ranked = 10; not ranked or absent = 11.

Species	PxS trial Mean	PxS trial Max.	Graze/fert trial Mean	Graze/fert trial Max.
Sown legumes				
Lupinus polyphyllus	4.1	1	3.9	1
Trifolium ambiguum	5.6	1	5.3	1
T. hybridum	7.9	1	7.9	1
T. repens	9.0	1	8.5	1
T. pratense	8.3	2	8.1	2
Lotus corniculatus	9.8	3	9.5	3
L. pedunculatus	10+	7	10+	5
Trifolium medium	10+	4	10+	4
Sown grasses				
Festuca rubra	5.8	1	5.5	1
Dactylis glomerata	7.1	1	7.7	1
Arrhenatherum elatius	8.3	1	7.7	1
Holcus lanatus	9.3	2	10+	2
Phleum pratense	9.8	2	9.6	1
Schedonorus phoenix	10+	3	10+	2
Lolium perenne	10+	4	10+	4
Adventive				
Hieracium pilosella	5.1	1	5.6	1
Agrostis capillaris	6.6	1	9.6	2
Bromus tectorum	8.3	1	8.5	1
Anthoxanthum odoratum	9.0	3	10+	3
Poa pratensis	9.1	2	9.6	3
Rumex acetosella	10+	3	10+	4
Hieracium praealtum	10+	4	10+	4
H. caespitosum	10+	6	10+	7
Myosotis stricta	10+	6	10+	7
Indigenous				
Festuca novae-zelandiae	8.5	1	8.8	1
Pyrranthera exigua	10+	5	10+	2
Coprosma petriei	10+	8	10+	3
Carex breviculmus	10+	8	10+	3
Pimelia oreophila	10+	6	10+	5

Other species with low ranking on occasions. Sown legumes: *Coronilla varia*; Sown grasses and herbs: *Bromus willdenowii*, *Cynosurus cristatus*, *Phalaris aquatica*, *Sanguisorba minor*; Adventive: *Achillea millefolium*, *Aira caryophyllea*, *Aphanes arvensis*, *Bromus diandrus*, *B. mollis*, *Cerastium fontanum*, *Crepis capillaris*, *Hypochoeris radicata*, *Taraxacum officinale*, *Trifolium arvense*, *T. dubium*; Indigenous: *Acaena caesiiglauca*, *Carmichaelia monroi*, *Cyathodes fraseri*, *Geranium sessiliflorum*, *Poa colensoi*, *Raoulia parkii*, *R. subsericea*, *Senecio haastii*, *Wahlenbergia albomarginata*.

resident adventive *Hieracium pilosella* and the sown legume *Lupinus polyphyllus*. Other species that recorded moderate mean ranking or abundance were four sown *Trifolium* species (*T. ambiguum*, *T. hybridum*, *T. pratense*, *T. repens*); three sown grasses *Dactylis glomerata*, *Festuca rubra*, and *Arrhenatherum elatius*; the adventive grass *Agrostis capillaris*; and the indigenous tussock *Festuca novae-zelandiae*. These were the principal species considered in subsequent analyses. The low mean abundance of most species in the combined data over all treatments and years is a consequence of species being abundant in only a few of the treatment combinations and minor or absent in many, so that their overall mean abundance was low.

The main trend of changes in species abundance over the trial period is illustrated in the mean data for both trials (Fig. 1). Some species established well and then decreased, others were slow to establish but increased in abundance over time, with most showing fluctuations in patterns. *Trifolium hybridum*, *T. pratense*, *L. corniculatus*, and, to a lesser extent, *Holcus lanatus* decreased with time. The main increasing species were *T. ambiguum*, *Arrhenatherum elatius*, *Bromus tectorum*, and *Agrostis capillaris*. There was a marked change in abundance of some species between the 1987 and 1988 measurements, which probably relates to drought.

The success and changes in abundance of species were related to the imposed treatments. Although both trials were in a common area, sown with a common mixture of species, and run over the same period under similar stock management, the most prominent result in both trials was the rapid grouping of species according to the imposed fertiliser and grazing management treatments. The differences between these groups continued to develop over time.

The main trend related to the different rates of S and P fertiliser input, the resulting variation in legume dominance during the soil nitrogen-building phase, and the subsequent increase of some of the sown pasture grasses. The effect of different grazing treatments was not large during the first decade, as measured by the late spring composition after a common regrowth period from midwinter. The cumulative effects of different grazing treatments became more conspicuous in the second decade.

Sown species were generally not successful in the zero fertiliser treatments that remained dominated by adventive *Hieracium pilosella* and

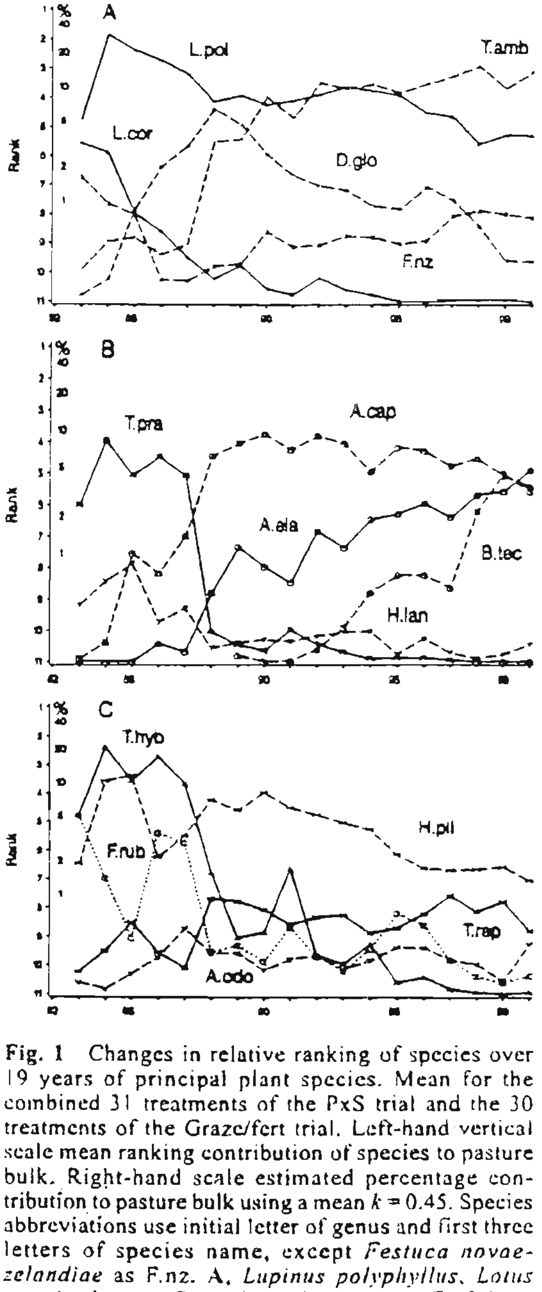

Fig. 1 Changes in relative ranking of species over 19 years of principal plant species. Mean for the combined 31 treatments of the PxS trial and the 30 treatments of the Graze/fert trial. Left-hand vertical scale mean ranking contribution of species to pasture bulk. Right-hand scale estimated percentage contribution to pasture bulk using a mean $k = 0.45$. Species abbreviations use initial letter of genus and first three letters of species name, except *Festuca novae-zelandiae* as F.nz. **A**, *Lupinus polyphyllus*, *Lotus corniculatus*, *Dactylis glomerata*, *Trifolium ambiguum*, *Festuca novae-zelandiae*; **B**, *Trifolium pratense*, *Arrhenatherum elatius*, *Agrostis capillaris*, *Holcus lanatus*, *Bromus tectorum*; **C**, *Trifolium hybridum*, *Hieracium pilosella*, *Festuca rubra*, *Trifolium repens*, *Anthoxanthum odoratum*.

indigenous tussock *Festuca novae-zelandiae*. The zero fertiliser treatments with low set-stocking most closely represent the resident vegetation prior to the trial establishment. The fertilised treatments were dominated by legumes for periods ranging from the first two years (high fertiliser plus irrigation) to the whole study period (some low fertiliser treatments).

In the PxS trial *T. hybridum* was the dominant species over all of the P fertiliser treatments in Years 2–4. *L. polyphyllus* was the 2nd ranked species at zero to moderate P fertiliser levels, and dominant at low P but high S fertiliser treatments, with *H. pilosella* either dominant or the 2nd ranked species at other fertiliser combinations. *T. pratense* was the 2nd ranked species in a few of the high P fertiliser treatments in the first period. In Years 5–7 most of the treatments previously dominated by *T. hybridum* became dominated by *D. glomerata*. There was some increase in the low P fertiliser combinations dominated by *L. polyphyllus*, with a 2nd ranking by *A. capillaris* in some elemental S fertiliser combinations and a 2nd ranking of residual *T. hybridum*. The dominance of the pastures by different species was the most varied in Years 8–10. *T. ambiguum* became dominant in some of the moderate to high P, low to moderate S fertiliser combinations, and *Festuca rubra* at high S fertiliser combinations. *T. ambiguum* increased in the higher P fertiliser combinations, so that by Years 14–16 it dominated the moderate to high P fertiliser treatments. The zero and low P fertiliser treatments were dominated by *L. polyphyllus*.

The ordering and spacing of the grazing treatments in the Graze/fert trial results was derived from the first principal component and showed a general trend of species separated for dominance associated with an increase from low to high stocking rates. Low stocking rates had greater effect on species abundance than the other stocking rates, though there was a general interaction between stocking rate and grazing method at the two higher stocking rates. The 2nd principal component in the same general analysis (not presented) separated set-stocking from mob-stocking in its effect on species abundances.

In the Graze/fert trial in Years 2–4, *L. polyphyllus* was dominant in the zero and moderate fertiliser treatments, *T. hybridum* in the high fertiliser dryland treatments and moderate fertiliser, hard-grazed, set-stocked treatments, and *T. repens* in the high fertiliser plus irrigation treatments. In subsequent periods *L. polyphyllus* remained the dominant species in the low and moderate fertiliser treatments with low stocking rates, but tended to decrease progressively under increasing stocking-rate, of set-stocked treatments. *T. hybridum* remained the dominant or 2nd ranked species at low or moderate fertiliser levels in Years 5–7, but ceased to be an important pasture component thereafter. *D. glomerata* replaced *T. repens* as dominant species in the high fertiliser plus irrigation treatment in the low stocking rate treatments in Years 5–7 and other mob-stocking rate treatments in Years 8–10. *T. ambiguum* did not feature as a dominant or 2nd ranked species in the first seven years but by Years 8–10 had reached dominance in some of the moderate fertiliser, moderate and high stocking-rate, set-stocked treatments, and subsequently increased to dominance in most of the low, moderate, and high fertiliser treatments. *Festuca rubra* increased to dominate in some of the high fertiliser treatments over time. The adventive grass *Bromus tectorum* increased during the second decade and dominated many of the treatments by the end of the experimental period.

The observation was that the differences between treatments in vegetation and species rankings were least in the late spring when measurements were taken, compared with later in the growing season. For example, in the first decade many of the grazing management treatments of the Graze/fert trial showed little difference in species abundance in late spring, but that was the only time when all treatments had a common regrowth period and were in unison for comparing species composition.

Species responses

Lupinus polyphyllus *(perennial lupin)*

This was the most successful of the sown legume species for both growth and persistence across a range of fertiliser and grazing treatments and over the 19 years duration of the trial to date. It was the dominant legume and pasture species across many of the low fertiliser treatments (Fig. 2). The high performance of this species under grazing was unexpected, as there had been no previous suggestion of its potential as an agricultural forage species and its inclusion in the trial had been somewhat fortuitous. It took two to three years for this potential to be expressed. Its long-term persistence at lower fertiliser levels before significant replacement by grasses is interpreted as being associated with a slower rate of soil nitrogen build-up under lupin and its large perennial root system.

In the PxS trial, lupin exhibited a uniform moderate to high abundance across all fertiliser combinations in Years 2–4, though more so at the zero and low P fertiliser rates. In Years 5–7 and 8–10, lupin became slightly more abundant at high S fertiliser combinations, and decreased at low S fertiliser rates. The pattern for Years 11–13 and 14–16 year showed lupin's continued high abundance under high S fertiliser rates but low to moderate abundance at lower S fertiliser rates and intermediate P fertiliser rates. In Years 17–19 it continued at high abundance under high S fertiliser conditions, but decreased in the nil or very low fertiliser conditions.

In the Graze/fert trial, in Years 2–4 lupin also showed uniform moderate to high abundance across the zero, low, moderate, and high dryland fertiliser treatments, but only a low abundance in the irrigated high fertiliser treatments. In Years 5–7 and 8–10, it remained the dominant species in the low and moderate fertiliser treatments, but decreased in the zero fertiliser treatments. It disappeared from the irrigated high fertiliser treatments. There was no discernible effect on lupin of the grazing management treatments during Years 5–10. In Years 11–13 and 14–16 it was reduced to moderate or low abundance in the moderate and high stocking-rate, set-stocked treatments, but not in the low stocking-rate treatments. In Years 17–19 it remained absent from the high fertiliser plus irrigation treatments and decreased slightly in general importance in other treatments as other species increased. The decrease was greatest in the low stocking rate treatments.

Hieracium pilosella *(syn.* Pilosella officinarum*)* *(hieracium or mouse-ear hawkweed)*

This adventive herb was abundant in the vegetation, along with *Festuca novae-zelandiae*, prior to sowing of the trial. It is considered a serious weed, limiting stock feed-intake, whose agronomic control was one of the justifications for the trial. The rotary-hoe drill removed it from a third of the area over which the drill passed. Hieracium was a high to moderately abundant species in the early years of both trials, and remained a moderate to low component of most treatments, particularly the low fertiliser treatments (Fig. 3).

In the PxS trial, hieracium retained a relatively uniform moderate to high abundance across the

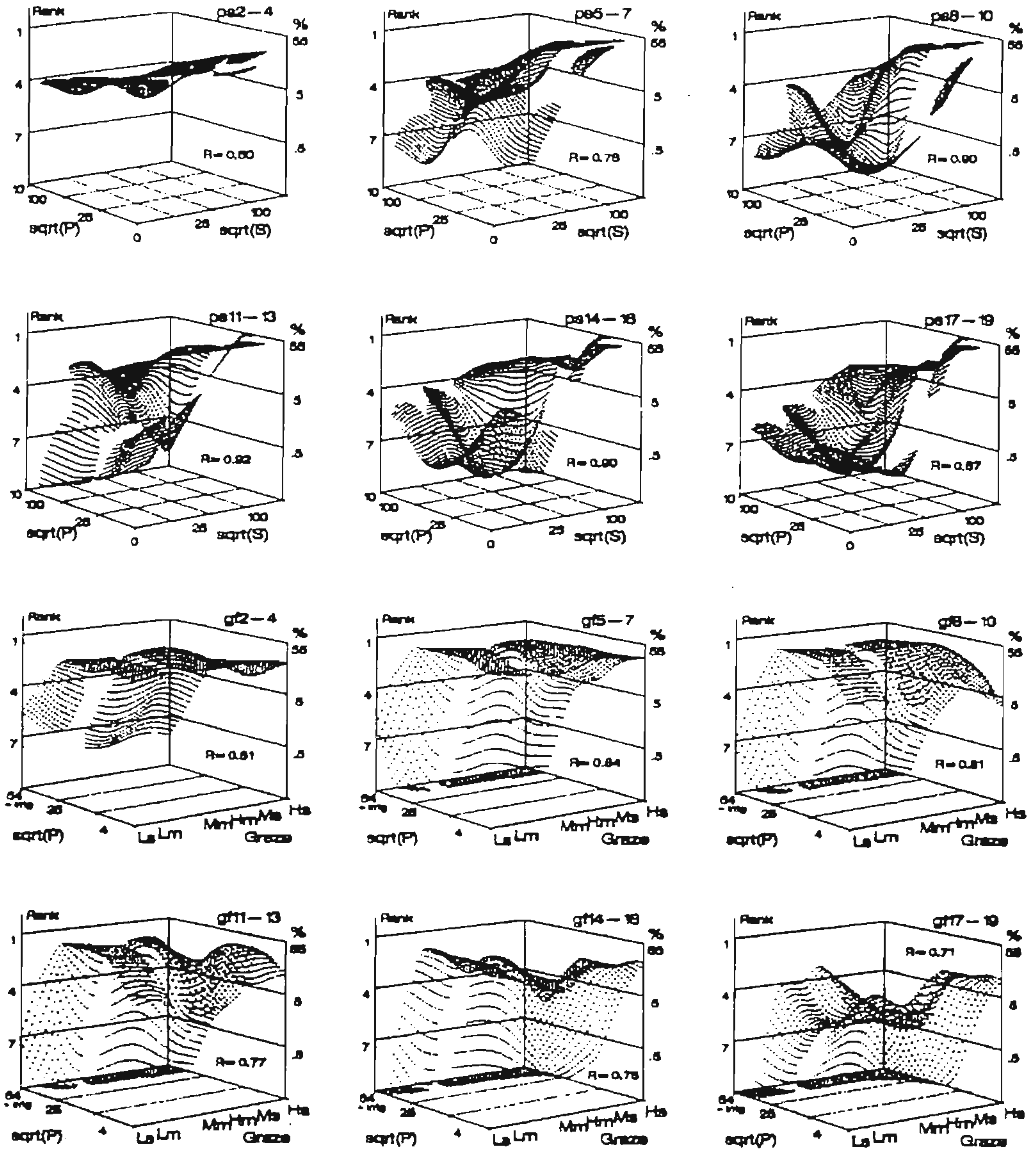

Fig. 2 Changes in rank contribution of *Lupinus polyphyllus* to pasture composition in six time periods, in relation to S and P fertiliser rates in the PxS trial (ps in upper set of figures), and in relation to fertiliser rate and grazing management in the Graze/fert trial (gf in lower set of figures). Time periods: Years 2–4, 5–7, 8–10, 11–13, 14–16, and 17–19.

range of fertiliser combinations in Years 2–4, with greatest abundance in the high S, low P fertiliser combinations. It showed a decrease relative to other species in Years 5–7, particularly at intermediate P fertiliser levels. In Years 8–13, it decreased to a rare or minor species at high S and P fertiliser combinations but remained relatively uniform at minor to moderate abundance at other fertiliser combinations. There was no clear pattern between abundance and fertiliser combinations in Years 14–16 and 17–19. Over the experimental period, the pattern of hieracium abundance was more closely related to P fertiliser rates than S fertiliser rates.

In the Graze/fert trial, hieracium retained relatively uniform low to moderate abundance across all treatment combinations in Years 2–4. It

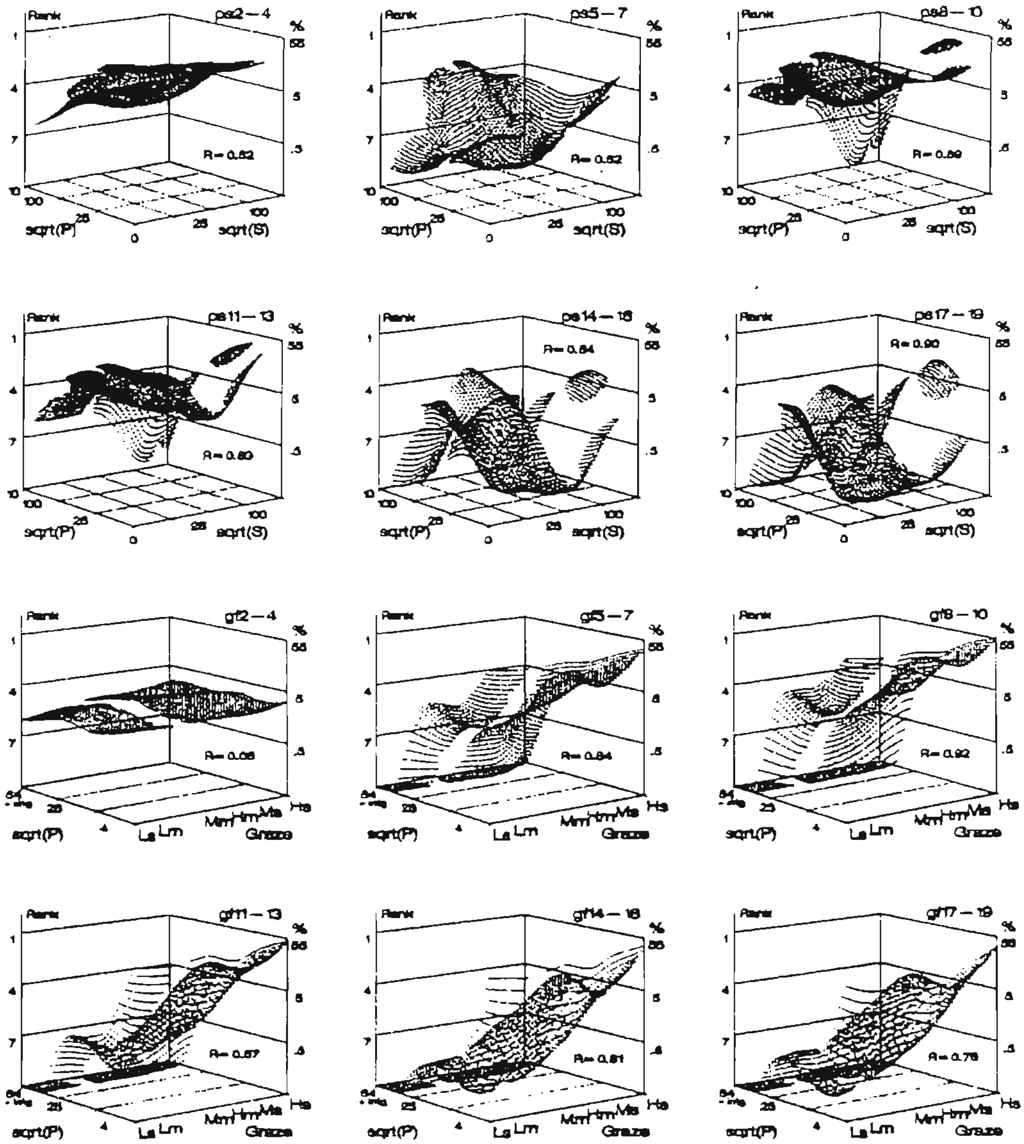

Fig. 3 Changes in rank contribution of *Hieracium pilosella* to pasture composition, Years 2–19. Layout as for Fig. 2.

then rapidly disappeared from the irrigated high fertiliser treatments, decreased to a minor species in the high fertility dryland treatments, and increased in relative abundance to become the dominant species in the zero fertiliser treatments. That general pattern has remained for the 19 years to date. By the last period (Years 17–19) it was noticeable that hieracium had spread into and become most abundant in the strips initially cultivated by the drill, and was sparser, with development of bare-soil areas, in the original uncultivated two thirds. The effect of grazing management treatments on hieracium abundance was minimal. It was slightly more abundant under low stocking rates in Years 5–10, but changed to lower abundance in subsequent years (Years 11–13, 14–16, and 17–19), possibly caused by the build-up of litter of other species. Hieracium was

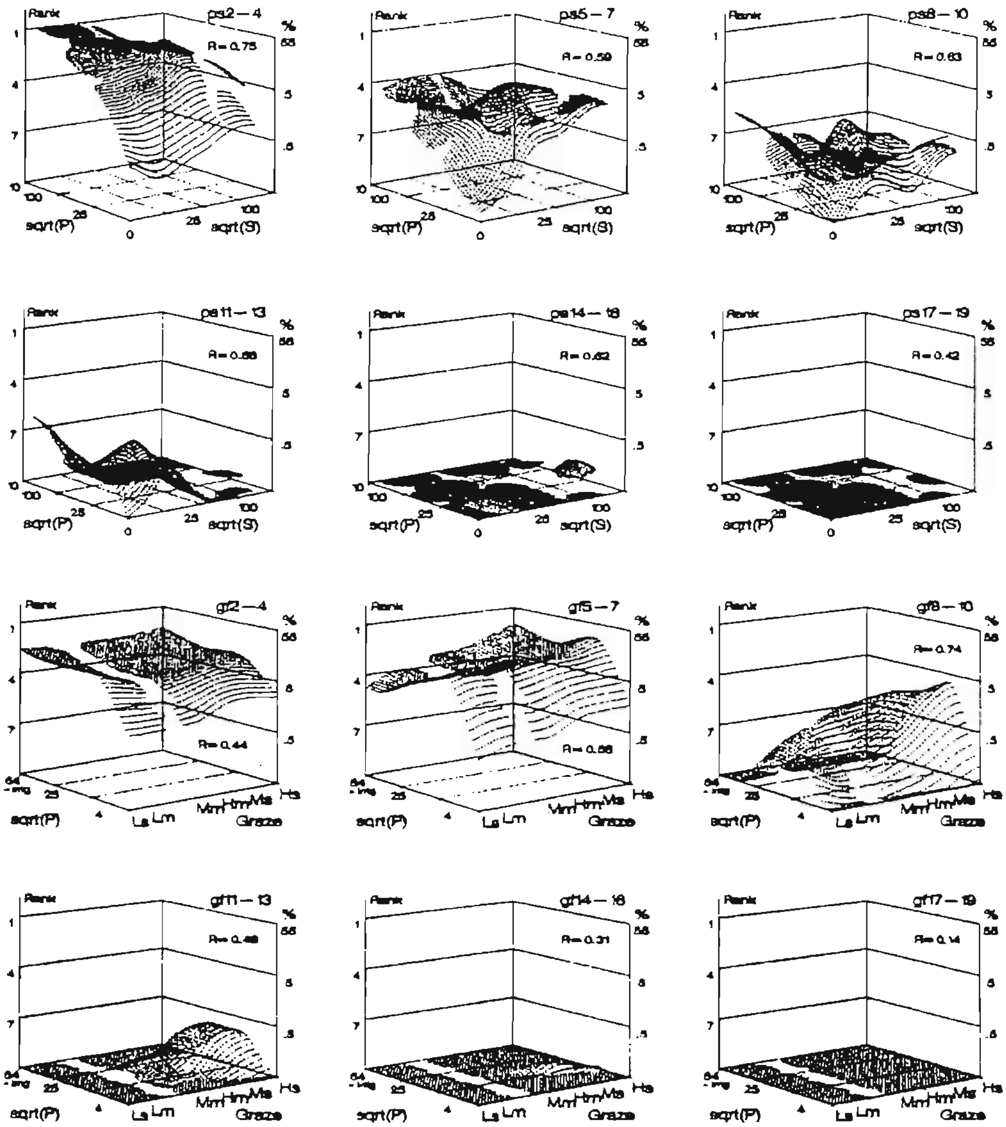

Fig. 4 Changes in rank contribution of *Trifolium hybridum* to pasture composition, Years 2–19. Layout as for Fig. 2.

most prominent in moderate and high stocking-rate, set-stocked treatments.

Trifolium hybridum *(alsike clover)*

This sown legume was highly dominant in both trials in the early stages of most fertiliser treatments. It decreased in abundance over Years 5–10 to became rare or absent in later years (Fig. 4), being replaced by white clover and caucasian clover in high fertiliser treatments and by lupin in low fertiliser treatments.

In the PxS trial, alsike clover was dominant in Years 2–4 in the high P fertiliser treatments, but of low abundance in the zero P fertiliser treatments, though with a small increase with increasing S fertiliser rates. As it decreased in subsequent years, it was a relatively uniform minor species across all fertiliser combinations in Years 8–10, with residual

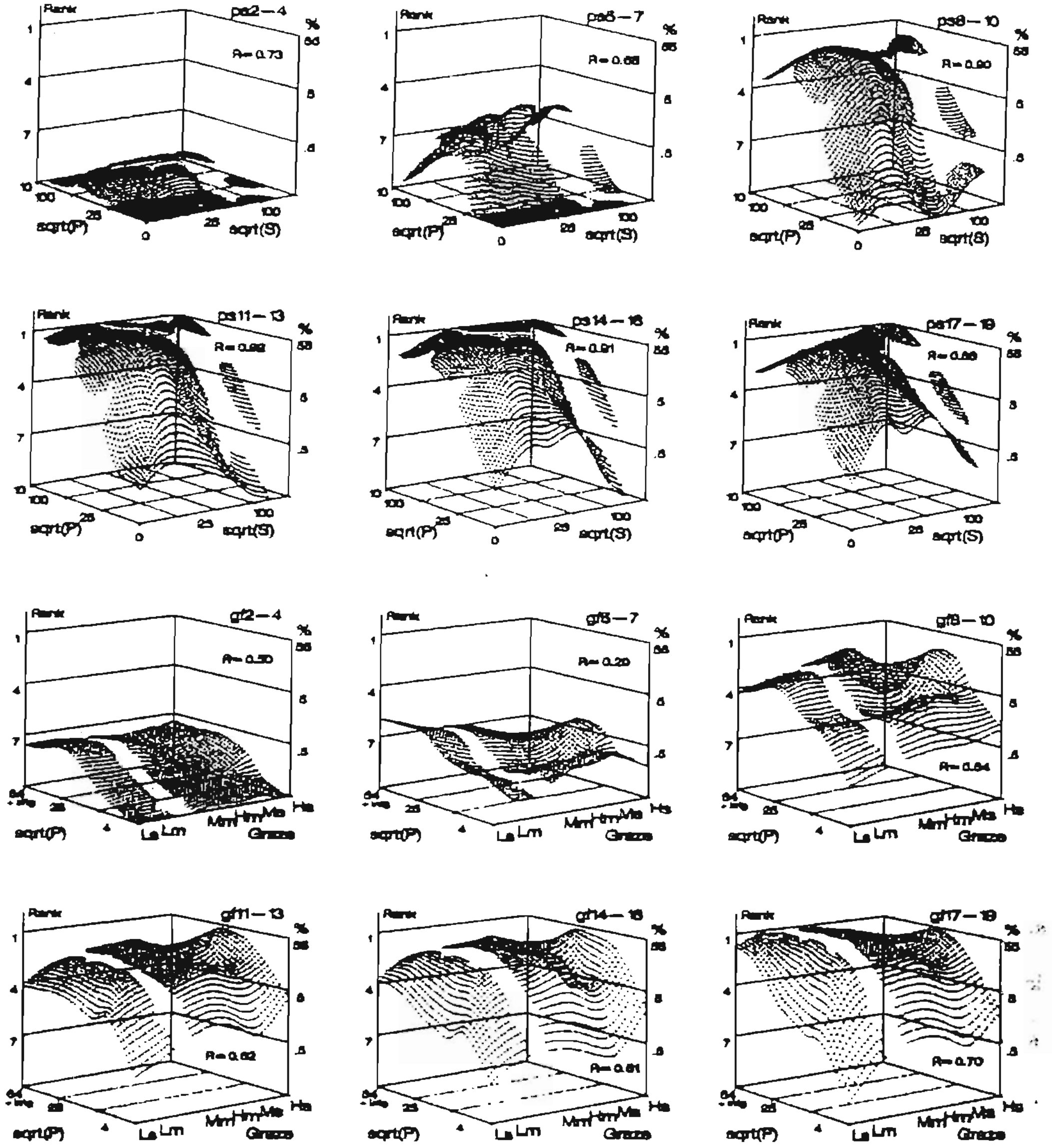

Fig. 5 Changes in rank contribution of *Trifolium ambiguum* to pasture composition, Years 2–19. Layout as for Fig. 2.

contribution at zero S and high P fertiliser combinations in Years 11–13, and generally unranked by Years 17–19.

In the Graze/fert trial, alsike clover had relatively uniform initial high abundance in all the fertiliser treatments. In Years 5–7 it retained its abundance in the moderate fertiliser treatments, with a large decrease at zero fertiliser and a small decrease in the high fertiliser treatment. Its main contribution was at intermediate fertiliser levels, though its abundance decreased in subsequent years. It was generally unranked by Years 17–19. There was a small effect of grazing management on alsike clover in the first 7 years. A pronounced effect developed in Years 8–10 and 11–13 where alsike clover retained its greatest contribution in the moderate and high stocking rate, set-stocked treatments.

Trifolium ambiguum *(caucasian clover)*

Although sown, this was only a rare or minor species in the early years of both trials (Fig. 5). It increased slowly by rhizome spread to replace white clover and eventually become the dominant legume and species in many of the high fertiliser treatments after a decade. Its environmental optimum was unimodal at combinations of moderate to high P fertiliser levels and moderate S fertiliser levels. Many of the high fertility treatments were in a grass phase before caucasian clover spread, and its increase in later periods was more at the expense of pasture grasses than of earlier-phase legumes.

In the PxS trial, caucasian clover's ranking was principally related to P fertiliser rate. In Years 2–4 it was only recorded as a rare or minor species at intermediate P fertiliser levels, but by Years 5–7 it had increased to being a moderately abundant species at those same intermediate P fertiliser treatments. By Years 8–10 it had increased to become the dominant species in plots at intermediate P fertiliser levels. Within the general P fertiliser response was a smaller S fertiliser response, as shown by a prominent ridge in the response functions in Years 8–10, 11–13, and 14–16. The slight displacement of the start of the ridge indicates that initially, for this site, S was more deficient than P for caucasian clover, but that thereafter there was a desirable S:P ratio for maximum contribution of caucasian clover, with the increase with S fertiliser rate being less than for P fertiliser rate. The converse was that caucasian clover made a lower contribution at zero, low, or very high S fertiliser levels. In Years 11–13, 14–16, and 17–19, caucasian clover continued to increase in abundance in all P fertiliser combinations, with the pattern in relation to S fertiliser rates remaining relatively constant.

In the Graze/fert trial, caucasian clover showed the same initial low abundance but increased over time to become a major or dominant species in many of the treatment combinations. It showed a large increase with fertiliser level, though the trend was for it to be slightly reduced in the irrigated high-fertiliser treatments where other species had greater responses. The grazing treatment effects on caucasian clover were small. The initial trend in Years 2–4 and 5–7 was for slightly greater abundance under the low stocking-rate treatments. In subsequent years it had greater abundance in the moderate and high stocking-rate, set-stocked treatments.

Trifolium repens *(white clover)*

This sown legume species was only a secondary legume in most treatment combinations, with different other legumes exceeding it in abundance in different treatments. The exception was its general moderate to high abundance in the irrigated high fertiliser treatments (Fig. 6). It had moderate abundance in most treatments in the early years of the trials, but tended to decrease in abundance over time and become rare or absent in several treatment combinations. There was a small resurgence in its importance in Years 14–16, but it was rare or absent in Years 17–19. It remained rare or absent in zero fertiliser treatments, although it was suspected that there was still a resident seed bank of white clover as well as the sown seed. Besides the general time trend of decrease of both species, *T. repens* and *T. hybridum* tended to alternate in their relative abundance in different years (Fig. 4 cf. Fig. 6), presumably related in some manner to previous autumn or spring climate growth conditions.

In the PxS trial, white clover's initial response and moderate to low abundance in Years 2–4 was to P fertiliser rates. Subsequently there was an interaction with P and S fertiliser rates, with white clover's main contribution at intermediate P and S fertiliser rates. The prominence of the ridge in the Year 5–7 response function (Fig. 6) indicates that the optimum S:P fertiliser ratio for white clover varied with total fertiliser rate.

In the Graze/fert trial, white clover increased with increasing fertiliser rate, particularly in the irrigated high-fertiliser treatments where it was often the dominant legume in the first 10 years of the trial. There was a trend for a bimodal distribution in white clover's abundance, with it also making greater contribution in the low fertiliser treatment than in the medium fertiliser treatment. Grazing management initially had a small effect on white clover's ranking, but it later increased in abundance in the moderate- and hard-grazed set-stocked treatments.

Trifolium pratense *(red clover)*

This sown legume was moderately abundant in the early periods of both trials, but decreased to become negligible or absent after a decade (Fig. 7).

In the PxS trial it was of low abundance without fertiliser in Years 2–4 but had moderate uniform abundance across the range of S and P fertiliser combination treatments. In Years 5–7 it decreased at high S and P fertiliser combinations, but

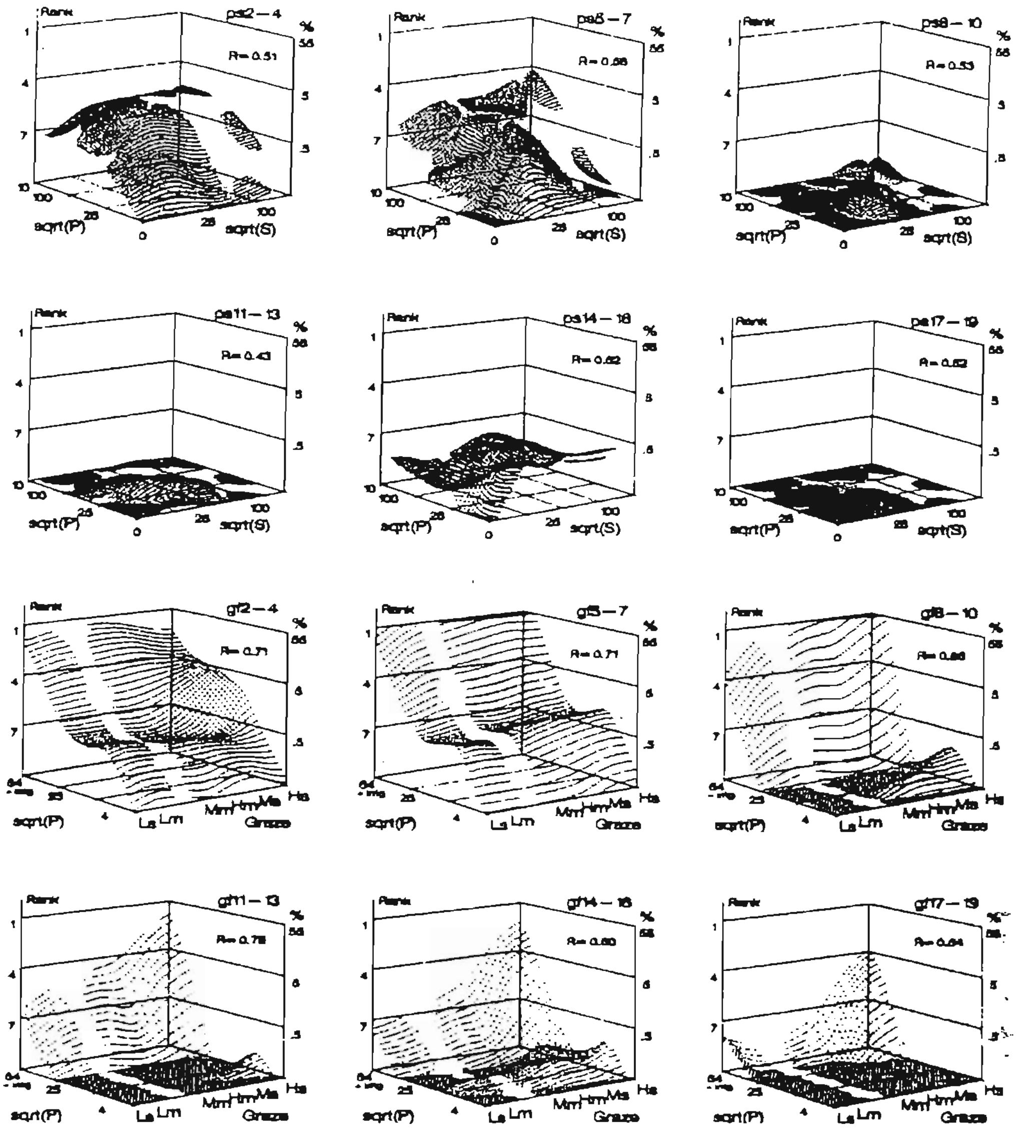

Fig. 6 Changes in rank contribution of *Trifolium repens* to pasture composition, Years 2–19. Layout as for Fig. 2.

maintained a modest abundance at intermediate S and P combinations.

In the Graze/fert trial, red clover had initially uniform moderate abundance across all treatment combinations in Years 2–4. In Years 5–7 it decreased in abundance with fertiliser level and irrigation as other species had greater responses to those conditions. Grazing management treatments had no discernible effect on red clover in Years 2–4 and 5–7. Somewhat unexpectedly, it remained a minor species in the high stocking-rate, set-stocked treatments in later periods.

Festuca rubra *(Chewings fescue)*

This sown grass initially established at only low abundance but increased over the experimental period (Fig. 8). It was relatively uniform in its ranking across all treatment combinations.

In the PxS trial it had relatively low uniform abundance during Years 2–4. The pattern of

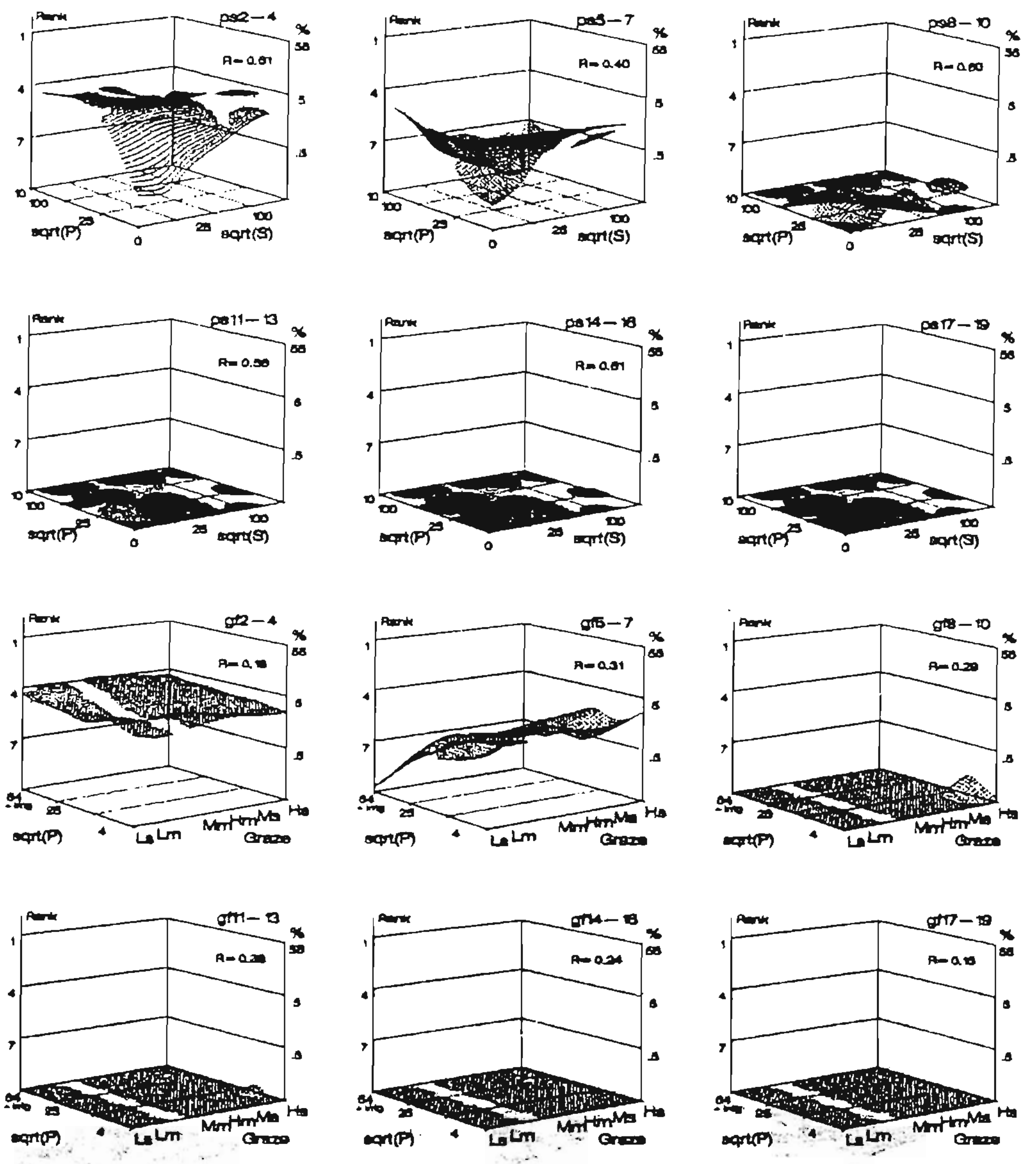

Fig. 7 Changes in rank contribution of *Trifolium pratense* to pasture composition, Years 2–19. Layout as for Fig. 2.

response was slightly more determined by P fertiliser than S fertiliser, with slightly lower ranking at intermediate P levels. It reached a maximum abundance in Years 8–10, with a trend of slight decrease subsequently.

In the Graze/fert trial it showed a gradual increase in abundance over time, particularly in the high fertiliser plus irrigation treatment. It had slightly lower abundance at intermediate fertiliser levels. There was a trend, most conspicuous in Years 8–10, of greater abundance under moderate to high rates of set-stocking.

Dactylis glomerata *(cocksfoot)*

This was generally the most successful and productive of the sown grasses at the higher fertiliser levels. It was a relatively minor species during Years 2–4 but increased to become the dominant species under high fertiliser levels, reaching a maximum in Years 8–10 then declining

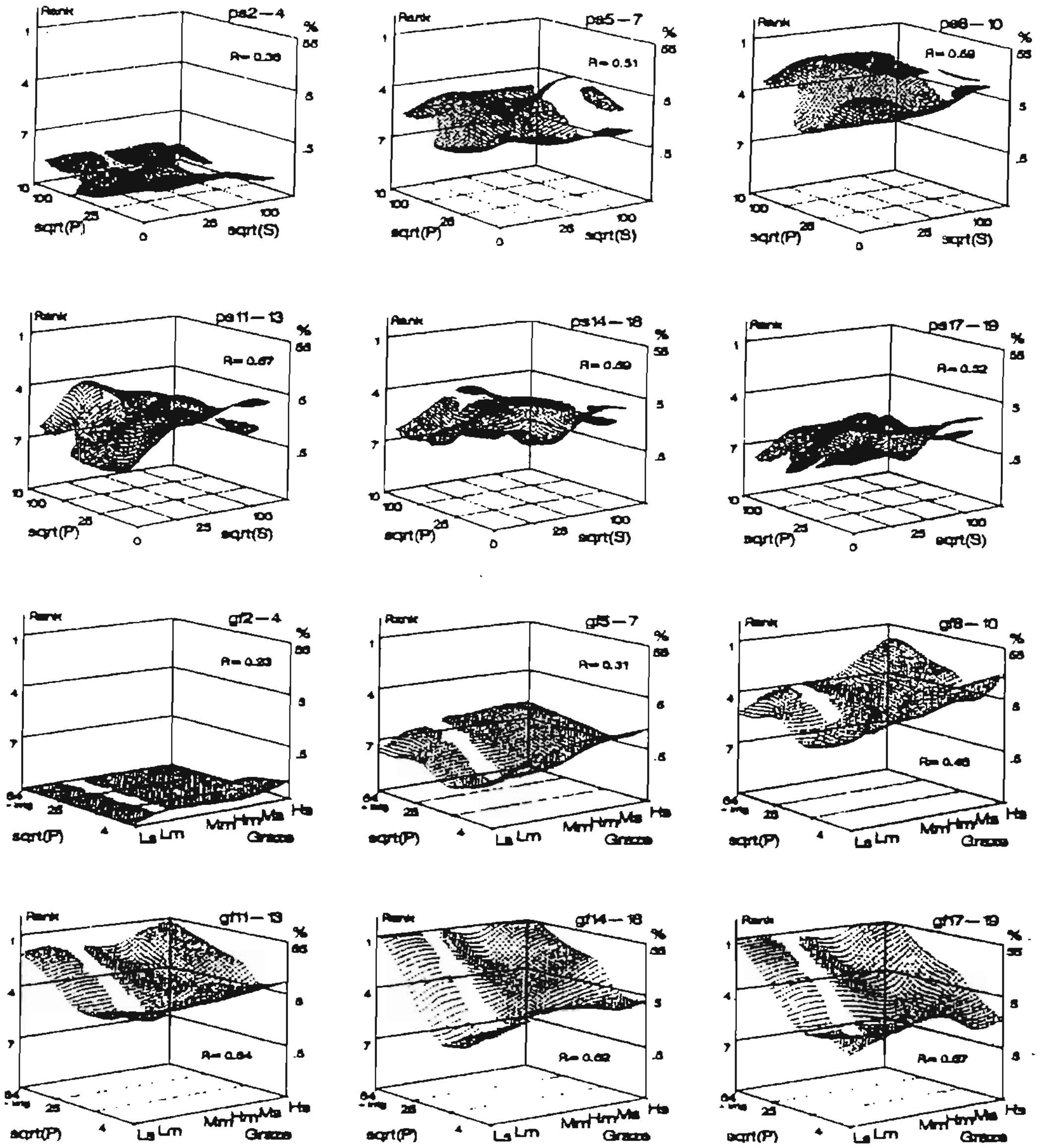

Fig. 8 Changes in rank contribution of *Festuca rubra* to pasture composition, Years 2–19. Layout as for Fig. 2.

subsequently (Fig. 9). There was a trend in both trials for cocksfoot to have a bimodal response with a maximum abundance at both intermediate (c. 25 kg P ha^{-1} yr^{-1}) and very high P fertiliser rates.

In the PxS trial, cocksfoot abundance showed an interaction with both S and P fertiliser levels. In Years 2–7 it increased rapidly in abundance, with the increase more related to the P fertiliser rate than to the S fertiliser rate. Subsequently, a more pronounced interaction between S and P fertiliser rates developed with maximum abundance at intermediate S fertiliser rates and a decrease at high S fertiliser rates. The bimodal response of cocksfoot had become marked by Years 17–19 with it being rare or absent from zero and low P fertiliser treatments.

In the Graze/fert trial, cocksfoot abundance was related more to the fertiliser treatments than to the

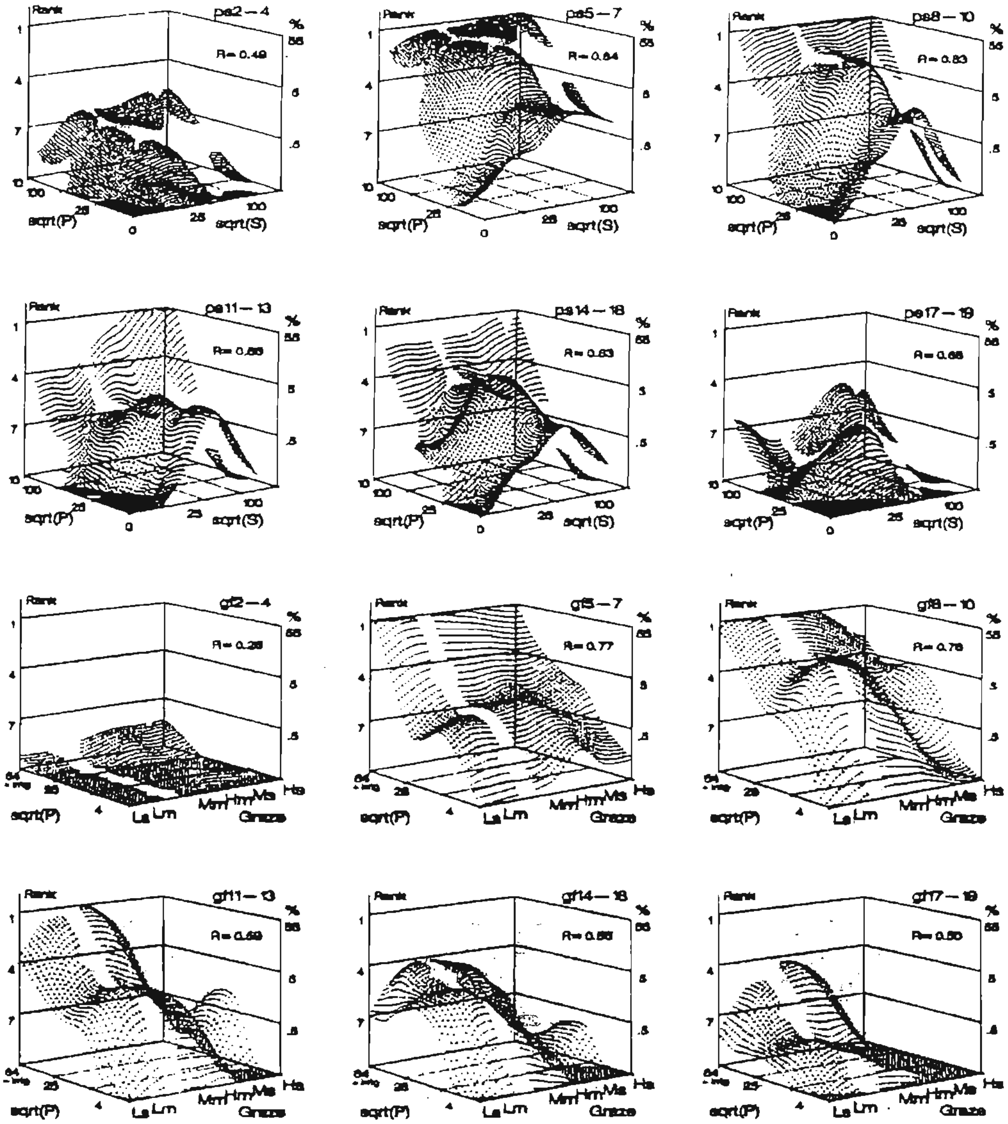

Fig. 9 Changes in rank contribution of *Dactylis glomerata* to pasture, Years 2–19. Layout as for Fig. 2.

grazing management treatments. Its greatest contribution was in the high fertiliser plus irrigation treatment. There was only a small trend relating to the grazing management treatments in the first decade, with only a slightly greater abundance in the mob-stocked treatments. In Years 11–16 and 17–19 there was a general decrease in cocksfoot, with the decrease greatest in the moderate and high stocking-rate, set-stocked treatments.

Festuca novae-zelandiae *(fescue or hard tussock)*

This indigenous species, which had historically dominated the area, was ranked 2nd or 3rd relative to 1st-ranked hieracium immediately prior to establishment of the trials. It did not have the vegetative spreading characteristics necessary to recolonise the cultivated strips following drilling but some remained in the uncultivated two thirds. It generally remained a species of low abundance

In the Graze/fert trial, fescue tussock in Years 2–4 retained moderate abundance in the moderate and high rate set-stocked treatments. In Years 5–13 it was of minor ranking in the zero fertiliser treatments. However, in later periods there was a resurgence in relative ranking as other species decreased, particularly in the set-stocked treatments.

Agrostis capillaris *(browntop)*

The contribution of browntop, although sown, was probably principally from previous resident plants remaining following drilling. The trials differed, with a higher previous abundance of browntop in the PxS trial area than in the Graze/fert trial area. There was no clear pattern of the environmental preference of browntop, though observations suggest that it was primarily occupying niches at the margins of the environmental domains of more dominant species (Fig. 11). The two trials differed in the relative abundance of browntop at intermediate P fertiliser rates.

In the PxS trial, browntop increased in abundance over time and reached moderate ranking. The change in its contribution in relation to fertiliser rates was somewhat variable. Unlike most other species, the pattern was more closely related to S fertiliser rates than to P fertiliser rates. The general pattern was for browntop to increase with S fertiliser rate, though with a lesser response at intermediate S fertiliser rates.

In the Graze/fert trial, browntop was only a minor species with slightly greater abundance at intermediate fertiliser rates. There was no clear pattern in relation to grazing management treatments but a slightly greater abundance under mob-stocking. The last period of Years 17–19 differed with a trend of increase under high fertiliser levels and set stocking.

Anthoxanthum odoratum *(sweet vernal)*

This was an unsown resident adventive grass. Initially rare, it increased slightly in Years 5–7 but remained a minor species (Fig. 12). It was slightly more common in the PxS trial where it was evident in the higher P fertiliser treatments. Subsequently, its greater abundance was in the zero or low P fertiliser treatments, and it decreased in high P treatments. Sweet vernal was a rare species in the Graze/fert trial, with only low abundance in the intermediate fertiliser low stocking-rate treatments, and zero fertiliser set-stocked treatments.

Arrhenatherum elatius *(tall-oat grass)*

Though sown, this was initially a rare component of pastures in both trials as it had been included at only a low seeding rate (0.2 kg ha^{-1}). However, it steadily increased in later years from initial plants, reseeding even in the presence of grazing, to become a common sown grass species (Fig. 13). It was still increasing in relative importance in Years 17–19.

In the PxS trial, the increased abundance of tall-oat grass in Years 5–10 related to both S and P fertiliser rates, with the response somewhat greater to P fertiliser. In later years the response to P fertiliser rate became more marked, with tall-oat grass becoming one of the top three ranked species in its contribution to total herbage bulk. At high P fertiliser levels there was little variation in tall-oat grass contribution in relation to S fertiliser rate, but at low P fertiliser rates its contribution was greatest at intermediate S fertiliser rates. There was a tendency for it to develop a bimodal distribution of high abundance in relation to the P fertiliser levels as it increased in abundance at low P fertiliser rates in later years.

In the Graze/fert trial the principal response over time was the increase in tall-oat grass with increasing fertiliser rate. The increase was rapid at low fertiliser, was of similar abundance at intermediate to high dryland fertiliser rates, and was slightly reduced in the high fertiliser plus irrigation treatments. The grazing treatments show that tall-oat grass initially (Years 5–7) increased in the low stocking-rate treatments but subsequently made its greatest contribution under mob-stocking, with low contribution under high set-stocking.

Phleum pratense *(timothy)*

The contribution of timothy to the pastures was probably underestimated because of the difficulty of identifying it in a vegetative state in a mixed sward during late-spring measurements. It was rare in Years 2–4, conspicuous and moderately ranked in Years 5–10, and decreased in dryland treatments in later years (Fig. 14).

The PxS trial indicated that timothy was more responsive to P than to S fertiliser rates, though with an apparent decreased contribution relative to other species at low (c. 20 kg ha^{-1} yr^{-1}) P fertiliser rates.

In the Graze/fert trial, timothy was initially rare but increased to become one of the more abundant grasses in the irrigated high fertiliser treatments. After its initial increase, it tended to fluctuate in

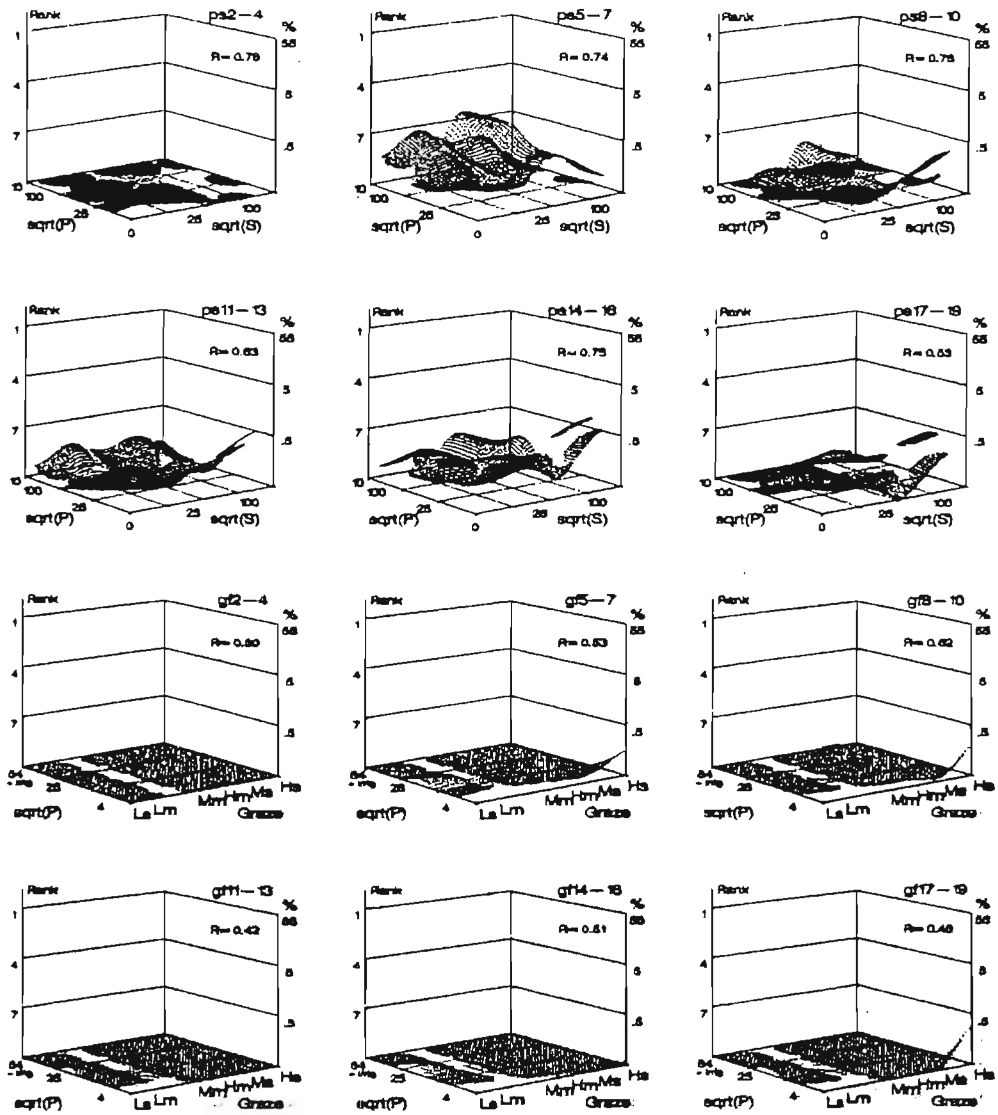

Fig. 12 Changes in rank contribution of *Anthoxanthum odoratum* to pasture composition, Years 2–19. Layout as for Fig. 2.

be the 1st or 2nd ranked species at intermediate S fertiliser rates across a range of P fertiliser rates.

In the Graze/fert trial it first appeared in Years 11–13 in the low fertiliser treatment and increased in all but the zero fertiliser treatments in Years 14–16. This increase was greatest under set-stocking, where it increased to become the dominant grass at the high and moderate stocking-rate and low and moderate fertiliser treatments by Year 19.

Schedonorus phoenix *(syn.* Festuca arundinaceae*)* *(tall fescue)*

This was a sown pasture grass that remained rare or absent in most treatments. In the dryland treatments of the PxS trial it reached low abundance at the highest S and P fertiliser rates from Year 10. In the Graze/fert trial it increased to become the 3rd to 5th ranked species in the high fertiliser plus irrigation treatment. Within those treatments there

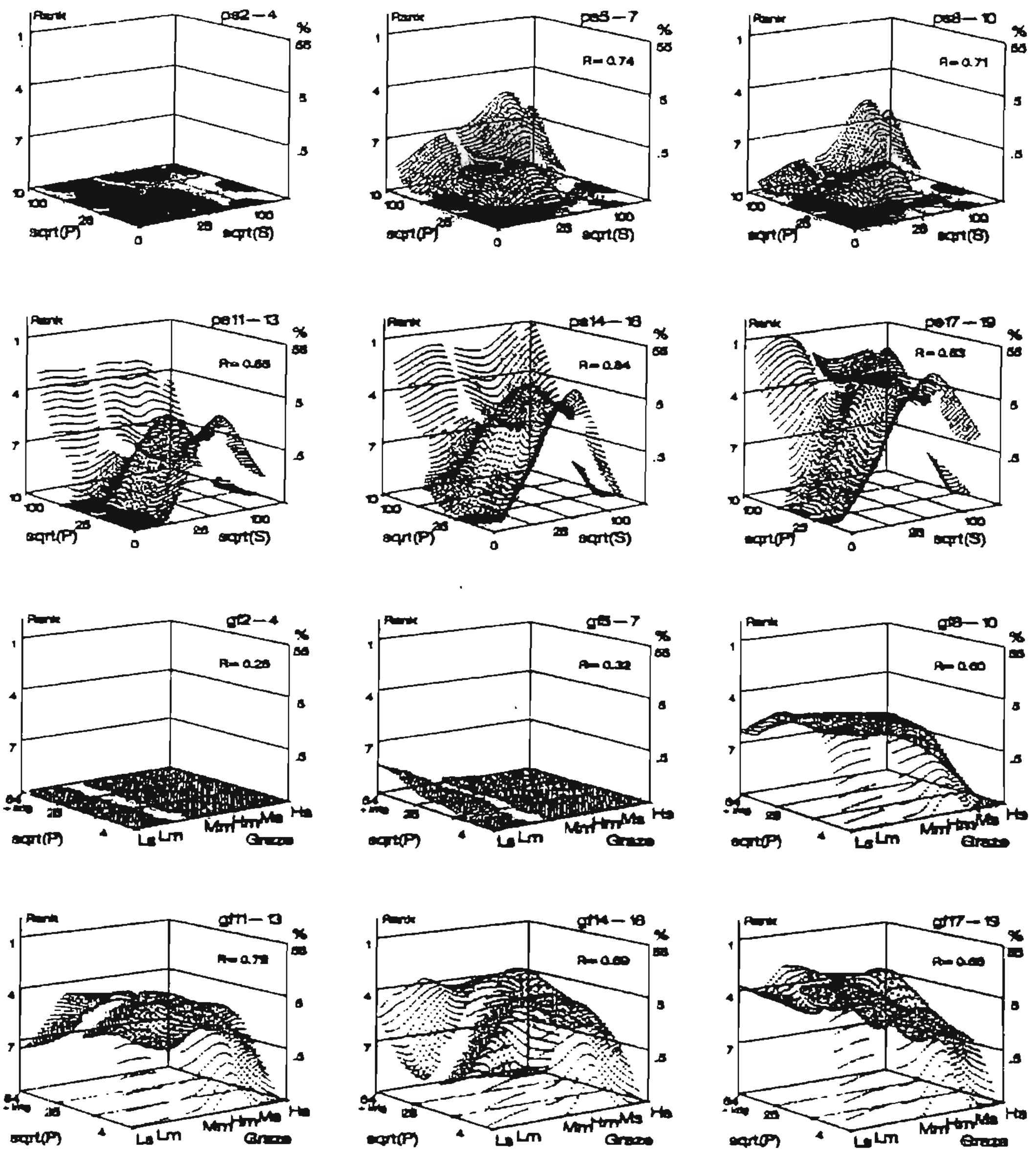

Fig. 13 Changes in rank contribution of *Arrhenatherum elatius* to pasture composition, Years 2–19. Layout as for Fig. 2.

was evidence for a slightly greater contribution in mob-stocked treatments.

Holcus lanatus *(Yorkshire fog)*

This established relatively uniformly across all treatments of both trials and was a minor ranked grass species during the early years. It decreased to a negligible ranking in dryland treatments from about Year 7. The exception was the irrigated high fertiliser treatments of the Graze/fert trial, where Yorkshire fog increased to 2nd–5th ranked species in Years 8–10 before decreasing to 7–10th ranked species in Years 14–16. During the earlier period there was no clear discrimination of Yorkshire fog in relation to S and P fertiliser rate, though in both trials its contribution was less in the intermediate fertiliser rate treatments relative to both higher and lower fertiliser treatments.

In the Graze/fert trial, Yorkshire fog made a greater contribution under set-stocking than mob-

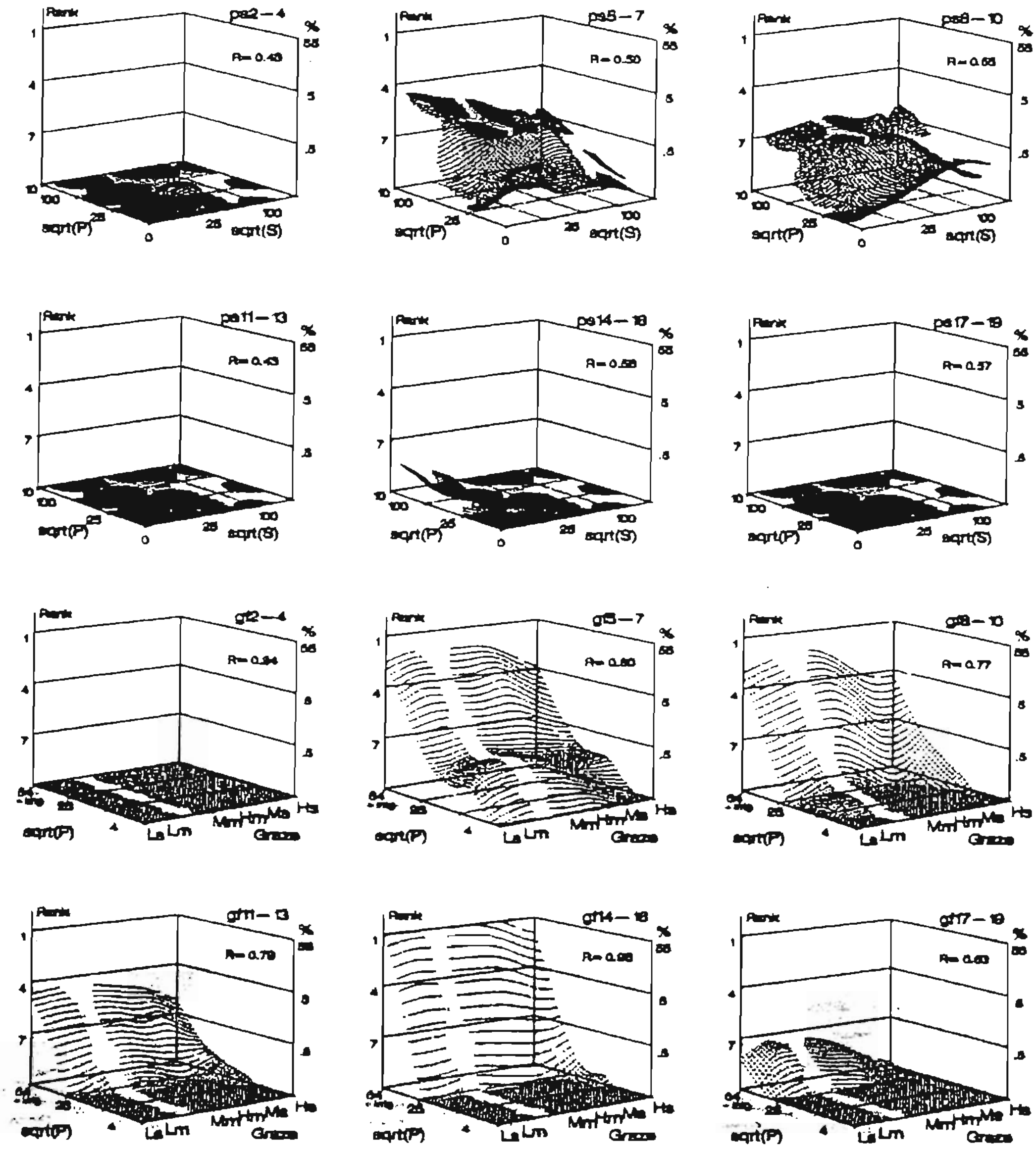

Fig. 14 Changes in rank contribution of *Phleum pratense* to pasture composition, Years 2–19. Layout as for Fig. 2.

stocking, and was more abundant at low stocking-rates than moderate or high stocking rates. On two occasions during the experimental period, Yorkshire fog suffered mortality from severe winter frosting.

Lotus corniculatus *(birdsfoot trefoil)*

In the initial two years there was moderate establishment of birdsfoot trefoil or its hybrid (G4712, *L. corniculatus* X *L. pedunculatus*), in both trials across all treatment combinations. During Years 2–4 (which included the 2nd establishment year and the first 2 years of grazing) it averaged as about the 7th ranked species across all treatment combinations in both trials, but by the Year 5 it was only the 9th or lower ranked species in some treatments and absent from most.

In the early period of the PxS trial birdsfoot trefoil was slightly more influenced by the S fertiliser rate than the P fertiliser rate, with lower abundance at the highest S rate.

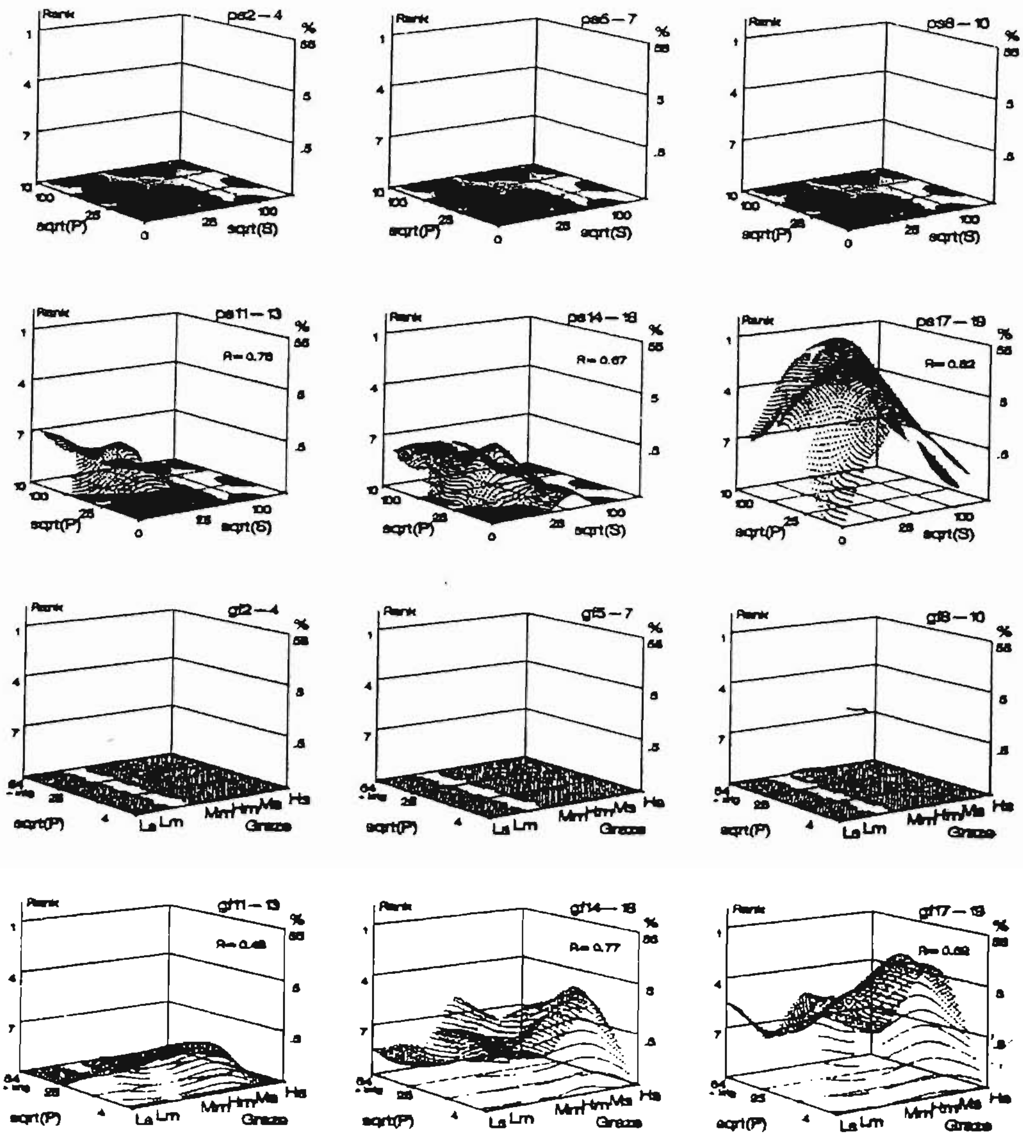

Fig. 15 Changes in rank contribution of *Bromus tectorum* to pasture composition, Years 2–19. Layout as for Fig. 2.

In the later period of the Graze/fert trial birdsfoot trefoil had low abundance in the zero and low fertiliser treatments and slightly greater abundance in the moderate and high rate set-stocked treatments.

Trifolium medium *(zig-zag clover)*

This sown legume remained a minor or rare species. Although present from the start, it increased slightly under some treatment combinations. In the PxS trial it reached a maximum abundance of 4th ranking in some of the combinations of zero or low S fertiliser by moderate P fertiliser combinations by Year 12. In the Graze/fert trial it reached a low to moderate ranking in some of the zero fertiliser, moderate to high stocking-rate, mob-stocked treatments towards the end of the period.

Rumex acetosella (sheep's sorrel)

This resident adventive species was of low abundance in most treatment combinations, reaching a maximum ranking of 6th to 8th in some combinations from Year 8. In the PxS trial these rankings occurred in the marginal environments of either very high S fertiliser rates or zero or low P fertiliser rates. In the Graze/fert trial the greatest contribution of sheep's sorrel was in the low, but not zero, fertiliser treatments under high or moderate stocking-rate, and set-stocking.

Other Hieracium spp.

Besides *H. pilosella*, other species of *Hieracium* occurred in the trials. *H. praealtum* was a minor species or absent in most treatments. It briefly reached a mean ranking of 8th in the high P, zero S fertiliser treatments of the PxS trial in Years 5–7. There were occasional plants of *H. caespitosum* within the moderate fertiliser treatments, with no discernible trends over time. Two plants of *H. lepidulum* were seen within the trial area.

Other sown species

Species sown that did not establish or were not present in the rankings from the second year on were *Coronilla varia* (crown vetch), *Bromus willdenowii* (prairie grass), *B. scoparius*, *Cynosurus cristatus* (dogstail), and *Phalaris aquatica* (phalaris). *Lolium perenne* (perennial ryegrass and *L.* × *hybridum*) was a minor grass component of the high fertiliser treatments during Years 2–4 but only rare plants remained thereafter. *Lotus pedunculatus* (lotus) had an occasional low ranking in the early years and then disappeared. Occasional plants of *Medicago sativa* (lucerne) established in both trials. The few plants present beyond Year 3 persisted, tended to increase in vigour, and survived to Year 19.

Other adventives

A number of other adventive species appeared in the trial plots over the experimental period, presumably from a distant seed source. This was most apparent in the high fertiliser plus irrigation treatments. Species included *Taraxacum officinale*, *Cirsium arvense*, *C. vulgare*, and *Marrubium vulgare*. Their appearance was interpreted as a change of site conditions to suit the species, from a continual small seed-source input, rather than the occurrence of a first influx of seed from some source.

Species number (n)

There were 86 native and 55 introduced vascular plant species present within 0.5 km of the two trials (Douglas 1987). There was a common potential species pool of 32 indigenous, 30 adventive (exotic species that have established naturally), and 19 sown introduced species (6 of the sown species did not establish) within the two trials.

The plant species had 12 years to adapt to the different environmental/management treatments prior to the diversity analysis presented. The mean number of species in each 0.04-ha plot of the Graze/fert trial was 17.7, composed of 3.3 indigenous species, 8.1 sown species, and 6.3 adventive species.

The treatment effects on plant diversity were not large. ANOVA showed significant fertiliser and stocking rate effects on the total number of species present. The total number of species was highest in the zero fertiliser treatments and lowest in the intermediate moderate fertiliser treatment (Table 2). The total number of species increased significantly with increased stocking rate.

The number of indigenous species was highest (mean 8.9) in the zero fertiliser, and similar (1.5–2.2) across the other fertiliser treatments. The number of established sown species increased approximately linearly from a mean of 6.8 in the

Table 2 Relationship between the plant diversity indices of total number of species (n), and distribution of biomass between species (k), with secondary sheep carrying-capacity (mean grazing days/365 ha^{-1} yr^{-1}) and stability (CV between years) for the main treatments of Graze/fert trial. ns, not significant.

	Plant diversity		2° Production	
Treatment	n	k	Mean	CV
Fertiliser				
Zero	21.1	0.34	2.3	62
Low	16.3	0.39	9.1	35
Mod.	15.6	0.42	8.1	35
High	17.8	0.37	8.0	39
Irrig.	17.6	0.55	20.9	22
LSD5%	1.7	0.03	0.9	3.8
Stocking method				
Set	18.0	0.42	8.1	40
Mob	17.4	0.41	11.1	38
LSD5%	ns	ns	0.6	ns
Stocking rate				
Low	16.5	0.38	6.6	43
Moderate	18.0	0.42	9.9	43
High	18.9	0.45	13.1	37
LSD5%	1.5	0.04	ns	3.1

zero fertiliser to 9.1 in the irrigation plus high fertiliser treatment. The mean number of sown species was higher under mob-stocking than set-stocking (8.5 cf. 7.5). There was no trend in the number of adventive species relative to treatments. The number of sown species increased (7.2 to 8.9) with increasing stocking-rate, with no trend in the number of indigenous or adventive species.

A stepwise regression analysis between diversity and fertiliser level, stocking rate, grazing methods, and/or resulting litter and soil parameters indicated that the best single predictor of the total number of species was an inverse relationship with 10th-year litter density followed by some of the non-treatment plot covariates. The relationship with litter was

Number of species =
21.3 –0.23*litter (t ha^{-1}) ($r^2 = 0.26$) (2)

The number of sown species was positively related to the elemental S fertiliser rates and inversely with litter density. The number of indigenous species was inversely related to elemental S fertiliser rates.

Diversity (*k*)

ANOVA of the *k* diversity index showed that it increased significantly from the zero fertiliser treatments to the irrigated plus high fertility treatment, indicating a more even subdivision of biomass between species in the higher growth potential treatments (i.e., decreased dominance) (Table 2). The *k* diversity also increased significantly with increasing stocking-rate. There were two significant interactions. A fertiliser by stocking-rate interaction indicated similar *k* diversity in the zero fertiliser treatments, an increase with stocking-rate within the three dryland fertiliser treatments (mean 0.32 for low, 0.41 for moderate, and 0.46 for high stocking-rate, respectively), and a decrease with stocking-rate in the irrigation plus high fertiliser treatments (corresponding means 0.57, 0.56, 0.52, respectively). There was a smaller fertiliser by grazing method interaction, with *k* diversity decreasing in set-stocking versus mob-stocking at lower fertiliser rates (0.45 versus 0.35) and higher under irrigation plus high fertiliser (0.52 versus 0.58). There was no significant time trend in the *k* diversity index in the 6 years around the 12th year.

The regression approach showed that the best single predictor of the *k* diversity index was a positive relationship with the sulphate fertiliser rate, followed by an inverse relationship with litter density.

The mean value of the diversity index for the PxS trial was $k = 0.42$ in the 12th year, with no time-significant trend around that time. The stepwise regression analysis for the 12th year values indicated a positive relationship with P fertiliser rate and a negative relationship with the plot topsoil bulk density prior to the commencement of the trial.

Interaction with grazing capacity

Secondary animal production as determined from the mean sheep carrying capacity from the 3rd to the 15th year, and the coefficient of variation over those years, as a measure of stability or sustainability, has been reported in Scott (2000b, table 2). The relationship between these and the 12th-year plant diversity parameters were determined by covariance analysis with and without their inclusion in an analysis between carrying-capacity and treatments.

The plant diversity parameters were a significant explanatory effect for the mean and variation in carrying-capacity when considered alone, but in only one instance did the effect remain significant when treatment effects were considered simultaneously, though the inclusion of plant diversity parameters did increase the variance explained.

There was no consistent trend between trials, or diversity parameters, in their relationship to secondary production or stability (Table 3). The single significant trend was from the Graze/fert trial, where mean carrying-capacity decreased 2.2% for each additional plant species in the vegetation, after taking account of the major effects of the main treatments. This compared with the 9[illegible]% difference related to those treatment effects.

An increase in the *k* diversity parameter is a measure of a more even distribution of biomass between plant species and can be interpreted as increasing diversity. Thus, the negative correlation

Table 3 Regression coefficient for relationship between plant diversity parameters and production and stability of secondary carrying capacity. ns, not significant; **, $P < 0.01$.

Trial	Diversity parameter	Carrying capacity	
		Production	Stability
Graze/fert	*n*	$-2.2\%^{**}$	$+0.2\%^{ns}$
	k	$-2.0\%^{ns}$	$-14\%^{ns}$
PxS	*k*	$+116\%^{ns}$	$-23\%^{ns}$

with the *k* coefficient in the Graze/fert trial is consistent with the negative correlation with the total number of species, while the correlation in the PxS trial was indicating the opposite trend. The non-significant correlation between the coefficient of variation and *k* in both trials was indicating greater stability with greater plant diversity, but with the opposite trend indicated by the non-significant trends with total number of species.

DISCUSSION

Gradient and niche concept

The trials have provided empirical support for the concept of environmental gradients and species niches. The trials were only conducted at one site, so that temperature and rainfall would have been constant, and the only variation in moisture was one group of irrigated treatments. A wide range of differing fertility and animal grazing effects were superimposed on a common sown and resident mixture of plant species. The main features of both trials were the very rapid separation of species according to the imposed fertility and grazing management environments; the principal effect due to the different S and P fertiliser rates, e.g., the continuation of *H. pilosella* dominance in the zero or low fertiliser environments; the dominance and long-term persistence of *L. polyphyllus* in many of the low fertiliser environments; and the progression through legumes, pasture grasses, or *T. ambiguum* in high fertiliser environments.

Many of the species showed high abundance over only a relatively small niche or domain within the total environmental range of treatments tested. The results have been given in terms of species ranking, but the associated transformations to percentage contribution to total vegetation bulk indicate that, collectively, the 1st and 2nd ranked species typically made up more than 80% of the vegetation bulk. In an oversowing or developing situation it would probably only be necessary to sow the two most suitable species for a particular set of proposed environmental conditions. To make full use of this concept of niche and dominance, however, there needs to be this close match between species selection and proposed environmental changes, i.e., seeding mixtures need to be matched with the proposed fertiliser and grazing managements.

In developing the gradients and niche concept prior to the present trials, attempts had been made to estimate the niche for a range of pasture species (Scott 1979a; Scott et al. 1995). The present results have modified some of those initial assessments. The present results show that *Trifolium ambiguum* is very much a high fertility species rather than a moderate fertility species. The niche for *Arrhenatherum elatius* extends more into the higher rainfall, more weathered soils, and into higher fertility conditions, than was previously indicated.

Two aspects not well covered in the original concept are time and the "valence" or extent of the niche over which a species can make a large contribution. The present results have shown that there is a time element involved, attributable either to time per se or the cumulative effects of fertiliser and grazing management. Some species, such as *Dactylis glomerata, Arrhenatherum elatius, Phleum pratense*, and *Hieracium pilosella*, had narrow niches compared with the broad niches of moderate rankings of *Festuca rubra, Agrostis capillaris*, and *Anthoxanthum odoratum*.

There was the appearance and increase of a number of adventive species (e.g., *Bromus tectorum*) into the present trials, often many kilometres from likely seed sources, and the appearance of legumes in adjacent tussock grassland trials that were fertilised but not seeded (Scott 2000f). These indicate a probable under-estimation of the continual seed-rain on all sites, whose existence is only apparent when the conditions of a site have changed to suit those particular species. Effective plant dispersion involves both an actual dispersion process and a site that is environmentally suitable to the particular species.

Accession evaluation

While the use of a multiple-species seeding mixture and the retention of part of the original vegetation were the experimental technique used to test the concept of species niche, there were also other interpretations. A species grown alone or in a simple mixture is likely to have a wider range of environmental conditions in which it could be successful and productive. However, in the multiple seeding mixture used, each species had many potential competitors, so that it was likely to succeed only in the niche where it was most suited and thus define its role. The multiple species seeding mixture is thus a very convenient experimental method for the simultaneous evaluation of a range of contending species, cultivars, or accessions in a new situation, even if subsequently only one or a few of the more successful are advocated for use in a sown pasture mixture (Scott 1993b).

The present results have shown that *Lupinus polyphyllus* has potential as an important forage legume for pasture development of such high-country sites. Its production and persistence under low fertiliser inputs exceeded other legume species requiring higher fertiliser inputs. The present results also show a wider potential role for *Festuca rubra* and *Arrhenatherum elatius*.

Differing fertiliser response

The PxS trial showed that in a competitive situation species differed in their relative responses to S and P fertiliser. For some there was a strong pattern of increase in relative abundance relating to the P fertiliser component (*Trifolium ambiguum* and *Dactylis glomerata* during the early phase), while for others the pattern was dominated by the relationship to the S fertiliser component (*Lupinus polyphyllus*, *Agrostis capillaris*, and *Festuca novae-zelandiae* during the early phase). However, for most species the relative contribution of species related to an interaction of S and P fertiliser rates. Generally, the correlation was stronger for the P component than the S component for all the *Trifolium* species, *Hieracium pilosella*, and most of the grasses, at least during the first decade. The pattern for *Lotus corniculatus*, *Festuca rubra*, and *Schedonorus phoenix* in the later years was more influenced by S fertiliser rates.

These patterns of pasture species contribution being more determined by the P fertiliser rate contrast with the few measurements of total pasture bulk increasing with both S and P fertiliser rate (Scott 2000d, fig. 12) and the resulting sheep grazing capacity being almost solely determined by the S fertiliser rate (Scott 2000b, fig. 1). This cautions against placing too much emphasis on estimating desirable outcomes, such as stock carrying capacity, from relative responses of pasture yield or successful pasture species.

Re-establishment

The role of seeding and re-establishment in the change in species abundance in the trials over time is open to speculation, as there were no direct measurements. Apart from the two-year establishment period, the subsequent sheep grazing management would not have been conducive to seeding and re-establishment of most species, except perhaps in some of the low stocking-rate treatments.

Annuals were rare in both trials, with only *Myosotis stricta* an occasional common species, and *Bromus tectorum* occurring and increasing in later years. Thus, perennials dominated the diversity changes, with an advantage to legumes. Each species was originally sown into a third of each plot. Differences relate mostly to plants that established in the first non-grazing year and a half, but which varied in their growth and survival subsequently. The original drill rows were still apparent in most plots 19 years after sowing. In particular, the impression was that the sown grasses that became prominent were seedlings that had persisted through the earlier years to respond once soil nitrogen increased from the earlier legume phase. This indicates the extended time-scale that may be needed to consider diversity estimates and why measures of relative abundance, such as the change in *k* diversity, may be a better estimate of shorter-term diversity trends than number of species.

The main exception to this was *L. polyphyllus*, with its rapid increase to totally dominate the low fertiliser rate treatments. It was a prolific seeder, and there was a tendency for sheep not to eat brown seeding stalks. There was usually prolific late autumn/early spring seed germination beneath its own canopy and sufficient of these seedlings survived to increase plant numbers.

The increase in abundance of *T. ambiguum* was related to vegetative rhizomatous spread from the initial low density of sown seed, with flowering and seeding very unlikely under the grazing management used. Similarly, changes in *T. repens* may relate to vegetative stoloniferous spread, though there may have been some re-seeding.

Another exception was *Arrhenatherum elatius*, initially sown at very low seeding rates but which became increasingly abundant with some seed spread and re-establishment even in the presence of grazing.

General high-country experience is that although *T. hybridum* is a very free seeder it does not re-establish within the proximity of space or time of other *T. hybridum* plants. The responses of the sown pasture grasses, *Dactylis glomerata*, *Festuca rubra*, *Schedonorus phoenix*, *Holcus lanatus*, and *Phleum pratense*, relate to plants originally establishing in the first year, even if it was 8–10 years before they responded to the increasing soil fertility conditions.

Diversity

In intensive pastoral agriculture environments, pasture renewal is often undertaken at 5–20-year intervals. If plant diversity were to be included in management considerations on those time-scales, then any beneficial effects on level or stability of animal production would have to be apparent within a few years. The present study, using 12th-year diversity estimates, showed only weak relationships for a developed range-land environment and would appear to have no implications for more intensive pasture environments.

The results indicated some trends in plant diversity parameters with respect to the fertility and grazing treatments, but there was only a weak and inconsistent effect in their relationship to secondary production of carrying capacity. Thus, management for plant diversity *per se* does not seem to be an important issue in the consideration of the production and sustainability of high-country pasture development options.

The three particular features of the present trial relative to other biodiversity studies were the use of secondary production (sheep carrying capacity) as the measure of productivity; the determination of whether diversity parameters changed from an original common species pool as a result of the treatments imposed; and that such diversity changes occurred where changes in pasture production as a result of treatments were utilised by a corresponding increase in grazing.

There could be some debate on how these empirical results relate to the general consideration of dominance/diversity versus productivity/stability of vegetation. This is because of the dilemma of whether the range of treatments within such trials can be considered as perturbations of some general environment, or whether each treatment combination is seen as a different new environment in its own right. None of the present treatment combinations could be regarded as pristine or climax.

The results probably may not be seen as a test of the biodiversity/productivity/stability hypothesis, but rather as just another measure of how these aspects vary under a controlled experimental situation. Huston (1997) has critically reviewed some of the difficulties and alternative explanations in diversity investigations. It is probably only after some consistency in pattern between diversity and function has been detected across a wide range of situations that causality (in either direction) can be contemplated.

The trends of lowest species number at intermediate fertility conditions in the present trials is somewhat at variance with experience of a "humped back" distribution of greater plant diversity at intermediate conditions in other studies (Grime 1973).

The increase in k biodiversity with increasing growth potential could be seen as being in accordance with the general recorded increase in biodiversity associated with latitudinal and vegetation type increase in stature/biodiversity, but to be at variance with general agricultural experience of lower k biodiversity (tendency to monoculture) in agricultural development at one site. The species sown were pasture species, which by their evolution or selection are adapted to grazing and treading. The increases in the number of sown species under high versus lower stocking-rate, under the higher mean stocking rate of the higher growth conditions, and under mob- versus set-stocking probably reflect the adaptability of these species.

For the vegetation within plots there was no measure of the within-year or between-year variability in productivity as might be related to diversity/stability/resilience considerations. I consider all treatments to be still undergoing re-adjustment to new environments rather than being fluctuations around some norm.

The total vascular plant flora of New Zealand is about 4005 species (Wilton & Breitwieser 2000). Of these c. 50% are introduced, naturalised, adventive species. The proportion would be even higher if it included the thousand or so introduced species present in horticulture. In the present study 25 of the species were deliberately sown. However, 39% of the 141 species in the area surrounding the trial site were also non-indigenous. Slightly lower proportions have been reported in other, older, high-country studies (15% of 386 species (Scott 1959), 21% of 796 (Holgate 1985), and 25% of 136 (Svavarsdóttir 1995)). Thus, introduced species must now be considered an integral, and probably increasing, part of the ecology of high-country vegetation. From the perspective of biodiversity considerations in ecosystem functioning, it is unhelpful to make the artificial differentiation between indigenous and introduced species, even if that may be a valid differentiation for indigenous biota conservation.

The present results have shown a relatively weak relationship between the mean number of plant species and applied annual fertiliser gradients under grazing (Table 2). In a similar high-country study there was a very strong relationship after 13 years in an ungrazed (by sheep) situation between species numbers and a single initial application of a gradient of 9 superphosphate levels (Svavarsdóttir

1995). In that study the mean number of vascular plant species decreased approximately proportionally to the logarithm of the initial fertiliser rate. That would be consistent with the inverse trend between biodiversity and accumulated litter reported by Tilman (1993) and in hay removal treatments of the Park Grass Experiment at Rothamsted (Silvertown 1980). The difference in the present trials was that, for a pastoral agricultural system, animal stocking rates were increased to utilise the higher pasture growth rates of the fertilised treatments, thus maintaining a more similar vegetation biomass across the treatments, but with the differences being reflected in the secondary production of total sheep carrying capacity.

Though there was a significant inverse relationship between species diversity and litter in the present Graze/fert trial, and pre-trial soil bulk density in the PxS trial (which may relate to a previous litter regime), the litter effect was not large. Why litter should decrease biodiversity can only be the subject of speculation. While it may limit seed establishment sites, litter is more likely to reflect dominance of a treatment by tall species or by trampled material from higher grazing pressures.

The present results have similarities and differences with other work. It is similar to Tilman's (1993) Minnesota results in showing that the changes were principally in perennial species and the decrease in species number was associated with increasing litter density, but different from that study in that the number of species did not decrease with increasing fertiliser/productivity. McNaughton's (1993) New York old-field also showed that changes were mainly in perennial grasses and herbs, with productivity decreasing from the less diverse young-field to the more diverse old-field. The present results also support the cautions of Sala et al. (1995) and Olff & Ritchie (1998) that grazing intensity can increase biodiversity (both number of species and *k* diversity), contrary to common perception.

As a number of authors have pointed out, in the discussions of biodiversity, productivity, stability, and resilience relationships, theoretical and modelling approaches have largely exceeded empirical field measurements, for which the latter should be both the guide and test of relationships (e.g., Pimm 1984; Naeem & Cushman 1995). The present study has added some further empirical data on diversity and secondary production to these discussions. As indicated, some of the present results were similar to other studies and others were different, but all relationships were relatively weak.

However, in relating the present work to some of the other biodiversity literature a number of points warrant comment, particularly on plant/environmental relationships. The first is the general lack in species quantitative interaction models or methods for accommodating the changing competitive and other relationships between multiple species in different environments or differing environmental fluctuations.

Some of the approaches to biodiversity seem to work from the concept that species differ in their growth potential and that the total primary production can be determined as the sum of the growth potentials of all species present. The current work was based on a different concept, that total potential primary production of a site is dominantly a function of environment, in particular a function of the soil moisture, temperature, fertility, and growing point/grazing/treading interactions of the site (Scott et al. 1995). The similarity in total biomass of a particular type of ecosystem has also been suggested by Pimm (1984). Within that, all species were perceived as having the same general relationship to these environmental factors but to differ in detail, so that for each environmental combination there is a hierarchy of species partitioning, of which one species present is likely to capture the dominance of the site. The present results seem to be in accordance with that concept in the separation of species in the different treatments from a common seeding mixture.

This partitioning of species is reinforced by a second concept which was implicit in the vegetation sampling technique used in the present work, but which has been expanded in more detail by others (Preston 1948; Whittaker 1965; Scott 1986). The literature on the commonness and rarity of species suggests that in any vegetation (or ecosystem) species occur in relatively fixed proportions, generally approximated by a linear relationship between the logarithm of abundance and rank order of species. While the physiological basis of why such a community restraint should hold has only been speculated on, it seems to be a sufficiently strong phenomenological relationship that it should be taken into account in any biodiversity discussion. In particular, it may explain why organisms tend to form communities of approximately constant compositions, and why they tend to return to that composition after small disturbance (local stability) but may change to a new domain following large disturbances. The concept would seem to be a good explanation of the hill-and-valley model of community/environmental relationships (Laycock 1991), and, in the present work, to the differences in species proportions (k) between different treatments or over time.

Thus, while conceptually each species may have a unique response function and niche in relationship to a range of environmental factors, in practice it may appear that species vary in response to a particular level of an environmental factor. This is either because the levels of other controlling factors are unmeasured or unknown, or because there is community adjustment so that species abundances approach their log/linear proportions (i.e., fundamental versus realised niches).

The present work also demonstrates the dilemma in using manipulative treatments, such as fertiliser and grazing, as perturbations for measuring empirically the resilience of systems, as has been done in other studies (e.g., McNaughton 1993; Tilman 1993, 1996). These difficulties have been discussed by Huston (1997). In a climate-controlled climax view of an ecosystem, then, fertiliser and grazing could be regarded as perturbations. If the soil moisture/temperature/fertility/grazing concept is used, as here, then the perturbations are better viewed as a change to several new, different environments, and the consequent species changes as being an adjustment to the new conditions. It would seem that for valid empirical determination of resilience, the factors varied have to be new (e.g., sub-lethal selective herbicide), extremely rare, or of very short duration. Even rare events have to be treated with caution, e.g., Grime et al. (1988) argues that the uncoupling of resource capture and growth is a long-term evolutionary adaptation that characterises stress-tolerating species, to accommodate such infrequent events.

Sustainability

The main concept or test of sustainability is consistency through time. This means that pasture species have to at least establish and then persist for useful periods. A lesson from the present work was that suitable pasture species for a particular environment might not be predictable by extrapolation from other environments. A doubt initially expressed about the use of a multi-species mixture in the reported trials was that perennial ryegrass would competitively exclude all other species. In practice, however, perennial ryegrass proved unsuitable for any of the treatment combinations for the site, whereas other species not previously considered as pasture species were highly successful.

The main implication of the present work relating to the sustainability of pasture mixtures is that species selection for sowing must be closely linked to the actual environment and inputs proposed, i.e., species productivity and persistence was very dependent on the particular S and P fertiliser rates and the grazing management used. The results demonstrate the long-term sustainability of *Lupinus polyphyllus* pastures under low fertiliser inputs, the gradual increase in dominance and potentially long-term sustainability of *Trifolium ambiguum* under moderate and high fertiliser inputs, and that sowing pasture species alone without fertiliser will not overcome the *Hieracium pilosella* problem.

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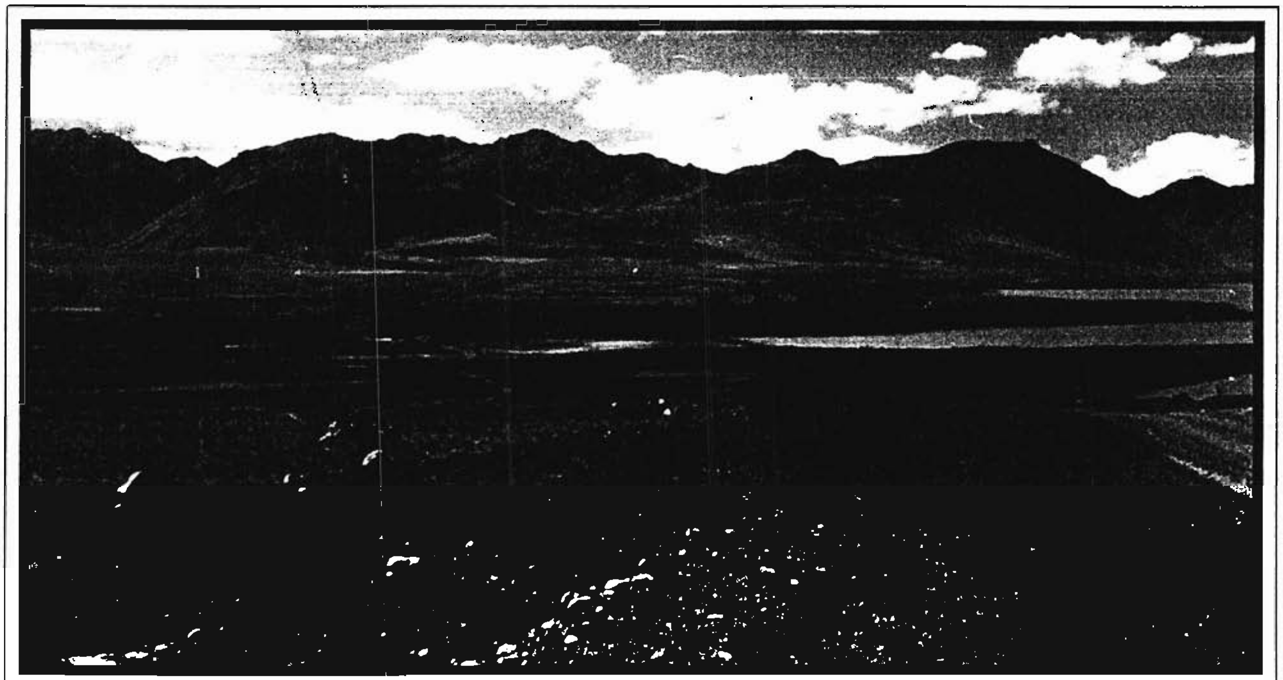

D Scott, L A Maunsell, J M Keoghan, B E Allan, W L Lowther, G G Cossens

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