Pasture composition and production from different cropping sequences in dryland pasture converted from *Pinus radiata* forest

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Abstract
Dry matter production and pasture composition were measured over 22 months in eight cropping sequences on a dryland site converted from forest to pasture. Cropping sequences involved different combinations of: (i) autumn and spring sowing; (ii) sowing immediately into pasture or into oat and triticale forage crops followed by pasture; and (iii) undersowing pasture beneath rape or conventional sowing. Annual DM production varied little among treatments (mean 6. 8 t DM/ha) once pastures were established in all sequences. Sites sown directly into pasture in autumn had a high (27%) annual legume content in the first spring but a low annual legume content in the second spring (<3%). Pastures undersown beneath a rape nurse crop after triticale and oat crops contained no gorse and had a higher percentage of white and Caucasian clover than conventionally sown pastures. Managers of forest to pasture conversion programmes should consider utilising a sequence of winter forage crops followed by pasture establishment beneath a rape nurse crop. This ensures superior woody weed control and a high abundance of pasture legumes to enhance nitrogen inputs.
Keywords: land-use conversion, plantation forestry, pasture, clover, weeds

Introduction
Increased demand for land for pastoral farming and declining returns from forestry are leading to large areas of *Pinus radiata* plantation forestry in the North and South Island being converted to pasture. The conversion to pasture is subject to a range of constraints that may limit pasture establishment and productivity. These include a low soil pH (4.6. to 4.9) which may lead to toxic levels of available aluminium in the soil; a large soil seed bank of woody weeds such as gorse (*Ulex europaeus*), broom (*Cytisus scoparius*) and blackberry (*Rubus fructicosus*), that may compete with establishing pastures and crops; a large quantity of woody pine debris, leading to a high soil C:N ratio and immobilisation of N during wood decomposition; a poor soil structure due to mulching and cultivation, which may make soils prone to wind erosion in dryland environments; and a lack of earthworms (Hawke 2004; Lloyd *et al*. 2007).

To overcome these constraints, it is important to develop crop sequences and establishment methods, and to choose species, that allow pastures of a high legume content to be established with few weeds and a low risk of erosion. A range of establishment methods is also desirable as the mechanical clearing and cultivation process of large blocks of forestry land may make land available for conversion at times of the year which are generally sub-optimal for pasture establishment.

This paper is part of a package of work investigating the conversion of pine forest owned by the Selwyn Plantation Board Limited on the Canterbury plains to productive grass-legume dryland pastures. The objectives of this trial were to examine the effects on dry matter production, botanical composition, the abundance of weeds, and earthworm populations of:

(i) sowing pastures directly or after the forage crops oats (*Avena sativa*) and triticale (x *Triticosecale* Wittmack);
(ii) undersowing pastures beneath rape or conventional sowing;
(iii) sowing pasture mixtures dominated by annual or perennial legumes.

Materials and Methods
Experimental site
The trial was located on a 30 ha dryland research site at Darfield, Canterbury. The site had been through three rotations of timber production between 1890 and 2003. *Pinus radiata* trees were felled and timber cleared during 2004. Following the removal of larger timber to burn piles, stumps and woody debris were mulched from September 2004 to March 2005. The site was then cultivated in preparation for sowing of crops and pastures in April 2005.

The soil type is a Lismore stony silt loam. Soil tests taken on 27 February 2005 after site clearing and mulching showed: soil pH = 4.6, Olsen P = 12 mg/kg, sulphate-S = 8 mg/kg, aluminium = 2.5 me/100g and C:N ratio = 23 (soil component only). To correct initial soil deficiencies, the site was fertilised with 10 t lime/ha, 300 kg superphosphate/ha, 0.5 kg boron/ha and 5 kg copper sulphate/ha on 23 and 24 March 2005. This gave soil test results of soil pH = 5.9, Olsen P = 21 mg/kg, sulphate-S = 12 mg/kg and aluminium <0.1 me/100 g in September 2005. Compared to the long term average

(777 mm), there was less rainfall in 2005 (485 mm) and more in 2006 (888 mm). Full climate details are given in Moot *et al*. (2007).

Experimental design

The trial consisted of four replicate blocks of eight cropping sequences allocated to 20 x 50 m (0.1 ha) plots. The eight cropping sequences were combinations of: autumn (13 April 2005), spring (28 September 2005) and autumn (3 March 2006) sowing; pastures sown either immediately or after forage crops; and pastures containing different grass, clover and herb species. The eight cropping sequences were:

GGG 20 kg/ha 'Tabu' Italian ryegrass (*Lolium multiflorum*) sown in autumn 2005;

PPP 12 kg/ha 'Meridian' perennial ryegrass (*Lolium perenne*), 3 kg/ha 'Grasslands Demand' white clover (*Trifolium repens*), 8 kg/ha 'Leura' subterranean clover (*Trifolium subterraneum*) and 2 kg/ha Bolta balansa clover (*Trifolium michelianum*) sown in autumn 2005;

TPP 100 kg/ha 'DoubleTake' triticale sown in autumn 2005, followed by 12 kg/ha 'Meridian' perennial ryegrass, 3 kg/ha 'Grasslands Demand' white clover, 3 kg/ha 'Grasslands Pawera' red clover (*Trifolium pratense*), 8 kg/ha 'Endura' Caucasian clover (*Trifolium ambiguum*), 1 kg/ha 'Grasslands Puna' chicory (*Cichorium intybus*) and 1 kg/ha 'Grasslands Lancelot' plantain (*Plantago lanceolata*) sown in spring 2005;

TRP 100 kg/ha 'DoubleTake' triticale sown in autumn 2005, followed by 1.5 kg/ha 'Winfred' rape, and the same clover and herb pasture mixture as in TPP. The triticale was grazed on 15 August 2005 and the pasture was undersown beneath rape, which was grazed off during January 2006. On 3 March 2006, 12 kg/ha 'Meridian' perennial ryegrass was direct drilled into half of the plot, and 3 kg 'Vision' cocksfoot was direct drilled into the other half;

OPP 100 kg/ha 'Hokonui' oats sown in autumn 2005, followed by the same pasture mixture as in TPP sown in spring 2006;

ORP 100 kg/ha 'Hokonui' oats sown in autumn 2005, followed by the same pasture and rape mixture as TRP sown in spring 2006. On 3 March 2006, 12 kg/ha 'Meridian' perennial ryegrass was direct drilled into half of the plot, and 3 kg 'Vision' cocksfoot was direct drilled into the other half;

FPP Fallow from autumn 2005 to spring 2005, followed by the same pasture mixture as in TPP sown in spring 2006;

FFP Fallow from autumn 2005 to autumn 2006, followed by same pasture mixture as in PPP sown in autumn 2006.

Initial crops were established by conventional drilling following cultivation; subsequent pastures were direct drilled using a triple disc drill. New seedlots were used at each time of sowing. Germination of all species tested on moist filter paper in the lab exceeded 85%. Nitrogen fertiliser (50 kg N/ha), as urea, was applied to oat and triticale plots in May 2005. The eight cropping sequences in each block were grouped together for grazing and rotationally grazed in common five or six times per year with Corriedale ewes or hoggets at a stocking rate of 600 sheep/ha. The first grazing was on 15 August 2005. Subsequent grazing was scheduled to occur when pasture mass was in the 2000 to 2250 kg DM/ha range. Post grazing pasture masses were in the 400 to 700 kg DM/ha range. Grazing typically took 2 days to complete. Later establishing crop sequences were fenced to exclude sheep until plots were ready for grazing. Glyphosate was applied at 2.5 L/ha on 26 September 2005 to FPP plots and Roundup Transorb was applied at 4 L/ha to FFP plots on 26 February 2006.

Measurements

Pasture mass was assessed pre- and post-grazing from August 2005 to January 2007 (Table 1) by taking 30 rising plate meter measurements per plot. The meter readings were calibrated each time by 20 x 0.2 m^2 quadrats cut across a range of treatments. Three 0.2 m^2 quadrats per plot were cut to ground level on 1 December 2005 (GGG and PPP), 31 January 2006 (FPP, TRP, TPP, ORP, OPP), and 6 November 2006 (all treatments). A sub-sample of the cut herbage was sorted to species, and oven dried at 65ºC to determine botanical composition on a dry matter basis. Earthworms were counted in four 20 cm x 20 cm x 15 cm deep cores in each FFP, PPP and TPP plot on 5 September 2006. Data were analysed by ANOVA of a randomised block design. For botanical composition data, the analysis of treatment effects on a given species only included those treatments where the species had been sown. Percentage botanical composition data were arcsine transformed prior to ANOVA to homogenise variance. Untransformed mean percentage values are presented in Tables, but all tests of significance were done on the transformed scale.

Results

Dry matter (DM) production

From a 13 April 2005 sowing, triticale and oat crops produced more DM by 15 August 2005 than grass (GGG) or pasture (PPP) plots (Table 1). From 16 August 2005 (late winter) to 31 January 2006 (mid summer), DM production was lower in TPP, FPP and OPP than

Table 1 Mean pasture or crop grown (t DM/ha) in the eight cropping sequences during seven regrowth periods from April 2005 to February 2007. Means followed by the same letters within a row do not differ significantly according to a LSD (α=0.05) test following a significant ANOVA.

Regrowth periods	GGG	PPP	TRP[3]	TPP	ORP[3]	OPP	FFP	FPP	P value	LSD
13 Apr - 15 Aug 05[1]	1.5b	1.4b	2.6a	2.5a	2.8a	2.7a	nr	nr	<0.01	0.47
16 Aug 05- 31 Jan 06[2]	4.6a	5.2a	4.5a	3.3b	4.6a	3.2b	nr	3.5b	<0.01	0.93
1 Feb - 20 Jun 06	1.6a	1.9a	1.1b	1.2b	1.1b	1.2b	0.5c	1.4b	<0.01	0.31
21 Jun - 21 Sept 06	0.8c	1.1a	0.5d	0.9bc	0.5d	0.8c	0.5d	1.0ab	<0.01	0.16
22 Sept - 8 Nov 06	1.5a	1.7a	1.8a	1.9a	1.7a	2.0a	1.6a	2.0a	0.06	0.36
9 Nov 06 - 1 Feb 07	2.4a	1.9a	3.5a	3.1a	3.2a	2.7a	2.2a	2.8a	0.11	0.89
1 Feb 06 - 1 Feb 07	6.3a	6.6a	6.9a	7.1a	6.5a	6.7a	4.8b	7.2a	<0.01	1.09

[1] Triticale or oats DM in TRP, TPP, ORP and OPP.
[2] For GGG and PPP, pasture grown is combined value of pasture mass measurements prior to grazing on 15 November 2005 and 31 January 2006; other plots were only grazed once on 31 January 2006.
[3] DM recorded for perennial ryegrass half of plot.
nr: not recorded as cropping sequence yet to start

Table 2 Mean botanical composition (%, untransformed data) for the eight cropping sequences on 31 January 2006. Means followed by the same letters within a row do not differ significantly according to a LSD (α=0.05) test following a significant ANOVA on the transformed scale.

Species	GGG[1]	PPP[1]	TRP	TPP	ORP	OPP	FFP	FPP	P value
Ryegrass	85.2	52.6	nr	20.4a	nr	19.5a	nr	39.6a	0.15
White clover[2]	0.2	6.8a	20.4a	16.4a	17.3a	16.3a	nr	12.2b	0.50
Red clover	nr	nr	31.8a	39.8a	25.7a	36.0a	nr	21.2a	0.15
Caucasian clover	nr	nr	1.5a	0.1c	0.5b	0.1c	nr	nr	0.04
Sub clover	nr	15.9	nr	nr	nr	nr	nr	nr	nr
Balansa clover	nr	11.3	nr	nr	nr	nr	nr	nr	nr
Rape	nr	nr	26.7a	nr	36.8a	nr	nr	0.0	0.35
Plantain	nr	nr	2.3a	9.1a	4.2a	5.4a	nr	4.9a	0.14
Chicory	nr	nr	6.3a	8.0a	3.9a	12.3a	nr	6.3a	0.21
Gorse	5.8a	2.9b	0.2d	0.9c	0.3d	1.3c	nr	2.3b	0.04
Other weed	1.5b	2.5b	1.9b	1.4b	1.0b	5.3a	nr	7.6	<0.01
Dead	7.3a	8.0a	8.9a	3.9a	10.3a	3.8a	nr	5.9a	0.09

[1] GGG and PPP based on 1 December sample, so not included in ANOVA.
[2] White clover not analysed in GGG plots as not sown there.
nr: not recorded as cropping sequence not yet started or not sown in that treatment.

Table 3 Mean botanical composition (%, untransformed data) for the eight cropping sequences on 6 November 2006. Means followed by the same letters within a row do not differ significantly according to a LSD (α=0.05) test following a significant ANOVA on the transformed scale.

Species	GGG	PPP	TRP	TPP	ORP	OPP	FFP	FPP	P value
Ryegrass	81.0a	76.7a	8.1d	27.0c	13.5d	31.6c	67.2a	42.0b	<0.001
White clover[1]	4.2	10.8e	41.3a	26.9b	37.5a	26.9b	21.3c	15.6d	<0.001
Red clover	nr	nr	28.3a	30.0a	24.3a	22.5a	nr	23.6a	0.67
Sub clover	nr	2.6	nr	nr	nr	nr	2.8	nr	na
Balansa clover	nr	0.3	nr	nr	nr	nr	0.3	nr	na
Caucasian clover	nr	nr	5.6a	0.0b	6.0a	0.1b	nr	nr	<0.001
Chicory	nr	nr	8.8a	7.8a	9.5a	8.8a	nr	8.0a	0.58
Plantain	nr	nr	4.3a	3.5a	5.5a	4.9a	nr	5.4a	0.41
Gorse	3.6a	1.6b	0.0e	0.8d	0.0e	0.9d	1.9c	1.4c	<0.001
Other weeds	3.8a	1.4b	0.8c	1.3b	0.5c	1.1b	3.1a	0.6c	0.03
Dead	7.4a	6.6a	2.8a	2.7a	3.2a	3.2a	3.4a	3.4a	0.12

[1] White clover not analysed in GGG plots as not sown there.
nr: not recorded as cropping sequence not yet started or not sown in that treatment.
na: not analysed as present in low abundance.

autumn 2006 sown pasture (PPP, GGG) or pastures containing rape (TRP and ORP) (Table 1). Rape contributed 1.2 t DM/ha (26.7%) in TRP and 1.6 t DM/ha (34.8%) in ORP treatments in January 2006. From 1 February to 20 June 2006, DM production was greatest in PPP and GGG (Table 1) and lowest in FFP. All other cropping sequences produced similar DM. Winter and early spring DM production (21 June to 21 September 2006) was lowest in pastures undersown beneath rape (TRP and ORP) (Table 1). Early spring (21 September to 8 November 2006) and summer (9 November 2006 to 1 February 2007) DM production did not differ among treatments. Annual DM production (February 2006 to February 2007) was lowest in FFP, with all other treatments producing similar DM (Table 1).

Botanical composition

In December 2005, subterranean and balansa clover combined contributed 27.2% of the DM, but in November 2006 they were only present in low abundance (<3% combined, Tables 2 and 3). The percentage of perennial legume in all spring sown pastures (TRP, ORP, TPP, OPP and FPP) was high in January 2006 (>30% total perennial clover, Table 2) and remained high in November 2006 (>39% total clover, Table 3). In November 2006, the percentage of white and Caucasian clover was greater when undersown beneath rape (TRP and ORP) than when drilled with ryegrass (TPP and OPP) (Table 3). In TRP and ORP cropping sequences, where perennial ryegrass was direct drilled into clover-herb based pastures in April 2006, the percentage of perennial ryegrass was considerably lower than other sequences in November 2006 (Table 3). In November 2006, the percentage of sown grass in the part of the TRP plot drilled with cocksfoot (1%) was lower than in the part of the plot drilled with ryegrass (8.1%). There was no effect of cropping sequence on the percentage of chicory and plantain in both January and November 2006. The percentage of gorse was lowest in treatments where triticale and oats were initially sown, with no gorse found in TRP and ORP sequences in November 2006 (Tables 2 and 3). Other weeds (Table 2 and 3) were made up of mainly sheep's sorrel (*Rumex acetosella*) and fathen (*Chenopodium album*) and these were most abundant in the GGG and FPP plots in November 2006.

Earthworms

No earthworms were found in any plots sampled in September 2006.

Discussion

A feature of the results was the higher legume content in November 2006 where pasture mixtures were undersown beneath the rape sown at 1.5 kg/ha (TRP and ORP) and perennial grass was added later compared to those that were conventionally sown (TPP, OPP). This reflected a greater abundance of white and Caucasian clover but not red clover where these species were undersown compared to where they were conventionally sown with perennial ryegrass. Previous studies (Cullen 1964; Mills *et al.* 2007) have indicated that rape may be a useful nurse crop, particularly on low fertility sites such as former forestry land. It is notable that the high legume content was achieved with little cost in terms of DM production. Although winter DM production was lower in TRP and ORP than other treatments, reflecting a low grass content (Table 3), total annual DM production (February 2006 to February 2007) was similar between pastures that were undersown and conventionally sown. Moreover, for spring 2006 sown pastures, greater (*c.* 1.1. t DM/ha) production was recorded in the establishment period with undersowing than with conventional sowing due to the extra growth of the rape crop.

The aim of drilling grass into the TRP and ORP treatments in autumn after the legumes and herbs were established the previous spring was to minimise the competitive effects of the grass at establishment and to enhance and sustain high legume abundance (Hurst *et al.* 2000). In these treatments, both cocksfoot and ryegrass remained at low abundance (<9% in November 2006), indicating that the competitive effect of the established legume, chicory and plantain plants on grass seedlings may have been marked, even when their growth may have been slowing due to the onset of cooler winter temperatures. Of note is that cocksfoot (1%) had a lower abundance than perennial ryegrass (8.1%) in TRP plots in November 2006. This result is probably due to the slower establishment and lower seedling vigour of cocksfoot compared to perennial ryegrass (McWilliam *et al.* 1970; Moot *et al.* 2000); a better strategy for the less competitive cocksfoot may have been to undersow it beneath the rape in spring at the same time as the legume-herb mixture (Mills *et al.* 2007).

Cropping sequence also had an important impact on weed abundance, with land that was first sown into the winter forage crops, triticale and oats, and then into pastures having less gorse and other weeds than land sown directly into pasture. It is notable that no gorse was found in both treatments where pasture was undersown beneath rape (TRP, ORP). The low gorse abundance in undersown plots of high pasture legume abundance is consistent with previous studies (Hartley & Phung 1982) noting reduced gorse seedling survival where white clover was added to a grass based pasture mixture. A more detailed analysis of gorse seedling survival at this site (Edwards *et al.* 2007) indicated that the low gorse abundance in the TRP sequence was due to low gorse seedling survival when oats or triticale were intensively grazed during August 2005 and further high mortality during the pasture phase.

Pasture sown directly into grasses and legumes in April 2005 (PPP) had a very low abundance of the annual legumes subterranean clover and balansa clover in spring 2006. This was despite both legumes establishing well in the first year, reaching 15.9% (subterranean clover) and 11.3% (balansa clover) of the DM in late spring 2005, being grazed laxly to promote seed production (estimated at 150 kg seed/ha in balansa clover, G.R. Edwards unpublished data), and then grazed to pasture residuals of 700-1000 kg DM/ha in January to open up the pasture for establishment in late January. The low re-establishment may reflect the high level of hard seed in Luera subterranean clover and Bolta balansa clover under Canterbury conditions (Snowdon 2000; G. Edwards unpublished data). The phenomenon of low re-establishment in balansa clover despite high seed yields in the summer after establishment has been evident at other experimental dryland sites in Canterbury and is the subject of current investigations.

Hawke (2004) recorded some colonisation of a 1 ha area by earthworms 3 years after a forest site was converted to pasture in the South Waikato district. However at this 30 ha site, no earthworms were found in the soil 18 months after the first crops and pastures were established. This is a concern as earthworms have long been regarded as beneficial soil organisms, enhancing nutrient availability, increasing drainage and improving soil structure and root penetration (Stockdill & Cossens 1966). The value of worm seeding has been demonstrated in degraded pastures (Stockdill & Cossens 1966) and work is proceeding at the current site to investigate the most effective strategy of introducing earthworms.

Conclusions and Practical Implications

In conclusion, managers of forest to pasture conversion programmes should consider utilising a sequence of annual forage crops before sowing permanent pasture. This ensures superior woody weed control and high legume abundance. The clover dominant pastures will enhance livestock feeding value and increase nitrogen inputs into the soil, which in turn should promote pasture growth and the decomposition of woody debris (Condron *et al*. 2007).

ACKNOWLEDGEMENTS

Selwyn Plantation Board Limited provided financial support for this project.

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