THE EFFECT OF GRAZING WILLOW (*Salix* spp.) FODDER BLOCKS UPON REPRODUCTIVE RATE AND MANAGEMENT OF INTERNAL PARASITES IN MATED HOGGETS

A thesis presented in partial fulfilment of the requirements for
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DECLARATION

The studies presented in this thesis were completed by the author whilst a Postgraduate student in the Institute of Veterinary, Animal and Biomedical Science, Massey University, Palmerston North, New Zealand. I hereby affirm that the content of this thesis is original research conducted by the author. All views and conclusions are the sole responsibility of the author. All references to previous work are included in the references section of each chapter. Any assistance received during the preparation of this thesis has been acknowledged.

I certify that the content of this thesis has not already been submitted for any degree and is not being currently submitted for any other degree. I certify that to the best of my knowledge any help received in preparing this thesis, and all sources of materials used, have been acknowledged in the thesis.

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ABSTRACT

A grazing experiment was conducted for 116 days from 19 January to 15 May in the late summer/autumn of 2006 at Massey University's Riverside dryland Farm, near Masterton (New Zealand) to compare the effect of grazing willow fodder blocks or control perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture, during the pre-mating and mating periods, on gastrointestinal parasitism control and reproductive rates in 7 months old ewe hoggets. A rotational grazing system with 348 Romney weaned hoggets was used. Hoggets were randomly allocated to three treatment groups (116/group), being: control pasture with regular anthelmintic drenching, control pasture with trigger drenching (drenched only when mean faecal egg count of each group exceeded 1000 eggs/g wet faeces) and willow fodder blocks with trigger drenching. Four replicated pasture areas and five replicated willow fodder blocks were rotationally grazed by single groups of animals, using animals as the replicates for statistical analysis. The fodder blocks contained small trees and a mixture of herbage growing under the trees. After mating, the three groups were joined together and managed as one group until the end of the experiment at weaning, on 7 January 2007. Hogget live weight (LW), dag scores, faecal egg counts (FEC) and reproductive rate at foetal ultrasound scanning, lambing, docking and weaning were measured. Ewe hogget wool production was measured at weaning.

Relative to control pastures, fodder block herbage was of lower dead matter content and its legume content was slightly higher. Total N concentration (35 g/kg dry matter; DM), organic matter digestibility (OMD; 0.68) and metabolisable energy (ME; 10 MJ/kg DM) were similar for fodder block pasture and control pasture; the selected tree fodder had lower concentrations of N (24 g/kg DM) and was higher in OMD (0.74) and ME (10.4 MJ/kg DM). Tree fodder contained higher concentrations of CT (22.9 g/kg DM) compared to 1.6 g/kg DM in control pasture and herbage in willow fodder blocks.

Grazing willow fodder blocks increased LWG (approximately 97 g/day vs. 86 g/day; $P < 0.0001$) and increased reproductive rate corrected to equal LW by approximately 17% units ($P < 0.05$), due to increases in both oestrus activity ($P < 0.01$) and conception rates (hoggets pregnant/100 hoggets mated; $P < 0.05$). Calculated daily DM (1.41 kg) and ME (14 MJ) intake were similar in all groups. Calculated daily CT intake (6.0 g vs. 2.1 g) and CT intake/100 g CP intake (2.2 g vs. 0.7 g) was higher for willow fodder block hoggets than for the control pasture groups; this may have increased the flow of undegraded dietary protein (UDP) to the small intestine, leading to increases in reproductive rate of this group. Grazing willow fodder blocks failed to reduce the number of anthelmintic drenches (3) needed to maintain FEC below 1000 epg wet faeces, but was successful in reducing dag score relative to grazing conventional ryegrass/white clover pastures.

It was concluded that grazing willow fodder blocks can play a beneficial role in sustainable farming systems as it can sustain animal growth rates, increase reproductive rate and reduce dag formation in parasitized hoggets. These benefits were associated with reduced dead matter content and increased legume content in fodder block herbage and with increased intake of secondary compounds from the trees. However, both pasture and trees need to be managed as a tree/pasture system in order to produce herbage of higher nutritive value and more efficiently utilise willow fodder blocks as a supplementary feed. After 6 years of grazing in this manner, the survival rate of the trees was approximately 85 %.

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DEDICATED TO:

MY WIFE BRENDA,

MY CHILDREN KAPEMBWA, NATASHA, CHAMA AND MANASSEH,

DAD, MUM AND MOTHER IN LAW,

AND MY BROTHERS AND SISTERS,

FOR THEIR ENDLESS LOVE, PATIENCE AND ENCOURAGEMENT.

LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
B	Billion
BCAA	Branched chain amino acids
BCS	Body condition score
C	Carbon
CH_4	Methane
CHO	Carbohydrate
cm	Centimetre
cm^3	Cubic centimetre
CO_2	Carbon dioxide
CP	Crude protein
CT	Condensed tannins
D	Diameter
DM	Dry matter
DOMD	Digestible organic matter in the dry matter g/100 g DM
DP	Digestible protein
DS	Dag score
EAA	Essential amino acids
epg	Eggs per gram
FA	Feed allowance
FEC	Faecal egg count
G	Gram
GA	Grazing area
GI	Gastrointestinal
GLM	General linear model
h	Hour
ha	Hectare
HCl	Hydrochloric acid
HM	Herbage mass (kg DM/ha)
HT	Hydrolysable tannin
kg	Kilogram
L_1	First larval stage
L_2	Second larval stage
L_3	Third larval stage
LP	Lambing percentage
LW	Live weight
LWG	Live weight gain
M	Million
M/D	MJ ME/kg DM
MAF	Ministry of Agriculture and Forestry
ME	Metabolisable energy
MJ	Mega joule
m	Meter
mm	Millimeter
MRT	Mean retention time
MW	Molecular weight
N	Nitrogen
N_2O	Nitrous oxide
NAN	Non ammonia nitrogen

NDF	Neutral detergent fibre
NEAA	Non essential amino acid
NH_3	Ammonia
NV	Nutritive value
NZ$	New Zealand dollar
^{o}C	Degrees Celsius
OM	Organic matter
OMD	Organic matter digestibility
OR	Ovulation rate
P	Probability
PEG	Polyethylene glycol
pH	Measure of acidity
SE	Standard error
SSH	Sward surface height
TGD	Total grazing days
t	Days
UDP	Undegraded dietary protein
VFA	Volatile fatty acid
VFI	Voluntary feed intake
vs	Versus

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CHAPTER 1.

REVIEW OF LITERATURE

1. 1 Introduction

The sheep industry plays a fundamentally important role in New Zealand's economy, particularly in the export sector and employment. Estimates for the year-ending March 2005 from the New Zealand (NZ) Ministry of Agriculture and Forestry (MAF) show that the sheep industry earned a total of NZ$2.88 billion (B) in trade revenue alone. This accounted for 23% of total pastoral exports of an industry worth NZ$12.5B and 10% of the total New Zealand export earnings (MAF, 2005). Mating of ewe hoggets (6-9 months old female lambs) has been identified as one way of increasing net profits for the sheep industry, due to the extra generation of lambs produced (Kenyon *et al.*, 2004). However, in NZ, lambing percentages (LP; lambs weaned per 100 ewes mated) of hoggets are often disappointing (national average of 60%), limiting the uptake of this management strategy (Kenyon *et al.*, 2004). Subclinical infections of gastro-intestinal (GI) nematodes (Howse *et al.*, 1992) and poor nutrition due to dry summer conditions (McWilliam, 2004) are responsible for considerable economical losses on many NZ sheep pastoral farms, particularly on the East Coast.

GI parasites are estimated to cost the NZ sheep industry $300 M annually in lost production and anthelmintic control (Rattray, 2003). GI parasites cause extensive loss of protein, leading to a decline in animal performance such as reduced body growth, reduced reproduction rates and increased mortality. However, of great importance is the development of resistance of parasites in sheep, goats and cattle in NZ, to anthelmintic drenches (Pomroy *et al.*, 2002; Min *et al.*, 2003). Anthelmintic resistance was first confirmed in 1979 and is a common problem today; more than 50% of New Zealand sheep farms now have detectable levels of resistance to one or more chemical classes of anthelmintic (Leathwick *et al.*, 2001). Alternative non-chemical control strategies for nematodes are currently being explored. Experimental evidence indicates that grazing some forages containing secondary compounds may lead to more sustainable management of internal parasites, by reducing the frequency of anthelmintic administration required for control (Ramirez-Restrepo and Barry, 2005; Hoste *et al.*, 2006).

Nutrition is one of the most significant environmental influences on reproductive performance of sheep (Smith, 1991). Both ovulation rate and lambing percentage (LP) of ewes can be increased by provision of increased levels of nutrition in the pre-mating period (Smith, 1991; Smith *et al.*, 1983). However, dry summer/ autumn conditions reduce pasture growth and quality on dryland farms (farms experiencing annual water deficits in the 300- 500 mm range in the summer/autumn months), thus limiting feed availability for grazing ewes during the pre-mating and mating periods (McWilliam *et al.*, 2005b). This can lead to live weight (LW) and body condition score (BCS) losses and, during mating, reduced ovulation rate and subsequent LP (Rattray *et al.*, 1983; Smith and Knight, 1998). Studies recently conducted by McWilliam *et al.*, (2004, 2005b) showed that supplements of CT-containing forage trees (poplar and willow) in ewes grazing drought pasture during mating reduced LW loss and markedly increased reproductive rates.

The purpose of this review is to discuss the feeding and nutritive values of forages, including plant secondary compounds and their role in ruminant nutrition and to summarize the effects of parasites in young sheep, including current /potential alternative control methods. Special emphasis will be placed on the effect of including willow (*Salix* spp.) trees in a grazing rotation on sustainable control of internal parasites and on reproductive rates in mated ewes grazing dry summer pastures, with a view to applying this technique to the nutrition of hoggets before and during mating.

1.2. Sheep production and grazing systems in New Zealand

1.2.1 Sheep production

The New Zealand sheep population has shown a downward trend since the peak of 1982 (70.3 M), before stabilizing from the year 2002 onwards (Table 1.1; MAF, 2005). This is largely due to the removal of all forms of livestock subsidies in the mid 80's and land use changes in favour of deer, forestry and dairy (MAF, 2003). Despite the fall in sheep numbers over the last 23 years, the number of lambs weaned per 100 females mated increased from 100 in 1990 to 139 in 2005. This is attributed to improved genetic selection, ultrasound pregnancy scanning and better flock management i.e., improved nutrition. During the same period, there was an increase in the number of ewe hoggets put to the ram (MAF, 2005). New Zealand sheep production and management is based on an annual cycle, with the breeding season in March/April (autumn), lambing in

August/September (late winter/early spring), and weaning in November/December (early summer; Matthews *et al.*, 1999).

Table 1.1: Changes in the New Zealand sheep population from 1982 to 2005 (all values in Millions; M).

Year	1982	1994	1999	2002	2003	2004	2005
Total sheep	70.3	49.5	45.7	39.6	39.6	39.3	39.9
Ewe hoggets put to ram	2.1	1.3	1.9	2.4	2.3	2.7	3.1
Breeding ewes put to rams	50.3	34.4	30.4	26.8	27.1	26.7	26.3
Lambs weaned (from hoggets)	-	-	-	1.1	1.1	1.1	1.4
Lambs weaned (from breeding ewes)	-	-	-	31.5	32.2	30.8	39.7

Source: Ministry of Agriculture and Forestry (1994-2005)

1.2.2 Sheep grazing systems

In NZ, around 90% of the total nutrient requirements of ruminants come directly from pasture (Hodgson, 1990); typically comprising mixtures of white clover (*Trifolium repens*) and perennial ryegrass (*Lolium perenne*). The percentage of white clover in mixed pastures is normally 20 to 30% but can be as low as 2% in infertile hill country pastures (Kemp *et al.*, 1999). White clover fixes nitrogen and has a high nutritive value compared to ryegrass (Ulyatt *et al.*, 1988), but if used in excess can cause bloat problems in cattle. Ryegrass is widely used due to its ability to establish rapidly, grow throughout the year (winter-active grass) and tolerate treading damage and hard grazing. Livestock performance under grazing is affected by several factors, including grazing systems. A grazing management system is an integrated combination of animal, plant, soil and other environmental components designed to achieve specific results or goals of a producer (Clark and Kanneganti, 1998). The following is a definition of the two main grazing management systems used in NZ.

Continuous stocking management

In a continuously stocked system, animals remain on the same pasture for long periods of time (i.e. throughout the season). Set stocking is an extreme case of continuous grazing in which no adjustment to stock numbers is made despite changes in pasture conditions (Matthews *et al.*, 1999). Under continuous stocking management, pasture intake and animal performance increases at a progressively declining rate towards a maximum value as sward surface height (SSH) increases (Hodgson and Brooks, 1999). The critical SSH for grazing sheep is about 6 to 7cm. Generally, lamb producers favour a system of continuous stocking from lambing to weaning in order to maximise lamb performance (Matthews *et al.*, 1999). The advantages of this system are reduced input costs in fencing, water reticulation and labour. A major disadvantage is the requirement for greater skill in monitoring sward growth and in managing grazing pressure (Clark and Kanneganti 1998).

Rotational grazing system

In this system, a pasture is divided into smaller units called paddocks and is grazed in sequence, each for a short period (1 to 20 days) before the animals are moved into a new paddock. Intermittent stocking allows a rest period for plants to recover from grazing. The optimum rest period varies across the season depending on the stage of plant development, plant growth rate and defoliation intensity. Under this system, herbage intake and animal performance have often been related to variations in daily herbage dry matter (DM) allowance (Hodgson 1990; Clark and Kanneganti, 1998; Matthews *et al.* 1999). Rotational grazing, particularly over the winter months where feeding levels are relatively low and pasture intakes restricted, gives rise to a number of different rotational grazing systems such as the strip, block, on/off and leader follower grazing systems. Rotational grazing is popular with NZ sheep producers over the winter months.

1.2.3 Recommended pasture allowances, height and pre-and post-grazing herbage masses.

Typical LW gains during lactation for NZ twin-born lambs is 200 g/day and 300 g/day for single-born lambs, with a pasture allowance of 6 kg DM/ewe/day. However, sward characteristics affect sheep performance through its effects on pasture intake and quality. Recommended residual pasture mass, SSH and pasture allowance to achieve optimum sheep performance when grazing NZ pasture are shown in Table 1.2.

Table 1.2 Recommended continuous stocking sward surface height (SSH), rotational grazing herbage allowance and post grazing herbage mass for NZ sheep production systems.

Animal class and performance	Continuous stocking SSH (cm)	Rotational grazing		Energy value of herbage consumed (MJ ME/kg DM)
		Pasture allowance (kg DM/ha)	Post grazing herbage mass (kg DM/ha)	
Ewe plus twins (early lactation)	7-8	4.5-6.5	1400-1600	11-12
Ewe plus singles (early lactation)	6-7	4.5	1400	11-12
Dry ewes	3-4	-	800-1000	10.5-11.5
Pregnant hoggets	-	4-5	1100-1200	10.5-11.5
Lambing season (early spring)	4-5	-	1200	11.5 -12

Adapted from: (Rattary and Jagusch, 1987; Hodgson, 1990; Hodgson and Brooks, 1999; Matthew *et al.*, 1999; Gavigan and Rattray, 2002.)

1.2.4 Nutritional problems in dryland farming

In NZ, some areas (Gisborne, Hawkes Bay, Wairarapa, Marlborough, most of coastal Canterbury, and Inland Otago) are considered summer dry and experience annual water deficits in the 300-500 mm range in the summer/autumn months (NIWA, 2005). According to the definition by NIWA (2005), a potential evapotranspiration deficit (PED) between 200 mm to 400 mm indicates very dry weather conditions, a PED of >400 mm could result in a drought and >600 mm corresponds to a severe drought. Using current models of climate change, all scenarios indicate that both the frequency and severity of drought is likely to increase in NZ, especially in the dry East coast regions of both Islands, and that two new areas (Bay of Plenty and Northland) will have a higher risk of developing drought. Under all climate change scenarios, a 1-in-20 year severe drought in eastern regions becomes more common in future. By 2080s, the frequency of a current 1-in-20 year PED increases between two and more than fourfold, depending on the scenario. That is, a severe drought that currently occurs once in 20 years on average could become a 1-in-10, or even a 1-in-5 year, event in that same area in the future.

Long periods of hot dry weather conditions over the summer/autumn period in these regions (Gisborne, Hawkes Bay, Wairarapa, Marlborough, most of coastal Canterbury, and Inland Otago), inhibit grass and clover growth and create swards with low herbage mass (< 1200 kg DM/ha) and high dead matter content (> 50%). These pastures have low metabolizable energy (ME) and crude protein (CP) contents of 8 Mega Joules (MJ)/kg DM and 100 g/kg DM respectively, in contrast to typical summer/autumn pastures which have an ME content of 10 MJ/kg DM and 150 g CP/ kg DM (Ulyatt *et al.*, 1980; Waghorn and Barry, 1987a; Hodgson and Brooks 1999). For these reasons, farms in these areas are defined as dryland farms.

Low herbage mass and poor nutritional quality pastures lead to losses in ewe LW and body condition score (BSC). Loss of LW in the critical pre-mating and mating periods reduces ovulation rate and subsequent LP (Rattray *et al.*, 1983; Geenty, 1998; McWilliam *et al.*, 2004). Pasture with high dead matter content also creates perfect conditions for fungal growth, in particular, *Fusarium sp* which produce zearalenone; this reduces the ovulation rate and LP by 10-25% (Towers., 1992; McWilliam *et al.*, 2004). *Fusarium* spp. also produces trichothecenes toxins, which may be involved in animal ill-thrift disorders (failure to grow or produce) under New Zealand autumn grazing conditions (Lauren *et al.*, 1988; Towers., 1997).

1.3 Principles of forage feeding value

The feeding value of any forage ultimately determines its usefulness. Feeding value is defined as the animal production response to grazing forage under unrestricted conditions (Ulyatt *et al.*, 1973; Ulyatt., 1980), with its components being voluntary feed intake (VFI), the digestive process (digestibility) and the efficiency of utilisation of digested nutrients; the latter two comprise nutritive value (NV; Barry, 1998). The NV of forage can also be defined as the nutrient concentration per unit of feed, expressed in

MJ of ME / kg DM, or M/D (Ulyatt *et al.*, 1980). Legumes generally have a higher feeding value than grasses that is indicated by faster growth rate in lambs (Table 1.3 and 1.4) and greater milk production in lactating dairy cows grazing legumes. It is estimated that 50% of the differences in feeding value between forages is due to differences in voluntary feed intake (Ulyatt, 1981).

Digestion is a key process controlling both intake and utilisation of forage (Ulyatt *et al.*, 1980). There is a positive relationship between digestibility and VFI, with forage intake increasing as digestibility increases (Ulyatt *et al.*, 1980). Digestibility is clearly related to herbage maturity and there is a general pattern for all species. For temperate herbage, a high digestibility is maintained in the spring and this declines as the plant matures over the summer. The decline in digestibility with maturity is associated with an increase in the proportion of the less digestible structural carbohydrates (cellulose and hemicellulose) and lignin; and a reduction in readily fermentable carbohydrates (soluble sugars and pectin) and crude protein (Ulyatt, 1981). Feeds with a higher ratio of readily fermentable carbohydrates to structural carbohydrates (i.e. white clover and chicory) break down much faster in the rumen, increasing the fractional disappearance rate of the digesta from the rumen, reducing rumen mean retention time (MRT) and thus increasing VFI (Table 1.3 and 1.4). Forages containing less than 90g CP / kg DM are poorly digested and VFI is low as they fail to supply the minimum nitrogen (N) requirement for adequate rumen microbial synthesis. However, most New Zealand pastures contain 120-250 g CP / kg DM (Waghorn and Barry 1987a).

Table 1.3 Growth rate (g/day) and some digestive parameters from lambs grazing fresh 'Ruanui' perennial ryegrass and 'Huia' white clover.

	'Ruanui' Perennial ryegrass	**'Huia'** white clover
Live weight gain (g/d)	227	331
Organic matter (OM) intake (g/d)	1086	1243
Apparent OM digestibility (%)	80	82
OM retention time in rumen (h)	10.4	6.3
Carbohydrate ratio*	0.57	1.25

Adapted from Ulyatt 1981

*Ratio of readily fermentable carbohydrate: structural carbohydrate

Table 1.4 Live weight gain, dry matter intake, chewing time and rumen mean retention time of red deer fed chicory and perennial ryegrass

	Perennial ryegrass	Chicory
Live weight gain (g/d)	191	282
Intake (kg DM/d)	2.02	2.25
Carbohydrate ratio*	0.31	1.04
Apparent OM digestibility (%)	0.74	0.82
Chewing time (min):		
Eating	221	209
Ruminating	257	30
Rumen retention time (h)		
Liquid	8.9	6.4
Particulate (lignin)	49.0	37.7
Particulate (ADF)	52.5	27.9

Adapted from Kusmartono *et al.*, (1996; 1997)

*Ratio of readily fermentable carbohydrate: structural carbohydrate

In ruminants, 60% of total feed organic matter (OM) digested is digested in the rumen (Ulyatt *et al.*, 1980). Digestion in the rumen and large intestine is by microbial fermentation and while this process is beneficial, in that it enables ruminants to digest structural carbohydrates to volatile fatty acids (VFA), it occurs with a loss of approximately 25% of digestible energy as methane and heat (Ulyatt, 1981). In addition, fermentation of protein in the rumen results in loss of N as ammonia. Approximately 70% of protein in fresh temperate herbage is degraded to ammonia and only 30% escapes intact to the small intestine for absorption (Waghorn and Barry, 1987a). Although degradability of dietary protein is approximately the same for grasses and legumes, undegraded dietary protein (UDP) supply is generally greater for legumes than grasses either because the N in the legume is utilized more efficiently by rumen micro-organisms or because of the low MRT (Ulyatt, 1981). Low to moderate (5 to 40 g/kg DM) concentrations of condensed tannins (CT) in the diet can increase the flow of non-ammonia-nitrogen (NAN) to the intestine, relative to nitrogen intake (Barry *et al.*, 2001). Differences in chemical composition of the forage would therefore be expected to cause differences in the efficiency with which the diet is utilised.

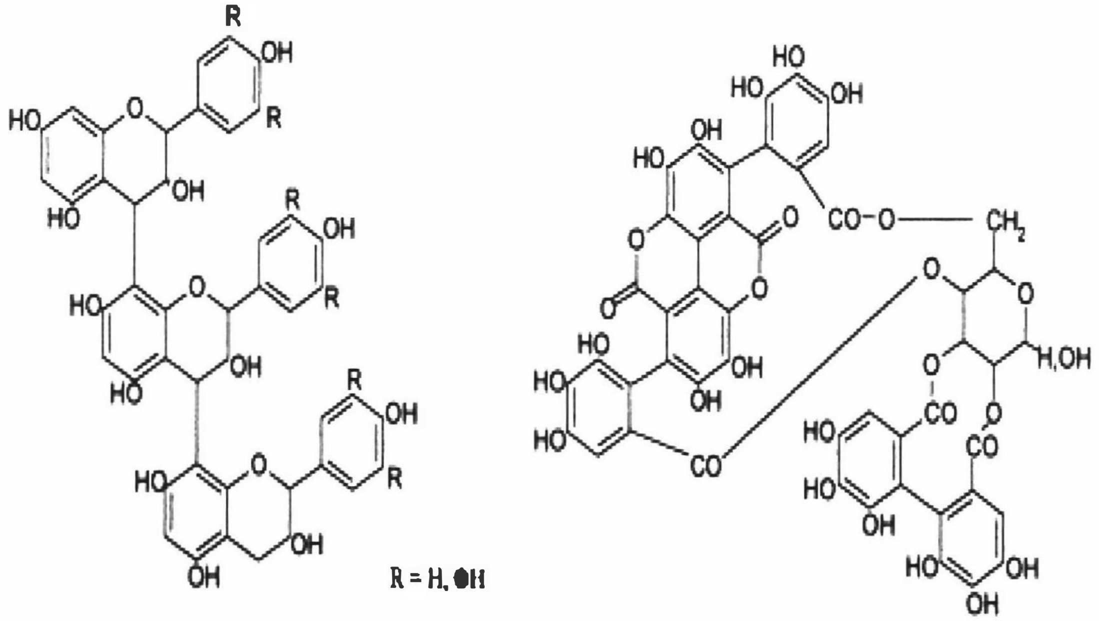
1.4 Plant secondary compounds and their role in ruminant nutrition

CT and hydrolysable tannins (HT), phenolic monomers and lignin are the major secondary compounds found in temperate and tropical forage plants (Barry *et al.*, 2001). Monomeric phenols are, or are closely related to, the building blocks of tannins and lignin. These include cinnamates and flavanoid monomers, and can have anti-nutritional effects; amino acid loss during their excretion as conjugates in the urine and altering the blood acid /base balance, leading to reduced VFI (Barry *et al.*, 2001).

Two groups of tannins have been classified according their structural types (Fig 1); HT and CT or proanthocyanidins (McLeod, 1974; McSweeney *et al.*, 2001). HT are complex esters consisting of a carbohydrate core in which two or more hydroxyls are esterified with phenolic groups such as gallic acid (gallotannin) and or hexahydroxydiphenic acid (ellagitannin; Haslam, 1989; McSweeney *et al.*, 2001). HT

Fig. 1.

Chemical structures of condensed and hydrolysable tannin. The hydrolysable tannin represented is the toxic compound (punicalagin) from *Terminalia oblongata* (**Doig** *et al.*, 1990)



condensed tannin　　　　hydrolysable tannin

mainly occur in fruit pods and plant galls and, unlike CT, their degradation products are absorbed from the small intestine of animals and are potentially toxic to ruminants (McLeod, 1974). Condensed tannins are complexes of oligomers that comprise ten to twelve polymerized flavan-3-ol-units, linked by carbon-carbon bonds (Barry and McNabb, 1999; Min *et al.* 2003). They are the most common tannin normally found in cell vacuoles of forage legumes, trees and shrubs (Min *et al.*, 2003). The reactivity of CT depends on its concentration, molecular weight (MW) and chemical structure (Barry *et al.*, 2001). The total CT concentration in a range of grazed temperate grasses, legumes, herbs and forage trees are summarized in Table 1.5. The average molecular

Table 1.5 Concentration of total condensed tannin in temperate forage species with pastoral value for New Zealand farming systems

Forage	Total condensed tannin [b] (g/kg DM)
Grasses	
Lolium perenne (perennial ryegrass)	1.8
Legumes	
Lotus corniculatus (birdsfoot trefoil)	47
Lotus pedunculatus (big trefoil)	77
Hedysarum coronarium (sulla)	
Spring	84
Autumn	51
Trifolium repens (white clover)	
Normal	3.1
High CT selection	6.7
Trifolium pratense (red clover)	1.7
Medicago sativa (lucerne)	0.5
Herbs	
Chicorium intybus (chicory)	4.2
Sanguisorba minor (sheeps burnet)	3.4
Plantago lanceolata (plantain)	14
Forage trees	
Willow *(salix spp)*[a]	33
Poplar *(Populus)*[a]	14

Adapted from Ramirez-Restrapo and Barry, 2005; Kemp *et al.*, 2001

[a] summer CT Mean values for leaves plus stems (5mm or less)

[b] Measured by the butanol HCl method (Terrill *et al.*, 1992a); total CT is the sum of extractable, protein-bound and fibre-bound CT fractions.

weight (MW) of CT from *L. corniculatus* is 1900 comprising predominantly procyanidin subunits with epicatechin (67%) the dominate subunit, while the average MW of *L. pedunculutas* is 2200, with the polymer being of the prodelphinidin type, with epigallocatechin (64%) as the major extender unit (Foo *et al*., 1996, 1997). In addition, *L. pedunculatus* also contains a very high MW CT polymer (13,200) which may contribute to the differences in biological activity observed between the two *Lotus* spp. (Meagher *et al*., 2004).

When cells disintegrate, CT binds to plant protein by pH-reversible hydrogen bonding. Stable and insoluble CT-protein complexes are formed in the neutral environment of the rumen (pH 6.0–7.5), which disassociate and release protein in the acidic environment of the abomasum (pH < 3.5; Jones and Mangan, 1977). Addition of polyethylene glycol (PEG; MW 3350) can be used to quantify the effect of CT, in both *in vitro* and *in vivo* studies including CT-containing forages, as PEG causes an exchange reaction where protein is released from the CT-complex and CT binds with PEG to form an insoluble complex. This releases protein in the forage for normal rumen degradation.

1.4.1 Effects of CT on protein digestion

When ruminants are fed fresh forages there is often extensive fermentation of dietary proteins to peptides, amino acids and ammonia in the rumen. A large portion of this nitrogenous substrate is reincorporated into microbial protein. However, the rapid release of ammonia often exceeds its rate of incorporation into microbial protein, resulting in 20 to 35% of N being lost as ammonia absorbed from the rumen and excreted as urea in the urine (Barry *et al.*, 2001). This loss results in an energy cost of 12 Kcal/g of excess NH_3 detoxified in the liver (Van Soest, 1994). For ruminants grazing perennial ryegrass (*Lolium perrenne*), short rotation ryegrass (*Lolium multiflorum* x *Lolium perenne*) and white clover (*Trifolium repens*), duodenal non-ammonia nitrogen (NAN) flow is only about 75% of N intake (Barry *et al.*, 1998). Studies have shown that low to moderate concentration of CT in the diet can increase the flow of NAN to the intestine, relative to N intake. With *Lotus* species, duodenal NAN flow increases linearly with increasing CT concentration and equals N intake at a CT concentration of approximately 40g/kg DM (Fig 2).

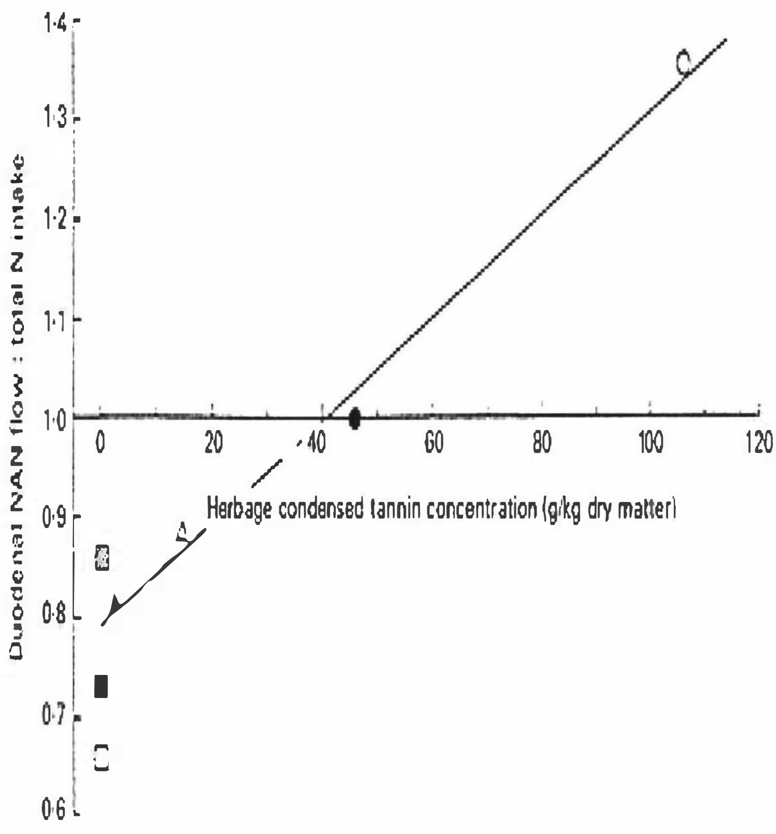


Fig. 2. Duodenal non-ammonia nitrogen (NAN) flow per unit total nitrogen intake as a function of herbage condensed tannin concentration in sheep fed on *Lotus* species. (○), High- and (●) low-tannin *Lotus pedunculatus*; (△), high- and (▲) low-tannin *Lotus corniculatus*. Results are compared with the non-tannin-containing herbages; (▨), short rotation ryegrass; (□), perennial ryegrass; (■), white clover. All results are for a nitrogen intake of 28 g/d and refer to fresh forages. From Barry & Manley (1984).

A number of studies have shown that low to medium concentrations of CT in *L. corniculatus* (22 g/kg DM) and *L. penduculatus* (55 g/kg DM) exert differing effects upon the digestion and absorption of amino acids (Table 1.6; Waghorn and Barry, 1987b, Waghorn *et al.*, 1994). CT in *L. corniculatus* increased abomasal flux of essential amino acids (EAA) by 50%. This change was associated with a 63% increase in the apparent absorption of EAA, with no significant change in apparent digestibility of EAA in the small intestine (Waghorn and Barry, 1987b). Although abomasal flux of non-EAA (NEAA) was increased by 14%, a 20% reduction in the digestibility of NEAA in the small intestine resulted in the apparent absorption of NEAA being similar in the PEG-supplemented and un-supplemented sheep (Table 1.6). A similar trend was observed in the abomasal flux of both EAA and NEAA in *L. pedunculatus*; +15% for EAA and +8% for NEAA (Waghorn *et al.*, 1994). However, apparent digestibility of EAA in the small intestine was reduced by 13 percentage units which resulted in apparent absorption of EAA from the small intestine being unaffected by CT. This could be caused by CT in *L. pedunculatus* not releasing some amino acids in the small intestine by increasing endogenous protein secretion or inactivating digestive enzymes (Barry and McNabb, 1999). Thus, effects of CT upon protein digestion in ruminants depend upon MW and structure, as well as concentration. No information is available on the MW, structure and reactivity of the CT in willow and poplar tree fodder. However, the CT concentration is greater, approximately 33 g/kg DM for willow and 14 g/kg DM for poplar respectively (Kemp *et al.* 2001). Five g CT / kg DM is enough to eliminate rumen frothy bloat through reducing protein solubility whereas 40 g CT / kg DM will give the optimum increase in amino acid absorption (Barry and McNabb, 1999). Concentrations in between these two values can be expected to have some effect on increasing amino acid absorption.

Table 1.6. The effect of condensed tannins (CT) on amino acid digestion in the small intestine of sheep fed *L. corniculatus* (22 g CT/kg DM) or *L. pedunculatus* (55 g CT/kg DM) with (-CT) or without (+CT) a continuous intra-ruminal infusion of polyethylene glycol (PEG; MW 3500)

	L. corniculatus[1]		***L. pedunculatus***[2]	
	+CT	-CT	+CT	-CT
Nitrogen intake (g N/d)	37.80	37.80	42.40	47.60
N digestibility	0.70	0.78	0.67	0.81
Abomasal NAN flux (g N/d)	29.50	25.80	34.00	31.30
Abomasal EAA flux (g/d)	95.60	63.90	121.00	105.60
Apparent EAA absorption (g/d)	58.80	36.10	81.40	83.50
EAA digestibility in small intestine	0.69	0.65	0.66	0.79
Abomasal NEAA flux (g/d)	68.50	60.00	84.30	77.70
Apparent NEAA absorption (g/d)	37.40	41.30	50.80	57.20
NEAA digestibility in SI	0.55	0.69	0.59	0.73

[1] From Waghorn *et al.*, (1987b)

[2] From Waghorn *et al.*, (1994)

N, nitrogen; NAN, non-ammonia nitrogen; EAA, essential amino acids; SI, small Intestine; NEAA, nonessential amino acids

1.4.2 Effects of CT on carbohydrate digestion

The effects of CT on carbohydrate digestion have been examined with sheep fed *Lotus spp*. High concentrations of CT in *L pedunculatus* (46 to 106 g/kg DM) markedly depressed rumen digestion of hemicellulose and slightly reduced rumen digestibility of cellulose and readily fermentable carbohydrates (soluble sugar + pectin). However, this was counteracted by increased post ruminal digestion (Barry and Manley, 1984). In contrast, carbohydrate digestion in sheep fed on *L. corniculatus* (25 to 35 g CT/kg DM) was not affected by CT (Barry and McNabb, 1999). It is proposed that high levels of free CT depresses rumen fibre digestion by forming complexes with lignocellulose and preventing microbial digestion or by directly inhibiting cellulolytic microorganisms, or both (McSweeney *et al.*, 2001). Free CT is defined as CT concentrations in excess of 90 g/kg DM not bound to plant protein (Barry and McNabb, 1999).

1.4.3 Effects of CT on voluntary feed intake

Studies with *Lotus* spp. and sulla (*Hedysarum coronarium*) suggest that moderate CT concentrations (34 to 45 g/kg DM) do not depress VFI. In contrast, high CT concentrations in *L. pedunculatus* (63 to 106 g/kg DM) substantially depressed VFI in sheep (- 27%; Barry and Duncan, 1984). Waghorn *et al.*, (1994) reported depressions in VFI of -12% in sheep fed *L. pedunculatus* with CT concentration of 55 g/kg DM. This is consistent with plant CT production being a chemical defence against pathogenic microorganisms, insects and grazing herbivores (Barry and McNabb, 1999).

1.4.4 Effects of CT on livestock production

CT present in forages has a profound effect upon animal performance due to its effects on VFI, the digestive process and upon the metabolism of absorbed nutrients. Livestock productivity gains from CT in *L. corniculatus* include increases in ovulation rate, wool growth, body growth and secretion rates of whole milk, lactose and milk protein in sheep (Table 1.7; Barry *et al.*, 2001; Min *et al.* 2003). In contrast to increased productivity obtained from CT in *L. corniculatus*, the action of CT in *L. pedunculatus*, containing 76 to 90 g CT/kg DM, markedly depressed rates of both body and wool growth and CT in sulla (88 g/kg DM) restricted carcass gain in growing lambs (Barry *et al.*, 2001), further illustrating the ecological role of CT as a chemical defence.

Table 1.7 Sheep production response to condensed tannin action in *Lotus* spp. (Barry *et al.*, 2001; Min *et al.*, 2003)

	Sheep Production Responses
Ovulation rates	21 to 32% increase in ovulation rate in ewes grazing *L. pedunculatus* (Min *et al.* 2001), with approximately half of this explained by the action of CT.
Wool production	12 and 19% increase in wool growth for lambs and ewes respectively (Wang et al 1996a).
Milk production and composition	21, 12 and 14% increase in secretion rates of whole milk, lactose and protein, respectively, in ewes in mid and late lactation (Wang *et al.* 1996c).

Studies have shown that some forage species containing CT may reduce the degree of parasite infestation and improve growth rates in young sheep (Niezen *et al.*, 1993; Waghorn *et al.*, 1995; Waller, 1999). Anthelmintic treated (i.e., parasite free) lambs grew at similar rates when grazing CT-containing legumes (sulla, *L. pedunculatus* and *L.corniculatus*) or non CT-containing lucerne. However, untreated (parasitized) lambs had higher growth rates on the CT-containing legumes, sulla and *L pedunculatus*, indicating that they could better tolerate parasites (Table 1.8). Worm burdens at slaughter were lower in parasitised lambs grazing sulla than for comparable lambs grazing pasture, lucerne, *L corniculatus* and *L. pedunculatus.* Sulla is probably more effective in parasite control because of its tall plant morphology (Moss and Vlassoff, 1993), the presence of high concentrations of an astringent CT (Terrill *et al.*, 1992b) and the effectiveness of the CT in the inhibition of larval migration (Molan *et al.*, 2000). The differences in the beneficial effects of CT in these forages may also partly be explained by the differences in CT concentration, structure, and chemical characteristics (Barry and McNabb, 1999). *In vivo* studies in sheep, goats and deer suggest that a threshold of at least 30-40 g of CT per kg DM has to be reached to observe antiparasitic activity (Hoste *et al*., 2006). Results obtained with the flavan-3-ol monomeric units also suggest that CT with high proportions of prodelphinidins are more effective in inhibiting larvae *in vitro* than CT with a high proportion of procyanidins (Hoste *et al.*, 2006).

Table 1.8

The effect of grazing condensed tannin-containing legumes (sulla, *L. corniculatus* and *L. pedunculatus*) on the growth and parasite status of anthelmintic drenched (parasite free) and non-drenched (parasitized) lambs. Lucerne and ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture were also grazed as CT-free control forages.

	CT-free		CT-containing		
	Pasture	Lucerne	*L. corniculatus*	*L pedunculatus*	Sulla
			Niezen *et al*., 1995		
Live weight gain (g/d)					
Anthelmintic drenched		184			200
non-drenched		39			129
Total worm burden					
Non-drenched		19,268			8,016
			Niezen *et.al*., 1998		
Liveweight gain (g/d)					
Anthelmintic drenched	166	243	208	232	226
non-drenched	88	121	86	160	175
Total worm burden					
Non-drenched	15,806	18,084	22,990	23,665	13,090
			Ramirez-Restrepo *et al*., 2005a		
Liveweight gain (g/d)					
Anthelmintic drenched	200		298		
non-drenched	187		228		
Total worm burden					
Non-drenched	9,679		16,812		

1.5 Internal parasites

1.5.1 Gastrointestinal nematode classification

Helminth parasites are by far the most serious cause of production losses in farmed ruminants (Familton and McAnulty, 1997) and the nematodes are the most important of these (Rattray, 2003). Twenty-nine species of nematodes were unintentionally introduced with sheep into NZ (Table 1.9; Brunsdon and Adam, 1975; Pomroy, 1997; Vlassoff *et al*., 2001), but it is principally the abomasal nematodes *Haemonchus contortus* (late summer and autumn), *Ostertagia* spp. (spring and summer), and *Trichostrongylus axei* (late summer and autumn) and the small intestinal species of *Trichostrongylus* spp., *Nematodirus* spp. (early spring through summer) and to a lesser

Table 1.9 Important nematode parasites of sheep in NZ

Lung	
Dictyocaulus filaria	*Muellerius capillarius*
Protostrongylus rufescens	
Abomasum	
Haemonchus contortus[a]	*Ostertagia (Teladorsagia) circumcincta*[a]
Ostertagia trifurcata[a]	*Ostertagia pinnata*
Ostertagia crimensis	*Ostertagia ostertagi*
Trichostrogylus axei[a]	
Small intestine	
Bunostomum trigonocephalum	*Capillaria bovis*
Cooperia curticei[a]	*Cooperia mcmasteri*
Cooperia oncophora	*Cooperia punctata*
Nematodirus abnomalis	*Nematodirus filicolis*[a]
Nematodirus furcatus	*Nematodirus helvetianus*
Nematodirus spathiger[a]	*Strongyloides papillosus*
Trichostrongylus capricola	*Trichostrongylus colubriformis*[a]
Trichostrongylus vitrinusri[a]	
Large Intestine	
Charbertia ovina	*Trichuris ovis*
Oesophagostomum columbianum	*Oesophagostomum venulosum*

[a]currently recognised as important in causing disease and loss of production. Compiled after Tetley (1934), Brusdon (1960), McKenna and Ozock (1971), and Townsend (1993)

extent *Cooperia* spp. (common in autumn), that are generally associated with production losses and clinical disease (Brunsden and Adam, 1975; Pomroy, 1997; Rattray., 2003). In NZ, *Ostertagia* spp. and *Trichstrongylus* spp. tend to predominate in all areas while *Haemonchus* spp. and *Cooperia* spp. occur with greater frequency in the northern North Island (Vlassoff *et al.,* 2001).

1.5.2 General life cycle

Most nematodes infecting sheep share the same basic life cycle. The typical life cycle takes six weeks or more and comprises the adult, egg and four laval stages (Charleston, 1982; Vlassoff, 1982). Adult worms in the gastrointestinal tract mate and females lay eggs containing the developing multi-celled embryos (morula), which pass out in the sheep's faeces (Vlassoff *et al.*, 2001). Given optimum climatic conditions (adequate moisture, optimum temperature; 15-30°C), the first stage larva (L_1) develops in the eggs, emerges, grows on pasture and moults to the L_2 stage and then to the non-feeding infective L_3 stage which is more resistant to adverse conditions (Vlassof *et al.*, 2001). This is then ingested by the suitable host (Charleston, 1982; Georgi, 1985). In contrast, the development of the L_3 stage in *Nematodirus* species occurs in the egg (Charleston, 1982). Following ingestion by the suitable host, the L_3 larvae ex-sheath in response to changes in CO_2 concentration, temperature and pH (Vlassoff *et al.*, 2001) before they reach their site of infection. They undergo two further moults and complete their development to mature adults at their site of predilection in 15-21 days for most common species (Familton and McAnulty, 1997; Vlassoff *et al.*, 2001).

1.5.3 Impact of gastrointestinal nematodes on reproduction and farm finances

Gastrointestinal nematodes in sheep pastoral grazing systems in NZ are responsible for a considerable economical loss due to the effects of subclinical infections (Howse *et al.*, 1992). Economically important consequences include increased livestock mortality; and reductions in fertility, LWG, wool growth or quality, and milk production; rejection of carcasses or organs for human consumption; and predisposing to other diseases (Rattray, 2003). The effects of parasitism have been estimated to cost the NZ sheep industry approximately $92, $150M, $92M and $5M per annum in reproductive failure, lost wool and meat production, and labour costs for dag removal, respectively. Total annual losses are therefore estimated as $339M. Furthermore, farmers spend about $26M per annum on anthelmintics, the majority of which is targeted for use in lambs (Kempthorne *et al.*, 1996), giving a total annual cost for parasitism of $365M.

1.5.4 Anthelmintic control (Anthelmintics and drench resistance)

Conventional methods of controlling nematode parasites of grazing livestock have been with the use of synthetic broad spectrum anthelmintics (Watson, 1994; Vlassoff *et al.*, 2001; Waller 2006). The broad spectrum anthelmintics used in the control of nematode parasites falls into just three classes. These include benzimidazoles, imidothiazoles (levamisole and morantel) and the macrocyclic lactones (avermectin / milbemycin; Watson, 1994; Waller, 2006). Recently, there has been the emergence of combination products which include a combination of two or three of these. Use of combination products has afforded increased efficacy or some control of multiple resistances involving all action groups (Watson, 1994). Benzimidazoles kill worms by interfering with intracellular microtubule and kill various stages of the parasites including the egg, while imidothiazoles affect the movement of the parasites by inducing a rigid paralysis which results in worms being 'flushed' down the gastro-intestinal tract. However, eggs remain unaffected passing into the environment and eventually developing into infective larvae. Though activity of macrocyclic lactones come by way of flaccid paralysis of the parasite, its mode of activity has an entirely different basis to that of imidothiazoles (Watson, 1994).

Anderson (1990) stated that preventive control is the best way to control gastro-intestinal parasites. This is consistent with the conclusion by Brunsdon (1981) and Leathwick *et al.*, (1995) that a basic five-drench programme for lambs and hoggets at 21 to 28-day intervals commencing at weaning in November resulted in far fewer worms contaminating pasture with eggs in summer and virtually eliminating the autumn larval peak. In contrast, Becket (1993) stated that the five preventive drench programme starting at weaning ceases too early for hoggets to prevent the build up of *Haemonchus* and *Trichostrongylus* genera during late autumn and winter respectively on the East Coast of North Island in NZ and indicated that extending the number of drenches to 6 resulted in further gains in productivity. Despite the risk of developing anthelmintic resistance, farmers ended up drenching adult sheep at an average of 1-2 times and lambs at almost 7 times each year (Vlassoff *et al*., 2001; Beckett 1993, Brunsdon *et al.*, 1983).

Anthelmintic resistance is becoming an increasing problem in the sheep and goat rearing areas of the world (Gopal *et al.*, 2001; Waller, 2006). Resistance has now been reported to all three of the currently available broad-spectrum families of anthelmintics (Gopal *et al.*, 2001; Mason *et al.*, 2001; Leathwick *et al*., 2000; McKenna, 1995). In NZ, information from Animal Health Laboratories suggests that the prevalence of sheep farms on which a proportion of nematodes are resistant to benzimidazoles is about 68%, levamisole about 42% and the combination of benzimidazole together with levamisole about 39% (McKenna, 1998). There have also been recent reports of ivermectin resitance in *Ostertagia species* in sheep (Leathwick *et al*., 2000; Mason *et al*., 2001). Increased incidence of anthelmintic resistance in domestic ruminants has been attributed to high frequency of drenching, prolonged use of members of one drench group, use of drugs from various families within the same year and improper dose rate (Watson 1994).

1.5.5 Alternative nematode control strategies

The increased prevalence of anthelmintic resistance of nematodes in domestic ruminants (Waller, 2006), combined with rising consumer concerns about chemical use on farms, has encouraged research into alternative strategies for control of internal parasites particularly in lamb production systems in NZ (Niezen *et al.*, 1993). These include the integration of chemotherapy with grazing management such as alternate grazing with different stock classes, pasture spelling and renovation, making hay or silage or use of tannin-containing forages in a grazing rotation; immunomodulants, vaccines and targeted silencing of genes regulating nematode development (Waller 1992, 1998, 2006; Williams, 1997; Sangster, 1999; Hein *et al.*, 2001; Sykes and Coop, 2001; Vlassoff *et al.*, 2001; Molan, 2002).

Studies have shown that some plant species containing CT have the potential to reduce the degree of parasite infestation, provide sheep with the ability to withstand helminth infection and improve growth rates in sheep. Niezen *et al.*, (1998) demonstrated that drenched lambs grazing CT-containing legumes (Sulla spp.) grew at a similar rate to lambs grazing non-CT-containing Lucerne (226 g/day vs 243 g/day) but faster than lambs grazing perennial ryegrass/white clover pasture (166 g/day). In contrast, daily gains were higher for undrenched lambs grazing CT-containing legumes (Sulla; 175 g/day) than when grazing either lucerne (121 g/day) or pasture (88 g/day). In the same study, it was shown that parasite burdens at slaughter were similar for lambs grazing *Lotus* spp. and pasture but were consistently lower for growing animals grazing sulla. Recently, Diaz Lira *et al*., (2007) showed that grazing undrenched weaned lambs in willow fodder blocks reduced burdens of some of the most important internal parasites (*Nematodirus spathiger, Trichostrongylus vitrinus* and *Trichostrongylus colubriformis*), compared with grazing undrenched lambs on conventional grass-based pastures, though grazing fodder blocks was not as effective as anthelmintic drenching. In the same experiment, non drenched lambs grazing in willow fodder blocks grew at similar rates (154 g/day vs. 155 g/day) to drenched lambs grazing perennial ryegrass/ white clover pasture but faster (111 g/day) than non drenched lambs grazing perennial ryegrass/ white clover pasture. This suggests that lambs grazing CT-containing forages, may withstand the pathogenic effect of gastrointestinal parasites better than lambs grazing non-CT containing forages.

Recent evidence suggests that the effect of CT on internal parasites can be mediated in two ways. Firstly, CT protect dietary protein (DP) from microbial degradation in the rumen and increase the proportion of UDP reaching the small intestine, thus improving the amount of amino acids absorbed (Waghorn *et al*., 1994; Aerts *et al*., 1999). High protein intakes have been associated with increased immunocompetence in young sheep (Coop and Holmes, 1996; Bown *et al*., 1991) and to reduce negative effects of intestinal nematodes on productivity (Niezen *et al*., 1995). Secondly, CT may disrupt the nematode life cycle by preventing their eggs from hatching and by preventing L1 larvae from developing to the infective L3 larvae. The mechanisms by which CT inactivate the eggs are not known, but they may inactivate enzymes responsible for the hatching process (Molan, 2002).

1.6 Willow trees on New Zealand farms

1.6.1 Origin

Willow (*Salix* spp.) is a member of the *Salicaceae* family, found mainly in the northern hemisphere (Van Kraayenoord *et al*., 1995) and has been introduced and extensively cultivated in New Zealand over the last 160 years for soil erosion control on hill pastoral farms and, to a lesser extent, to provide shelter, shade and supplementary forage for livestock (Wilkinson, 1999). Their multi-purpose attributes make willow useful for silvopastoral systems on New Zealand hill country where soil erosion is wide spread, and low rainfall in summer results in low pasture production (Pitta *et al*., 2004). The National Plant Materials Centre, established in 1969 at Aokautere, near Palmerston North and more recently (1994) the Crown Research Institute Hortresearch, have developed a range of improved, locally adapted clones and hybrids of *S.matsudana* x *Salix alba* willow suitable for soil conservation and river protection. These clones include Tangoio, Hiwinui, Warakei, Makara and Moutere (Van Kraayenoord, 1995).

1.6.2 Uses

1.6.2.1 Soil conservation

In New Zealand, willows and poplar are the principal trees planted for soil erosion control along with several other species, including *Pinus radiata*, *Eucalyptus* and *Acacia*. *Salix matsudana x alba* has been selected for soil conservation purposes and for shelter due to its high wind tolerance and very good lower branch retention (Hathaway 1986). Significant soil erosion control measures are necessary on an estimated 33% of the North Island (3.75 M ha) and 25% of the South Island (3.83 M ha), if physically sustainable pastoral use is to be maintained (Eyles and Newsome, 1992). Trees planted on hill country have been shown to reduce mass movement (i.e slippage) of pasture by 50 to 80% and have increased annual livestock carrying capacity by approximately seven livestock units/ha on previously unstable ground in the East Coast and Wairarapa (Hicks, 1995). Willow trees are also beneficial in that they help to dry out water- logged soils (Wilkinson, 1999), allowing a good cover of legume-dominant (*L. pedunculatus*) volunteer herbage to establish (Barry *et al*., 2006).

1.6.2.2 Shade and Shelter

Shelterbelts are the only option available on many New Zealand livestock farms to reduce the adverse effects of wind (Gregory 1995). Willow trees can be individually or group planted, at a low density (100 to 500 stems/ha), on established pastures or planted in strategic lines as shade and shelter belts (Gregory 1995). Generally, the most effective shelterbelt has a porosity of 40 to 60% that is distributed evenly throughout its length and height and protects the maximum area of pasture from wind (Gregory 1995). The combination of cold, wet and windy weather conditions can lead to excessive heat loss (hypothermia) in livestock, while hot, dry weather can lead to hyperthermia (overheating) (Gregory, 1995).

Climatic stress caused by extreme weather conditions reduces pasture and animal production and is a significant cause of animal suffering (Gregory, 1995). Providing greater protection from climatic stress reduces discomfort and distress attributable to heat, cold or the wind and reduces suffering associated with events that lead to death from hypothermia or hyperthermia (Flanagan, 1995; Gregory, 1995). Studies show that providing shelter can increase ovulation rates in ewes, reduce abortions and lamb mortality and improve lamb growth rates (Table 1.10; Griffiths *et al.*, 1970; Alexander and Lynch, 1976; and Alexander *et al.*, 1980). Shelter for low birth weight lambs, especially multiple born lambs, is particularly important when rain is accompanied by

Table 1.10. Beneficial effects of animals sheltered from cold climatic conditions on animal production (Gregory 1995).

	Shelter from cold conditions
Lamb growth rate	Growth rate to 21 days of age in lambs from sheltered paddocks was 7% greater than for unsheltered lambs (Alexander and Lynch, 1976)
Ewe ovulation rates	Protection from cold with a shed shelter for 17 days before and after chemically synchronised mating has raised ovulation rates (Griffiths et al 1970)
Lamb mortality	Mortality decreased from 17 to 9% in single-born and from 51 to 36% in multiple-born when phalaris grass shelters were provided (Alexander & Lynch 1976).

temperatures below 10^{o}c (Geenty, 1998). In hot conditions, shade/shelter improves reproductive performance in cattle and growth rate in fattening livestock (Gregory, 1995), particularly when grazing old perennial ryegrass-based pastures that contain high concentrations of the wild- type endophyte strain *Neotyphodium loli* (Fletcher *et al.*,1999). Endophyte produces the alkaloid metabolite ergovaline, which is known to increase the susceptibility of livestock to heat stress, with responses being more severe in summer and autumn when concentrations are the highest (Fletcher *et al.*, 1999).

1.6.2.3 Biomass for energy generation

Greenhouse gas (i.e. CO_2, CH_4 and N_2O) emissions are a significant global problem (Lemus and Lal, 2005). There is increasing evidence that the emission of these gases, mainly from burning of fossil fuels, is causing global climate change. Annual global temperature over the next 100 years is predicted to rise by 1.4-5.8^{o}C (Intergovernmental Panel on Climate Change, 2001).

Use of bioenergy crops (any plant material used to produce bioenergy) as C sinks has attracted special interest. Bioenergy crops, including grasses, such as switch grass (*Panicum virgtum L.*) and tall fescue (*Fetusca arundinacea L.*), and short rotation woody perennials, such as willow and poplar, have the capacity to produce large volume of biomass, have high energy potential and can be grown in marginal soils (Lemus and Lal, 2005). Studies have revealed that willow has a significantly higher wood specific gravity (0.41 g/cm^3 vs. 0.35 g/cm^3) than hybrid poplar. Higher densities (i.e., specific gravity) yield higher energy outputs on a volume basis, and help lower transportation costs. Overall, willow has lower elemental and ash concentrations than other biomass fuel, such as switch grass, and is nearly equivalent to clean wood, such as sawdust, in terms of its fuel properties (Tharakan, 2003). The New Zealand Government's voluntary target for biofuel use is 65 million litres of biodiesel or bioethanol by 2012 and it is calculated that 2,500 to 3,000 ha of willow will produce enough biomass annually to make 11 million litres of transport ethanol. The natural lignin extracted from willow can also replace fossil fuels in paints, resins, glues and adhesives (Howard, 2006)

1.6.2.4 Trees as Livestock Feed

Browse species are significant in ruminant nutrition on a world wide basis (Gutteridge and Shelton, 1994), especially in the arid and mountain zones of Africa (Otsyina and Kell, 1985), Asian- Pacific regions (Lefroy *et al.*, 1992) and the Americas (McKell *et al.*, 1972). Browse plants provide flexibility in the timing of their use and, in particular, provide green feed when grasses and other herbaceous materials are dry (Devendra, 1992). In New Zealand, willow trees have been used as a source of alternative supplementary fodder for sheep and cattle, during summer/autumn droughts when there are feed shortages (Moore *et al.*, 2003; McWilliam *et al.*, 2004). The edible fodder of willow trees (i.e. leaves and fine stems < 5mm) is adequate for nutritional maintenance of sheep, goats and red deer, and is generally higher in nutritive value than low quality summer pasture (McCabe and Barry, 1988; Kemp *et al.*, 2001). Willow trees are also inexpensive, easy to establish in a range of soil types and climates and provide an annually renewable feed source (McWilliam, 2004).

There are two general systems for feeding willow to ruminant livestock. The first involves mechanically pruning and /or thinning trees originally established for soil conservation or shelter reasons (McWilliam, 2004). This is more common on hill country where producing and feeding supplements can be difficult due to terrain. Another option involves densely planted blocks of trees (fodder blocks) that can be mechanically cut (coppiced) and the fodder blocks carried to livestock or grazed in situ as a fodder crop (Pitta *et al.*, 2005).

1.6.3 Establishment, growth and management of willow fodder blocks

Willow fodder blocks are generally planted at a density of 6,000 trees/ha and browsed at a height of 0.3 to 1.3 meters annually (McWilliam, 2004). Suitable areas for the establishment of the fodder blocks should have zero or very low productivity in the undeveloped state (i.e. rush infested low lying wet areas). Preparation for planting involves killing swamp-type plants, such as rushes, by cutting with a tractor mounted mower at the end of summer (approximately February) and applying a herbicide with no residual activity such as glyphosphate, to plant regrowth in late autumn (approximately May). Ripping the areas to break up the soil is also beneficial (Barry *et* *al*., 2006). Different tree and shrub propagation methods are available (Snook, 1986; Hawathway, 1986; Shelton, 1994). However, the use of rooted or unrooted stem cuttings is widely used (Oppong, 1998). The advantages of this method over trees established from seedlings include improved tree form, improved stability against wind damage and reduced cost per plant (Zsuffa, 1992). 0.7 m long stakes should be vertically planted to a depth of 0.35 m (Barry *et al*., 2006).

Two years after fodder block tree establishment, a tree-pasture system develops, with a significant increase in higher quality grasses, legumes and herbs, due to livestock grazing and evapotranspiration of the trees drying out these areas. For optimum management of willow fodder blocks, Barry *et al*., (2006) recommended areas be grazed three times, at 8 week intervals, during the growing season. This results in improved herbage control and nutritive value, while also allowing the trees to regenerate (Barry *et al*., 2006). The annual edible DM yield of coppiced Tangoio willow is 0.3 to 2.5 kg DM/tree, which is about 1 to 6 t/ha, depending on tree age, site and planting density (Hathaway, 1986, Douglas *et al*., 1996, Oppong *et al*., 1996, 2001).

1.7. Willow as livestock feed

1.7.1 Chemical composition, nutritive value and digestibility of willow

The nutritive value of willow tree fodder (leaves plus stems < 5 mm diameter) is superior to typical hill pasture in dry summers (Table 1.11). Willow fodder is substantially lower in fiber and higher in ME and CT concentration compared to low quality summer pasture (McCabe and Barry, 1988; Kemp *et al*., 2001; Pitta *et al*., 2005; McWilliam *et al*., 2005a), and is similar in digestibility and ME content to vegetative *L.corniculatus* and good quality lucerne (*Medicago sativa*) hay (McWilliam *et al*., 2005a). The digestibility of willow tree fodder declines from early spring to leaf fall in autumn. However, the decline in organic matter digestibility (OMD) and digestible organic matter in the DM (DOMD) with time is smaller than the decline in digestibility of grass-based pasture in NZ, explaining the reason why willow is an effective supplement for livestock grazing drought pasture (McWilliam *et al*., 2005a). McCabe and Barry *et al*., (1988) found that willow tree fodder has a higher ratio of readily fermentable carbohydrate to structural carbohydrate than fresh or dried perennial

Table 1.11: Chemical composition (g/kg DM) and nutritive value of willow tree fodder compared with that of forages commonly fed to grazing livestock in New Zealand over the late summer/autumn period

	ME[1] (MJ/ kg DM)	Total N	NDF	Total CT	OMD	DOMD
		g/kg DM				
Drought pasture						
McWilliam *et al.* (2005a)	7.5	25	571	1.5	0.53	0.46
Pitta *et al.* (2005)	7.7	23	588	2.6	0.53	0.47
Non-drought pasture						
Ramirez-Restrepo *et al.* (2004)	9.6	26	463	1.6	0.64	0.58
Willow[2]						
Pitta *et al.* (2005)	10.7	16	370	30	0.72	0.66
Diaz Lira *et al.* (2007)	10.4	16		42	0.70	0.64
Kemp *et al.* (2001)	9.8	23	367	33		
L.corniculatus						
Ramirez-Restrepo *et al.* (2004)	10.6	27	344	40	0.70	0.65
Lucerne hay						
Ulyatt *et al.* (1980)						
pre bloom	10.5	32		0.5		
early bloom	9.8	29		0.5		

[1] calculated from in vitro DOMD values

[2]leaves plus stem <5mm diameter

ryegrass (Table 1.12). Total nitrogen (N) content was comparatively low, however it was higher than levels known to limit voluntary intake of adult ruminants (<13 g N/kg DM).The study also revealed that willow tree fodder contained a higher concentration of lignin than a range of forages normally fed to grazing livestock in NZ (Table 1.12).

Table 1.12. Carbohydrate (CHO) ratio, lignin and total nitrogen (N) content of willow (*S.matsudana x alba*), cv. 'Wairakei', compared with other temperate forages (McCabe and Barry 1988).

	CHO ratio[1]	Lignin g/kg DM	Total N g/kg DM
Tree willow	0.51	182	17.8
Forage kale	2.6	32	26.3
White clover (summer/autumn average)	1.26	25	39.0
Perennial ryegrass (summer/autumn average)	0.34	20	42.0
Dried ryegrass (seed setting)	0.24	73	15.4
Lucerne hay	0.38	105	31.2

[1]Ratio of readily fermentable carbohydrate (CHO) to structural carbohydrate

1.7.2 Voluntary intake of willow

McWilliam *et al.* (2005a) reported that sheep voluntarily consume (Voluntary feed intake, VFI) 60.1g DM/kg W $^{0.75}$ of autumn/summer growth (leaf plus stem < 6 mm in diameter) from the tree willow species ‘Moutere’. With a reported DM digestibility (autumn/summer average) value of 65.2%, the digestible intake was 39.2 g DM/kg W $^{0.75}$. Values for VFI, digestibility and digestible intake (Table 1.13) from primary spring growth (leaf plus stem ≤ 5 mm in diameter) from willow tree reported by McCabe and Barry, (1988) were slightly higher than those reported by McWilliam *et al.*, (2005a). The differences in values reported are most likely due to differences in the clones used and in the stage of growth of the willow. McCabe and Barry (1988) also showed that the VFI intake of willow tree fodder is 29% lower than that of lucerne hay, but can still provide significantly more nutrients (22%) than maintenance requirement of sheep.

Table 1.13. Voluntary intake and *in vivo* digestibility of dry matter of *S. matsudana* x *alba*, clones‘Moutere’ and ‘Waikara’ .

	Voluntary dry matter intake g/kg $W^{0.75}$/day	Digestibility	Digestible intake g/kg $W^{0.75}$/day
McWilliam *et al.* 2005a			
‘Moutere'	60.1	0.65	39.2
McCabe and Barry (1988)			
'Wairakei'	69.6	0.64	44.7

1.7.3 Effects of willow supplementation upon reproductive performance

A series of experiments conducted at Massey University’s, Riverside dry-land farm has shown that supplementation of ewes grazing low quality drought pasture with willow tree fodder increases ewe reproductive rates (Table 1.14). McWilliam *et al.*, (2005b) found that supplementation with willow cuttings during mating increased scanning, lambing, docking and weaning percentages by 16, 17, 21 and 29% units respecti reproductive rates reported by Pitta *et al.*, (2005) in ewes grazing willow fodder blocks vely, compared to unsupplemented ewes. This is consistent with the 20% increase in reproductive rates reported by Pitta et al., (2005) in ewes grazing willow fodder blocks (full access) during mating, relative to ewes mated on drought pastures. Willow supplementation increased reproductive rate through an increase in fecundity (lambs born/100ewes lambing), with more ewes bearing multiple lambs and fewer bearing

Table 1.14. Effect of willow supplementation, during mating, on reproductive rates in ewes grazing control drought pasture during the late summer/autumn period.

	Short drought pasture	Willow supplementation
	McWilliam *et al.*, 2005b willow trimmings	
Live weight change (g/day)	-103	-86
Reproductive rate[1]		
Scanning	132	148
Lambing	131	148
Docking	107	128
Weaning	106	126
	Pitta *et al.*, 2005 willow fodder blocks	
Live weight change (g/day)	-101	-41
Reproductive rate[1]		
Scanning	124	148
Lambing	122	137
Docking	92	114
Weaning	90	109

[1]expressed as lambs/100 ewes exposed to the ram

singles, compared to ewes grazing short drought pasture (Table 1.15). Increased amino acid absorption from the small intestine due to higher CT intakes, was likely to be a contributing factor in the increased reproductive rates in ewes supplemented with willow fodder (McWilliam *et al.*, 2005b; Pitta *et al.* 2005). Similar experiments to evaluate the effect of willow supplementation on reproductive rates in mated hoggets have not been conducted.

Table 1.15 The effects of willow supplementation during mating on conception rate and fecundity, relative to control ewes grazing on short drought pasture.

	Short drought pasture	Willow supplementation
	McWilliam *et al.*, 2005b willow trimmings	
Conception rate[1]	91.4	91.4
Fecundity[2]		
Singles	56.1	37.8
Twins	43.9	62.2
	Pitta *et al.*, 2005 willow fodder blocks	
Conception rate[1]	92.0	95.0
Fecundity[2]		
Singles	66.0	50.0
Twins	34.0	50.0

[1]expressed as ewes pregnant per 100 ewes mated

[2]expressed as ewes per 100 ewes lambing

1.7.4 Effects on parasite management

Gastrointestinal (GI) nematode parasitism is a major impediment to high growth rates in intensive livestock grazing systems in New Zealand (Niezen *et al.*, 1998). Control of GI parasites is now becoming a serious concern, particularly in the small ruminant industries, due to the widespread and rapid development of nematode resistance to chemotherapy (Watson, 1994; Leathwick, 1995; Waller, 2006). Since first confirmed in sheep in New Zealand in 1979, the prevalence of anthelmintic resistance on New Zealand farms has steadily increased (Leathwick *et al.*, 2001). This is largely the result of a more-or-less complete reliance on anthelmintics for worm control (Watson 1994; Waller, 2006). With increasing demand by consumers for agricultural products that are both 'clean and green' (Waller, 2006), it is necessary to develop grazing management systems that are able to maintain high levels of animal production with less reliance on anthelmintic drenches (Niezen *et al.*,1998; Waller, 2006). One option may be to introduce bioactive forage plants that contain CT into grazing rotations (Niezen *et.*, *al.*1998; Ramirez-Restrepo and Barry, 2005).

Studies have shown that parasitized lambs grazing the bioactive forage legume sulla, *Lotus pedunculatus* and *Lotus corniculatus* maintain good growth performance

(Niezen *et al*., 1995; Ramirez-Restrepo and Barry 2005) and that CT may reduce larval establishment and increase nematode mortality (Niezen *et al*., 1998, 1995). An experiment reported by Diaz Lira *et al*., (2007) showed that grazing undrenched (parasitized) weaned lambs in willow fodder blocks reduced burdens of some gastrointestinal parasites and also increased LWG compared with undrenched lambs grazing conventional pastures (Table 1.16). Grazing fodder blocks for short intervals (i.e. restricted) was more effective in reducing burdens of abomasal worms particularly worms of *Teladosagia* spp. compared to continuous grazing (Full access), indicating that *Teladosagia* parasites may adapt to fodder block compounds under continuous grazing. Restricted grazing may have also reduced larval challenge due to reduced pasture larval contamination. However, full access grazing was more effective in reducing burdens of small intestinal parasites, particularly *Nematodirus* and *Trichostrongylus*. In this trial, grazing fodder blocks was not as effective as anthelmintic drenching for control of internal parasites; however, use of browse blocks could lead to a reduction in anthelmintic use and give a more sustainable grazing system (Barry *et al*., 2006).

Table 1.16

Live weight gain and gastrointestinal worm counts in undrenched lambs grazing control pasture (perennial ryegrass/white clover) and willow fodder blocks for 14 weeks (Daiz Lira *et al*., 2007)

	Control pasture	Willow fodder block	
		Restricted access	Full access
Live weight gain (g/day)	111[cd]	107[d]	154[b]
Carcass weight gain (g/day)	34[cd]	31[d]	40[c]
Abomasum			
Haemonchus contortus	45[b]	66[ab]	282[a]
Teladorsagia circumcinta	7314[a]	2479[b]	7627[a]
Teladorsagia trifurcata	587[a]	127[b]	534[a]
Trichostrongylus axei	221[a]	117[a]	197[a]
Small intestine			
Nematodirus spathagia	2891[a]	2525[a]	273[b]
Nematodirus filicollis	97[a]	155[a]	41[a]
Trichostrongylus vitrinus	3965[a]	1182[b]	609[c]
Trichostrongylus colubriformis	975[a]	233[b]	289[b]
Cooperia curticei	429[a]	286[a]	291[a]

[1]Received anthelmintic drench at four week intervals

A reduction in faecal egg count has been reported in goats grazing the tanniferous plant, *Lespedeza cuneata* (Min *et al*., 2003) and has also been described in sheep consuming other tanniferous legumes such as sulla, *L. pedunculatus* (Niezen *et a*l., 1995, 1998) and to a lesser extent, *L. corniculatus* (Marley *et al*., 2003), largely due to a reduction in worm fecundity rather than changes in worm numbers (Paolini *et al*., 2005). In contrast, Diaz Lira *et al*., (2007) reported a progressive increase in FEC with time in the undrenched lambs grazing willow fodder blocks compared to drenched lambs and concluded that the reduction in worm burdens in lambs grazing willow fodder blocks may be due to reduced rates of re-infection as the experiment progressed.

1.8 Hogget mating and nutrition

1.8.1 Reproductive performance of mated hoggets

Ewe hoggets have the potential to be mated at 6 to 9 months of age (Kenyon *et al*., 2004). However, puberty in the ewe lamb is more closely related to hogget LW than age (Geenty, 1998; Kenyon, 2004). It is well known that puberty does not occur naturally until the young ewe has reached 50 to 70% of mature weight (Jainudeen *et al*., 2000). Many studies have shown that mean LW of 30 to 40 kg is necessary for oestrus activity in most ewe hoggets and that 70 to 90% of them in this range will be mated (Gavigan and Rattray, 2002). Recently, Kenyon *et al*. (2005) suggested that Romney hoggets should weigh at least 36 kg prior to introduction of a ram, to ensure they are mated as early as possible during the breeding period and to be multiple bearing. In a non-peer reviewed publication, McMillan and Moore (1983) reported that heavier hoggets within a flock are more likely to attain oestrus, thus for every kg increase in LW, there is a 6% increase in the number of hoggets exhibiting oestrus and that the greater the LWG the greater the chance of hogget oestrus at the same final LW, which is similar to the 'dynamic' effect in flushing.

Hogget fertility and conception rates are lower and much more variable than for mature ewes and are often less than 50% especially if the mating period is restricted to less than four weeks (Smith and Knight, 1998). Stevens and McIntyre (1999) revealed an average NZ hogget conception rate of 59%, with a range of 29 to 87%, and it was not influenced by mating weight. In contrast, Stevens (2001) found that hogget conception rate was nearly linearly related to mating weight and increased by 2% per kg LW over the 38 to 53 kg range of mating weight. It has been concluded that poor egg quality is the major factor responsible for low conception rates in hoggets. However, egg quality and conception rates appear to improve after the first hogget oestrus cycle, probably due to higher levels of the circulating progesterone (Gavigan and Rattray, 2002). Kenyon *et al.*, (2005) found that pregnancy rates of mated hoggets were higher in teased compared with unteased hoggets and concluded that exposure of hoggets to teaser rams for 17 days prior to introduction of entire rams will result in more hoggets (89% vs. 74%) being mated in the first 17 days of the breeding period, and a greater percentage of hoggets conceiving.

Hogget lambing performance has been variable and often disappointing and is usually considerably lower than levels achieved by mature ewes (Kenyon *et al.*, 2004; Gavigan and Rattray, 2002). A survey by Stevens and McIntyre (1999) revealed a tailing percentage (of hoggets in lamb) of 109% (range 73 to 158%). Earlier studies by McMillan and Moore (1983) showed a lambing percentage ranging from 5 to 55% of hoggets joined. Kenyon *et al.*, (2004) reported a NZ mean lambing percentage of 60. Mating weight is critical and accounts for much of the variability in hogget lambing rates. Numerous studies have shown that similar to the incidence of oestrus and conception rates, lambing performance increases by about 2% per 1 kg increase in mating weight (Gavigan and Rattray, 2002).

Mortality of lambs born to hoggets is usually higher (20 to 30%; Gavigan and Rattray, 2002) than in lambs from mature ewes (15%, 25% and 35% for singles, twins and triplets; Barry *et al.*, 2004). Part of this would be caused by the lighter birth weight of lambs born to hoggets, especially mortality due to starvation and exposure. Lighter lambs are also prone to death from dystocia because they are weak (Morris *et al.*, 2000; Gavigan and Rattray, 2002). Optimum birth weight range for lamb survival has been estimated at about 3.9 to 5.0 kg for singles and 3.2 to 4.5 kg for twin lambs (Gavigan and Rattray, 2002). Studies have shown that supplementing ewes with CT-containing forages, such as *L. corniculatus* and willow or poplar, during mating reduced post-natal lamb mortality from 22.9% to 11.7% (Ramirez-Restrepo *et al.*, 2004) and 17.8 % to 11.7% (McWilliam *et al.*, 2005c) respectively. Pitta *et al.*, (2005) also showed that grazing willow fodder blocks during mating, reduced post natal lamb mortality from

23.5% to 18.1%. Similar studies have not been conducted in mated hoggets. The mechanism by which CT exerts its effects upon pre-and post-natal lamb mortality is not fully understood. However, this maybe explained by the ability of CT to increase the intestinal availability of EAA particularly the branched chain amino acids (BCAA) which in turn improves rates of development of the embryo/foetus and its placental attachments, with later, long term consequences upon the foetus'/neonate's carbohydrate and protein metabolism (Barry *et al.*, 2004).

1.8.2 Nutrition and fecundity

Nutrition is one of the most significant environmental influences on fecundity of sheep (Min *et al.*, 2001; Smith and Knight 1998; Smith 1991; Waghorn *et al.*, 1990). Fecundity is defined as the number of lambs born in proportion to the number of ewes lambing and significantly influences profitability of sheep production. Fecundity involves two significant factors, ovulation rate (OR), which is the first step in achieving a high lambing %, and pre-natal mortality, which determines what proportion of the ova ovulated and fertilized actually develop into lambs born. Both the 'static' (which reflects the long-term nutritional status) and the 'dynamic' (which reflects short-term changes in nutritional status) effects of LW near the time of breeding can affect OR (McCall *et. al.*, 1998). Heavier (fatter) ewes tend to be more fecund, thus for every extra 10 kg in LW at the time of mating there is an increase in ovulation rate of about 0.2 to 0.3. However, 'the static' effect is modified by the direction of LW change that takes place during the 6 weeks-premating (Smith and Knight, 1998).

Significant increases in OR in sheep have been demonstrated in response to both energy and protein supplementation. The effect of energy on ovulation rate appears to be linear while that of protein appears to have a threshold effect, with marked increases in ovulation rate being achieved when the digestible protein intake increases above 125 g/ewe/day (Smith, 1991). The response to increase in protein intake appears to be greatest when there is a marked change in blood plasma concentration of BCAA (valine, leucine and isoleucine) rather than absolute concentration (Min *et al.*, 2001; Waghorn *et al.,* 1990) which supports the observation that larger increases in ovulation rate occur when ewes are changed from a low to a high, rather than from a medium to a high level nutrition. Previous research has shown a strong correlation between OR and the plasma concentration of BCAA (r = 0.95; Waghorn *et al.*, 1990) and this has been confirmed by the findings that intravenous infusion of a BCAA mixture (33.1 g total BCAA per day per ewe), produced an increase in OR (2.4 vs. 1.5; Downing and Scaramuzzi, 1991; Downing *et al.*, 1995).

Work with pasture and other forms of energy (fodder crops, silage, and low protein grain) supplementation have indicated that ovulation responses can be obtained with a minimum period of 3 weeks feeding (Smith and Knight 1998).For high protein supplementation, it has been shown that the critical time to increase OR is during the luteal phase of the reproductive cycle, between days 9 and 12; 5 to 8 days prior to ovulation (Waghorn *et al.*, 1990; Stewart and Oldham, 1986). However, Ramirez-Restrepo *et al.*, (2005); Min *et al.*, (2001) showed that maximum OR in ewes can be obtained after grazing *L. corniculatus* for 42 days before mating.

High intake of dietary soluble protein or rumen degradable protein may affect reproduction via direct effects on the uterine environment where toxic by-products of nitrogen metabolism, such as ammonia/ammonium ions from the rumen may impair sperm, ova or early embryo survival. This effect may be mediated by changes in uterine pH. As action of CT simultaneously reduces protein degradation to ammonium in the rumen and increases EAA absorption from the small intestine, it is possible that they could increase reproductive rate by increasing fecundity and by reducing embryonic mortality in grazing sheep (Min *et al.*, 2001). Studies (Table 1.17) have shown that relative to mating on pasture, in Experiments 1 and 3 grazing *L. corniculatus* during mating (18 g CT/kg DM) increased both OR and lambing by 27% and 20% respectively without affecting VFI, with approximately 50% of the response being due to CT. However, the increase in OR (10%) during the second experiment could not be explained by the action of CT in *L. corniculatus* (24 g CT/kg DM), as deduced from responses to PEG supplementation. Best responses in OR and lambing percentage were in lighter ewes that gained weight during mating (Experiment 1 and 3) and lowest responses were obtained in heavier ewes that lost small amounts of weight during mating (Experiment 2).

Table 1.17

Effect of grazing ewes on *L. corniculatus* or perennial ryegrass/white clover pasture, with or without supplementation with polyethylene glycol (PEG; MW 3500), on ovulation rate (corpra lutea/ewe mated), lambing (lambs born/ewe mated) and liveweight gain (LWG). Mean LW at the start of Experiments 1, 2 and 3 were 54.2, 59.8 and 53.2 kg respectively.

	L.corniculatus		**Pasture**		
	CT-acting	PEG	CT-acting	PEG	**Reference**
		Ovulation rate at third cycle			
Experiment 1	1.78	1.56	1.33	1.35	Min *et al.* (1999)
Experiment 2	1.77	1.87	1.65	ND	Luque *et al.* (2000)
Experiment 3	1.79	1.58	1.48	ND	Min et al. (2001)
		Lambing			
Experiment 1	1.70	1.42	1.36	1.36	
Experiment 3	1.69	1.39	1.22	ND	
		LWG (g/day) during mating			
Experiment 1	40.3	33.8	18.6	4.5	
Experiment 2	-25.0	-20.0	-12.0	ND	
Experiment 3	22.3	16.3	43.2	ND	

ND: not determined

A series of studies at Massey's Riverside farm have shown that relative to control ewes mated on low quality drought pasture, willow supplementation increased scanning, lambing, docking and weaning percentages by 16, 17, 21 and 20% (McWilliam *et al.*2005b) and that grazing willow browse blocks increased reproductive rates by 20% (Pitta *et al.*, 2005) due to an increase in the proportion of ewes bearing multiple lambs. Similar studies have not been conducted in mated hoggets.

1.8.2 Feed requirements during mating

Hoggets gaining weight during mating have better reproductive performance (ovulation and lambing rate) than those maintaining or losing weight. Levels of LWG of 80 to100 g/day around mating are desirable and are controlled by the quantity and quality of feed eaten by the ewe hoggets (Gavigan and Rattray, 2002); this in turn is influenced by the total pasture mass (kg DM/ha), the percentage of green and dead material in the pasture, the quantity of pasture offered (kg DM/hogget/day) and the botanical composition (ratio of grass to legume; Gavigan and Rattray, 2002; Smith and Knight, 1998). Recent studies (Wallace *et al.*,1996, 1999) with pen fed pregnant hoggets have shown that very high levels of LWG (in excess of 225 g/day) over the first 100 days may result in reduced conception rates (30%) due to reduced levels of the hormone progesterone. On ryegrass/white clover pasture, hoggets should not be allowed to utilise over 20 to 30% of the feed at each grazing as intakes and performance will reduce. This coincides with a pasture allowance of 4 to 5 kg DM/hogget/day, which will allow intakes of around 1.2 to 1.5 kg DM /hogget/day. Pastures should be in the 1500 to 2000 kg DM/ha range and grazing below this level will depress hogget growth rates and reproductive rates (Gavigan and Rattray, 1998).

Studies on the effect of pasture allowance on ovulation rates in ewes have shown that ovulation rate increases in a curvilinear manner, as the amount of pasture fed increases, reaching a peak at allowances of around 3 to 4 kg green DM/ewe/day and post-grazing residual around 1000 kg green DM/ha (Rattray *et al.*, 1983). The importance of fresh green material is easily understood, for as well as the marked preferences that sheep have for it over dead material in the sward, the proportion of green material is very closely related (r = 0.98) to the overall digestibility of the pasture. Rattray *et al.*, (1983) reports that for autumn pastures, for every one percentage unit increase in green matter, average sward digestibility increases by about 0.5 percentage units. The benefits of legumes over grass species for finishing lambs is well known; similar advantages have been demonstrated for white clover dominant pastures as opposed to ryegrass dominant swards for flushing ewes. At any particular allowance clover-fed animals showed significant increases in ovulation rates above those grazing ryegrass pastures (Rattray *et al.*, 1983). It is expected that clover will have similar effects in flushing mated hoggets.

1.8.3 Sensitivity of hogget mating to effective parasite control.

Smith *et al.*, (1983), Smith and Knight (1998), McWilliam *et al.*, (2005b), and Pitta *et al.* (2005) have all shown that LW change prior to and during mating has a beneficial effect on reproductive performance of ewes. Ewes with low levels of parasitic infection are more likely to achieve pre-mating liveweight targets and increased reproductive rates (Kempthorne *et al*., 1996). Earlier works by Lewis (1975) showed a 6.5% and 3.6% mean increase in lambs born by ewes drenched prior to mating. Similar experiments to evaluate the effect of parasite status on reproductive rates in mated ewe hoggets have not been conducted.

1.9 Conclusions

- Long periods of hot dry weather conditions over the dry summer/autumn period in some areas of NZ (Gisborne, Hawkes Bay, Wairarapa, Marlborough, most of coastal Canterbury, and inland Otago) reduces herbage mass and nutritive value, and can lead to losses in ewe LW and BCS during the pre-mating and mating periods, which can lead to a reduction in ovulation rate and subsequent lambing %.

- Willow is a member of the Salicaceae family, found mainly in the Northern hemisphere and has been introduced and extensively cultivated in NZ for soil erosion control on hill pastoral farms and riverbanks, for animal welfare i.e shade and shelterbelts and recently for energy generation due to its high capacity to produce large volumes of biomass, high energy potential and ability to grow in marginal soils.

- In NZ, willow trees originally planted for soil conservation have been used successfully by a number of farmers as a source of alternative supplementary fodder for sheep and cattle during the dry summer/autumn period when there are feed shortages. Edible willow fodder (< 5 mm diameter) is substantially lower in fibre and higher in ME and CT concentration compared to low quality summer pasture and is similar in digestibility and ME content to vegetative *L. corniculatus* and good quality lucerne hay. Willow trees are also inexpensive, easy to establish in a range of soil types and climates and provide an annually renewable feed source.

- There are two systems of feeding willow to ruminant livestock. The first involves mechanically pruning of trees originally established for conservation or shelter reasons and fed as supplement to grazing livestock. This method is easy to do but is labour intensive. The second option involves densely planted blocks of trees (willow fodder blocks) that can be mechanically cut and fodder carried to livestock or grazed *in situ* as fodder blocks. Suitable areas for the establishment of fodder blocks should have zero or very low productivity in undeveloped state (i.e rush infested low lying wet areas). For optimum management, the fodder blocks should be grazed three times at eight week intervals, during the growing season. This method of feeding is less labour intensive. The annual edible DM yield of coppiced Tangoio willow is 0.3 to 2.5 kg DM/tree.

- Low concentrations of CT are present in willow (approximately 33g /kg DM). This is however greater than the minimum (5g /kg DM) suggested requirement to have beneficial effects on protein digestion in ruminants. Low to moderate (5 to 40 g /kg DM) CT in the diet of ruminants fed fresh forages reduces nitrogen degradation by rumen micro-organisms, increases the flow of NAN to the intestine, relative to nitrogen intake and increases the absorption of EAA from the small intestine, without depressing rumen CHO digestion or voluntary feed intake. This has been shown to increase the productivity of grazing ruminants. Effects of CT upon protein digestion in ruminants depend upon MW, structure as well as concentration. MW and structure of CT in willow tree fodder is unknown.

- Hogget reproductive rates are lower and much more variable than for mature ewes, especially if the mating period is restricted to less than four weeks. Several studies have shown that reproductive rate in hoggets is influenced by mating weight and increased by 2% per kg increase in LW. Both supplementation with cut willows and grazing ewes on willow fodder blocks for 7 to 8 weeks, during mating under drought conditions reduced LW loss and increased reproductive rate by 20% units, compared to ewes grazing short drought pasture. Increased amino acid absorption from the small intestine, particularly BCAA, due to higher CT intakes, was likely to be a contributing factor in the increased reproductive rates in ewes grazing on willow fodder blocks. To date, there has been no scientific experimentation on the effect of this practice upon reproductive rates in mated hoggets.

- Control of GI nematodes has relied heavily on the use of anthelmintics, leading to the development of anthelmintic resistance. Studies into alternative strategies for control of internal parasites in lamb production systems in NZ have shown that parasitized lambs grazing willow fodder blocks had reduced worm burdens relative to parasitized lambs grazing control pasture. Increased supply of EAA. due to the action of CT may stimulate the immune system, enabling the animals to better resist a parasite burden. CT may also disrupt the nematode life cycle by preventing eggs from hatching into larvae and developing into the infective L3 larvae. The mechanism by which CT inactivates the eggs and reduces larval development are not fully known

- Results summarized above were obtained in trials that evaluated the effect of grazing willow fodder blocks on growth rates in weaned male lambs for meat production over the dry summer/autumn period with reduced reliance on anthelmintic options to control GI parasites and on reproductive rates in ewes grazing drought pasture before and after mating. There is need to evaluate the effect of grazing hoggets on willow fodder blocks during the late summer/autumn including mating, on reproductive rate, with reduced reliance on anthelmintic use to control GI parasites. These aspects are investigated in this thesis, comparing trigger drenched (drenched only when the mean faecal egg count of each group exceeded 1000 eggs/g wet faeces) hoggets grazing willow fodder blocks with regularly drenched and trigger drenched hoggets grazing perennial ryegrass/white clover pasture.

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CHAPTER 2

THE EFFECT OF GRAZING WILLOW (*Salix* spp.) FODDER BLOCKS UPON REPRODUCTIVE RATE AND AND MANAGEMENT OF INTERNAL PARASITES IN MATED HOGGETS

2.1 Introduction

Sheep production in New Zealand (NZ) is based on year round grazing of temperate pastures predominantly consisting of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), that support low cost, efficient production of meat and wool. However, in some areas (i.e. Gisborne, Hawkes Bay, Wairarapa, Marlborough, most of coastal Canterbury, and inland Otago) dry conditions in the summer/autumn reduce pasture growth and quality thus limiting the feed available for grazing ewes during the pre-mating and mating periods. Mating of ewe hoggets (6 to 9 month old female lambs) has been identified as one method of increasing net profits for the sheep industry, due to the generation of extra lambs produced (Kenyon *et al*., 2004). However, hogget reproductive rates are often disappointing (NZ national mean 60 lambs born/100 ewes mated). This is usually due to inadequate live weights (LW) at mating caused by gastrointestinal (GI) nematode burdens (Howse *et al*., 1992) and poor nutrition during dry summer/autumn and drought conditions (McWilliam *et al*., 2004), thus limiting the uptake of this management strategy (Kenyon *et al*., 2004).

Internal parasites are estimated to cost the NZ sheep industry $300 M annually in lost production and anthelmintic control (Rattray, 2003). Control of GI parasites is mainly by chemotherapy (Vlassoff and McKenna, 1994) but the effectiveness of anthelmintics is being reduced by the emergence of nematode anthelmintic resistance (McKenna *et al*., 1995; Waller, 2006). Development of integrated programmes to control GI nematodes is vital, but such control programmes require viable alternatives to the use of anthelmintics (Waller, 1999). One such alternative maybe the use of plants containing condensed tannins (CT; Ramirez-Restrepo and Barry, 2005). Grazing undrenched lambs on CT-containing willow fodder blocks lowered the establishment of some GI parasites at slaughter compared to undrenched lambs grazing control pasture (Diaz Lira *et al*., 2007).

Willow and poplar trees have been extensively planted on NZ East Coast hill country farms to control soil erosion. Supplements of willow tree trimmings during mating, to ewes grazing low quality drought pasture have been shown to increase ewe LW and reproductive rates (McWilliam *et al*., 2005b). The planting of densely populated willow browse blocks for grazing by sheep is a logical extension of this work, to reduce labour costs associated with trimming trees to provide supplements. Pitta *et al*., (2005) reported that grazing willow fodder blocks during the pre-mating and mating periods reduced LW loss from 100 g/day to 40 g/day and increased reproductive rate by approximately 20% units, with more ewes bearing twin lambs, relative to ewes mated on drought pasture. However, there are no reports on the potential benefits of supplementing ewe hoggets on willow fodder blocks during the pre-mating and mating periods.

The objective of this study was to evaluate the effect of grazing willow browse blocks pre-mating and during mating on GI parasite control and reproductive rates in mated ewe hoggets.

2.2 Materials and methods

2.2.1. Experimental design

A grazing trial involving 348 shorn Romney weaned ewe hoggets (6 to 9 month old female lambs) was conducted at Massey University's Riverside dryland farm (farms experiencing annual water deficits in the 300-500mm range in the summer/autumn months), near Masterton, New Zealand, on the North Island East Coast. The experimental areas were grazed over 116 days from 19 January 2006 to 15 May 2006 (i.e., summer/autumn), including one 17 day cycle of mating. Hoggets were randomly allocated to three treatment groups each of 116 animals: control pasture with regular anthelmintic drenching, control pasture with trigger drenching and willow fodder blocks with trigger drenching. During the experimental period, all three groups grazed separate breaks/paddocks and were rotationally grazed at least twice over the same breaks. These comprised four breaks of control pasture and five breaks of willow fodder blocks.

Control pasture consisted of low quality herbage typical in normal dryland farming conditions during summer/autumn, while feed in the willow fodder blocks comprised trees (approximately 1.0-1.2 meters tall) and herbage grown underneath the trees. All groups of hoggets were fed at the same dry matter (DM) allowance during each break (fenced areas), which increased as the experiment progressed; mean daily allowance was 4.5 kg_DM/hogget/day. Mating occurred from 27 April to 15 May with hoggets being exposed to vasectomised teaser rams for 17 days prior to mating. Mating ceased after one cycle, due to the onset of autumn leaf fall of willow trees. After mating, the three groups were joined together and managed as one group until the end of the experiment at weaning, on 7 January 2007. Live-weight (LW), dag scores (DS; measure of faecal matter in the wool around the anus) and faecal egg counts (FEC) of hoggets were measured regularly throughout the experiment, whilst reproductive rate was measured at ultra-sound pregnancy scanning, lambing, docking (tail removal) and weaning. Wool production was measured at weaning.

2.2.2 Animals

On 19 January 2006, weaned Romney ewe lambs of similar age, size and LW were randomly assigned to the three treatment groups, individually tagged and weighed. All lambs were drenched with "Erase MPC plus Scanda" (Coopers®, Schering-Plough, Upper Hutt, New Zealand), a combination of ivermectin, albendazole and levamisole anthelmintics at the start of the experiment. The control pasture regularly drenched lambs were drenched at monthly intervals, whilst the control pasture and willow fodder block trigger drenched lambs were drenched only if the FEC geometric mean of each group exceeded 1000 eggs/g (epg) wet faeces. Trigger drenching occurred during the experimental feeding period on 22 February, 1 April and 29 April, and during the post experimental feeding period (all groups), on 15 June, 15 September and 22 November.

All lambs were vaccinated with Campylovexin (Coopers® Schering-Plough, Upper Hutt, New Zealand), ToxoVax (AgVax Developments Ltd, Upper Hutt, New Zealand) and Salvexin™ +B (Schering-Plough Animal Health Ltd., Upper Hutt, Wellington, New Zealand) vaccines on 22 February to prevent *Campylobacter fetus fetus* and, toxoplasma abortions and salmonella infection, respectively. Campylovexin and Salvexin TM +B booster vaccines were administered a month later. Approximately 75% of the regularly drenched control hoggets became infected with parapox virus (scabby mouth; contagious pustular dermatitis) on 16 May and were treated with oxytetracycline (Boehringer Ingelheim New Zealand Ltd, Wiri 1702, New Zealand) and the lesions painted with iodine mixed with glycerol. Hoggets in the two trigger drenched groups were vaccinated with Scabigard (Pfizer New Zealand Ltd, Auckland, New Zealand) on

23 March and remained free of scabby mouth. Prior to lambing, all hoggets were vaccinated with Multiline^{TM}(Coopers$^{®}$ Schering-Plough Upper Hutt, New Zealand), a combination 5-in-1 vaccine against clostridial infections.

During the teasing and mating periods, three harnessed vasectomised and three harnessed non-vasectomised Romney rams, respectively, were exposed to each group of 116 hoggets (2.6 rams/100 hoggets). All hoggets were scanned for pregnancy using ultrasound 74 days after the end of the mating period, and identified as being non-pregnant, single- or twin-bearing. All hoggets were crutched (wool removed from around the tail and anus; 14 June and 10 September) and had their feet soaked (14 June) in 10% formalin to prevent foot scald. Hoggets lambed between 15 September and 9 October 2006 and reproductive data was recorded at lambing. Lambs were tail docked with a searing iron on 22 November and weaned on 7 January 2007.

2.2.3. Forages

2.2.3.1. Control pasture and willow fodder blocks

Control pasture and willow fodder block breaks were grazed by undrenched non-experimental ewes during winter and early spring (June to October 2005) and by undrenched weaned lambs in early summer (December 2005) to ensure contamination with GI parasites and to reduce pasture mass to approximately 2500 to 3000 kg DM/ha, prior to the start of the experimental period. After experimental hoggets grazed control pasture breaks (1 to 3) and willow fodder block breaks (2 to 4), drenched non-experimental ewes grazed each break for three days, followed by mechanical topping of control pastures to reduce the proportion of stem, remove any flowering tissue, stimulate vegetative growth and improve pasture quality for subsequent grazings. Recently drenched (2 to 5 days after drenching with "Erase MPC plus Scanda") ewes were used, to minimise any changes to the parasite status of the breaks.

Five willow fodder blocks (approximately 1ha each) were established on Riverside farm in 2000 and 2001, with 6,000 trees/ha spaced at 1.2 m, in rush-infested, low-lying wet areas not suitable for grazing livestock. Tree species planted were *Salix matsudana*

Plate 1.1 General View of willow fodder blocks before grazing

Plate 1.2 General view of control pasture breaks with electric fences

Koidz x *alba* L. (hybrid willow) clones 'Tangoio' (NZ 1040) and 'Moutere' (NZ 1184). Site preparation and planting details have been described by Pitta *et al.* (2005). The four breaks of control pasture were located near each of the five fodder block breaks.

2.2.3.2. Grazing management

Willow fodder blocks and control pasture areas were rotationally grazed in 10 and 8 breaks, respectively, each lasting 5 to 14 days, using front and back semi-permanent electric fences. All treatment groups were moved to a new break on the same day. At all times during the experiment, all three groups were grazed in separate breaks and, during the second grazing rotation, each group grazed the same breaks as were grazed in the first rotation. Total grazing days (TGD) were calculated for each break, using the following equation.

$$TGD= (HM * GA) / (n * FA) \qquad (1)$$

where HM is herbage mass (kg DM/ha), GA is grazing area (ha), n is the number of hoggets, and FA is feed dry matter (DM) allowance/hogget/day (4.5 kg). For willow fodder blocks, DM allowance refers to the combined total of trees and herbage growing in the blocks. This management system was aimed at providing similar levels of available feed to each treatment group. Water was provided *ad libitum* to all groups from portable water troughs.

During the experiment, willow fodder blocks were grazed in two rotations. The first experimental grazing rotation (19 January to 15 March) was on second growth (pasture and tree growth after winter and early spring grazing with undrenched non experimental ewes), while the second experimental grazing (11 April to 15 May) was on third growth (pasture and tree growth after early summer grazing of secondary growth with weaned experimental lambs). First growth was grazed by non-experimental undrenched lambs in December 2005 as described in section 2.2.3.1. Between 15 March and 11 April, lambs were moved out of the fodder blocks and grazed on pasture only close to the fodder blocks to allow sufficient re-growth of trees. The pasture used was reserve pasture that was prepared by grazing with undrenched sheep in the same way as the pastures and fodder blocks used in the experiment, in order to maintain a similar parasite status. During this period, hoggets were supplemented with 30 kg willow tree trimmings three times per week as described by McWilliam *et al.*, (2005a,b). 'Tangoio' (NZ 1040) willow trimmings were delivered from Greater Wellington Regional Council's Akura nursery, near Masterton. Willow was cut once a week and stored in a room at 4°C to reduce dehydration and weight loss. Willow supplementation was aimed at maintaining a similar rumen environment, microbial population and diversity to that of hoggets grazing willow fodder blocks.

2.2.4. Forage measurements

2.2.4.1. Pasture

Control pasture and fodder block herbage mass was determined immediately before and after grazing each break by cutting eight random quadrats (0.6 m x 0.3 m) per treatment group per break to ground level, washing and then drying in a forced-air oven (Contherm, Thermotec 2000, New Zealand) at 80°C for 18 to 24 hours. Pooled sub-samples of pasture from all eight quadrats in each break were collected before and after grazing to estimate green and dead matter content. The pre-grazing green material was further dissected into grasses, legumes and herbs. Six exclusion cages, approximately 1.0 m x 0.5 m x 0.5 m were placed in each break before grazing. After grazing each break, hand plucked samples were collected from the exclusion cages, to simulate the diet consumed by ewes. These samples were pooled and stored at -20°C for nutritive value analysis. These sampling procedures were developed and validated by Pitta *et al.*, (2005; 2007).

2.2.4.2. Willow fodder blocks

The mass of willow per ha was estimated before grazing each break by cutting four trees/break, selected at random, to stump level, cutting the material into approximately 2 cm lengths and drying. Willow material remaining after grazing was similarly estimated. Four round exclusion cages (2 m height x 0.7 m diameter) per break were placed around individual trees. After grazing each break, samples corresponding to the

Plate 1.3 Herbage cuts for measurement of herbage mass and botanical composition

Plate 1.4 Pasture cages for diet selected

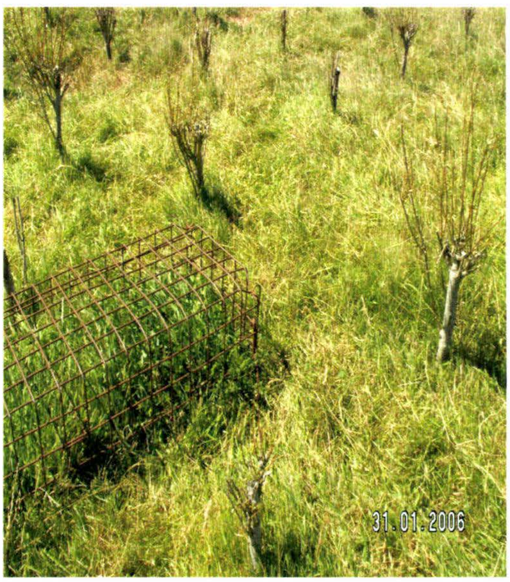


Plate 1.5 Willow cages for diet selected

willow diet selected by the hoggets were collected and pooled by break. Representative samples were cut into 2 cm lengths and were stored at -20°C for nutrient analysis. DM percentage was estimated from the diet selected samples taken from each break. Diameter of willow residue eaten was determined after grazing each break, using electronic callipers (Mitutoyo Corp., Japan), with 150 measurements made per break (75 measurements each, for leader and basal shoots). These sampling procedures were developed and validated by Pitta *et al.*, (2005; 2007).

The mass of herbage growing in the fodder blocks and sampling for botanical and chemical composition were carried out as described in section 2.2.4.1.

2.2.5. Animal Measurements

Mean initial LW was similar among the three treatment groups with the control pasture regularly drenched, control pasture trigger drenched and willow browse block trigger drenched groups weighing 27.4 kg, 27.2 kg and 27.3 kg (S.E 0.68), respectively. During the experimental feeding period, hoggets were weighed by electronic scales (Tru-test, Auckland, New Zealand) and evaluated for DS on a scale of 1 to 5 (1 = no dags, 5 = highest incidence of dags) fortnightly. During the experimental feeding period, rectal faecal samples were collected fortnightly from 15 hoggets in each of the two trigger drenched groups and monthly from 15 hoggets in the regularly drenched group to measure FEC, before being drenched. After the experimental feeding period, faecal samples were collected monthly from all three groups. Hoggets were selected randomly for initial faecal collection and the same individuals were sampled on each subsequent occasion. Reproductive data were collected during the lambing period, including lamb birth date, weight, rank and sex. Lamb weaning weights were recorded. Scanning, lambing, docking and weaning percentages were calculated. Scanning rate was defined as foetus/100 ewe hoggets mated, conception rate as ewe hoggets pregnant/ 100 ewes mated and fecundity as lambs born/100 ewe hoggets lambing.

2.3.6 Laboratory analyses

Willow and pasture samples of diet selected were stored at -20°C, freeze dried and ground to pass through a 1 mm diameter sieve. Total nitrogen (N) concentration was determined using the Dumas method (Leco Corporation 1994) and organic matter (OM) by ashing samples for 16 hours at 550°C. *In vitro* OM digestibility (OMD) was determined by the enzymatic method of Roughan and Holland (1977), using separate standard curves prepared from *in vivo* values for forages and willow fed to sheep (McWilliam *et al.*, 2005a). Metabolisable energy (ME) calculated as 16.3 x *in vitro* digestible organic matter/100g DM (DOMD; Drew and Fennessy, 1980).

All samples were analysed for acetone/water-extractable, protein-bound and fibre-bound CT fractions, using the butanol-HCl colorimetric procedure (Terrill *et al.*, 1992) and total CT concentration was calculated by adding the three fractions. All CT concentrations were determined using CT extracted from *Lotus pedunculatus* as a reference standard (Jackson *et al.*, 1996).

Faecal samples for FECs were refrigerated at 4°C and FEC determined using a modified McMaster method (Stafford *et al.*, 1994) with a precision of 1 counted egg: 50 epg wet faeces.

2.3.7. Statistical analyses

All animal data were analysed considering each animal as the experimental unit (Pitta *et al.*, 2005; 2007). Due to the high costs associated with developing new fodder blocks and the long period of time (three years) it takes to get them ready for grazing, as well as the large numbers of hoggets needed to determine significance in reproduction experiments, it was not possible to graze each replicate as an independent area in this trial and so use areas of land as the replicate in the statistical analysis. Whilst it is realised that this results in confounding between nutritional treatments and areas of land, it is believed not to have altered the conclusions that can be drawn from the present study due to the large number of animals per land area and the overwhelming impact of treatment on land areas utilised. All data were analysed using Statistical Analysis System version 9.1 (SAS 2003).

Mean and standard errors of forage botanical composition and pre- and post-grazing herbage masses were obtained using the GLM procedure, fitting a linear model that considered the effects of treatment. Differences in chemical composition of the diet selected in each of the treatments and regression equations for the diameter of willow shoots eaten over time were estimated by using the MIXED procedure.

LW and DS were analysed using the MIXED procedure; the linear model included the fixed effects of day, treatment, treatment by day interaction, and the random effect of animal. Using the Akaike's information criterion, a compound symmetric error structure was determined as the most appropriate residual covariance structure for repeated measures over time within animals (Littell *et al*., 1998). FEC values were analysed using the GENMOD procedure, assuming a Poisson distribution with a logit transformation to normalise the data. The linear model included the fixed effects of day, treatment, day by treatment interaction and the random effect of lambs.

Differences in ovulation rate and pregnancy rate between treatments were tested using GENMOD procedure, assuming a binomial distribution with a logit transformation. The linear model included treatment and LW at the start of mating as a covariable. Least square means for reproductive rate at scanning, lambing, docking and weaning were obtained for each treatment using the MIXED procedure. Reproductive rate was expressed as a proportion of number of lambs to hoggets mated. PROC GENMOD was used to run a categorical analysis to compare the proportion of ewes bearing single and multiple lambs, assuming a binomial distribution with a logit transformation. Lamb birth and weaning weights were analysed with the MIXED procedure by fitting a linear model that included the fixed effect of treatment, sex and birth rank. Lamb mortality data were analysed using PROC GENMOD assuming a binomial distribution (0=dead, 1=alive) considering the fixed effect of treatment, sex and birth rank. Data were transformed using the logit transformation, and least square means and 95% confidence intervals were back transformed into the nominal scale. Greasy fleece weight was analysed using PROC MIXED and adjusted for the effects of LW and birth rank.

2.3 Results

2.3.1 Forages and botanical composition

Pre- and post-grazing herbage masses for second and third growth were generally similar for all three groups at each grazing, with second growth herbage mass greater than third growth (Table 2.1). Willow fodder block tree yields were greater for second than third growth, and were low relative to herbage mass in the fodder blocks, contributing approximately 0.13 and 0.11 of total DM yield for second and third growth, respectively (Table 2.1).

Pre-grazing dead matter content was generally similar for second and third herbage growth, for all groups, with willow fodder blocks having lower values than control pastures (Table 2.1). The Legume content in the willow fodder blocks was consistently greater than that of control pasture. Pasture grazed for four weeks between the second and third grazings, had similar pre- and post- grazing herbage masses and botanical composition for all groups, with mean values of 3217 and 2601 kg DM/ha, respectively, 45% dead matter content and 10% legume content.

Diameter (D, mm) of the willow eaten increased with time ($P<0.001$) over the experimental period (t, days) for both leader and basal shoots (Fig. 1a and b; Eqs. 2 and 3), with differences between the regression intercepts and slopes ($P<0.001$). Overall diameter means were 3.27 mm for leader shoots and 1.98 mm the basal shoots.

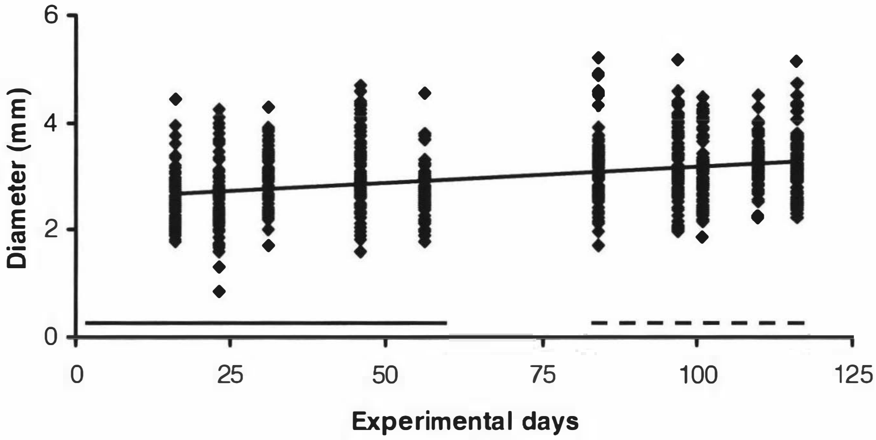
Table 2.1: Pre- and post-grazing herbage mass (kg DM/ha) and botanical composition (%) of second and third growth of control pasture and willow fodder blocks grazed during the experiment in 2006 (mean values with standard errors)

	Control pasture		Willow fodder block	
	Regularly drenched	Trigger drenched	Trigger drenched	
			Herbage	Tree
Second growth[1]				
n	4	4	5	5
Pre-grazing mass	4747 ± 582.0	4221 ± 527.0	4542 ± 520.6	698 ± 41.4
Post-grazing mass	3232 ± 288.7	2989 ± 202.2	3445 ± 258.3	417 ± 33.8
Botanical composition (%)				
Dead matter content	33.1 ± 3.72	33.4 ± 3.92	22.2 ± 3.3	
Grasses[2]	86.9 ± 3.34	85.3 ± 3.30	68.4 ± 2.95	
Legumes[2]	6.4 ± 2.99	6.6 ± 3.49	17.4 ± 2.67	
Others[2]	6.7 ± 3.16	8.1 ± 3.76	14.2 ± 2.83	
Third growth[1]				
n	4	4	5	5
Pre-grazing mass	2732 ± 302.5	2931 ± 342.5	3139 ± 270.6	367 ± 33.3
Post-grazing mass	1635 ± 260.7	1811 ± 276.7	2039 ± 233.2	287 ± 36.0
Botanical composition (%)				
Dead matter content	29.2 ± 4.48	30.4 ± 6.07	20.3 ± 4.01	
Grasses[2]	91.8 ± 6.41	88.8 ± 4.41	77.6 ± 4.00	
Legumes[2]	6.0 ± 2.47	6.5 ± 2.98	9.5 ± 2.21	
Others[2]	2.2 ± 2.77	4.7 ± 3.07	12.9 ± 2.48	

[1] Primary growth was grazed by non experimental lambs in December 2005, before the experiment started

[2] Expressed as a proportion of green matter content

(a)



(b)

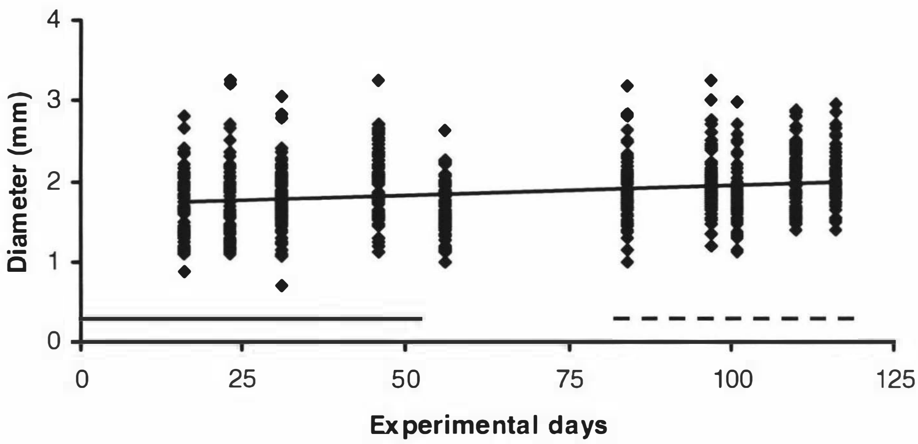


Figure 1: Change in (a) leader and (b) basal shoot diameter eaten in samples of willow selected by lambs grazing willow fodder blocks. The solid line indicates the second growth grazing period (56 days); the broken line indicates the third growth grazing period (32 days); and in between is the grazing period (28 days) when all three groups grazed on pasture.

D = 2.61 + 0.006t

S.E. 0.072 0.0007 **(2)**

P * * * * * *

D = 1.69 + 0.003t

S.E. 0.043 0.0004 **(3)**

P * * * * * *

2.3.2 Chemical composition

Total N concentration (34.7 g/kg DM), OMD (0.68) and ME (10.0 MJ/kg DM) of the diet selected samples of second and third growth were similar for control pasture and herbage in the willow fodder blocks (Table 2.2). Similar values were observed when all three groups grazed only pasture for 28 days between the second and third grazing (Table 2.2). Willow selected from the fodder blocks had lower concentrations of N (24 g/kg DM) and was higher in OMD (0.74) and ME (10.4 MJ/kg DM) compared to herbage selected. The willow diet selected contained considerably higher concentrations of CT (22.9 vs1.6 g/kg DM) than control pasture and herbage in willow fodder blocks ($P<0.0001$; Table 2.2).

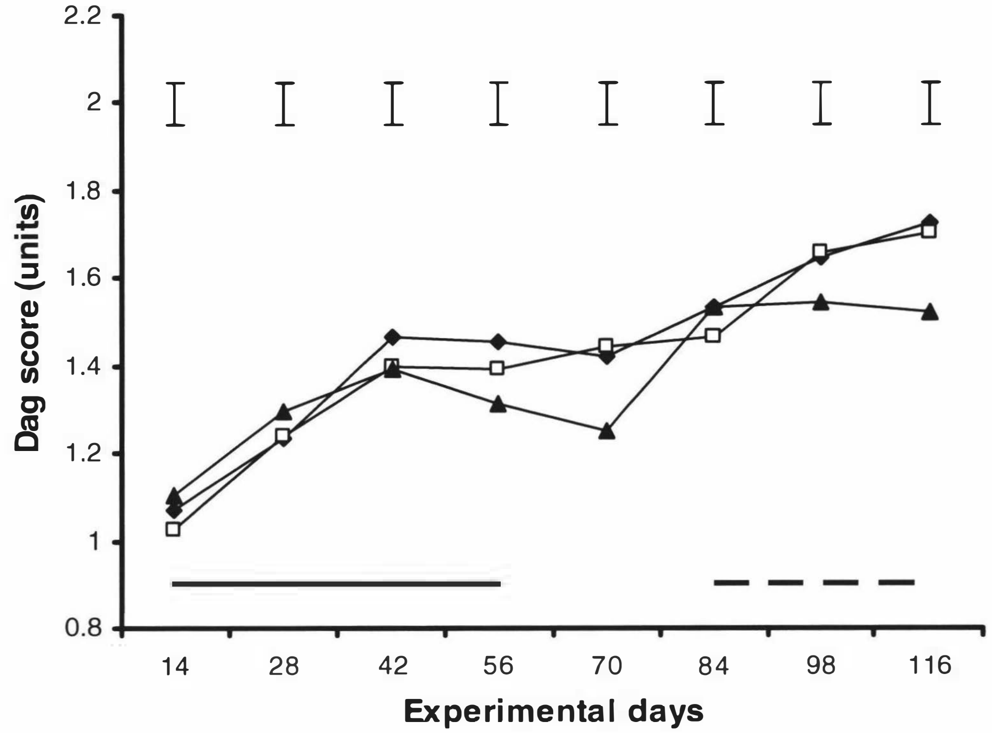


Figure 2: Changes in least square mean values of dag score units in trigger drenched groups grazing control pasture (□) and willow (▲); and the regularly drenched group grazing control pasture (♦).The solid line indicates the second growth grazing period (56 days); the broken line indicates the third growth grazing period (32 days); and in between is the grazing period (28 days) when all three groups grazed on pasture. (I) standard error of the mean.

FEC values increased with time of experimental feeding to day 116 ($P<0.0001$) in all three treatment groups, with time x treatment interactions ($P < 0.05$; Fig 3). FEC of control regularly drenched hoggets increased until day 70, and then rapidly declined. FEC of the two trigger drenched groups were lower than that of regularly drenched lambs at the end of the second grazing period (day 56; $P<0.0001$) but higher than that of regularly drenched hoggets at the end of third grazing period (day 116; $P<0.0001$). FEC values of the two trigger drenched groups were generally similar until day 116, when FEC for the willow fodder block group was lower ($P<0.05$) than trigger drenched hoggets grazing control pasture. In the post-treatment period, from day 116, FEC values were similar for all three groups. During the experimental period, trigger drenched hoggets received three administrations of oral anthelmintic, compared with the four for regularly drenched group, in addition to all hoggets being drenched at the start of the

Table 2.2: Chemical composition (g/kg DM) and nutritive value of the pasture and willow diet selected by regularly drenched and trigger drenched lambs grazing control pastures and willow fodder blocks (mean values with standard errors)

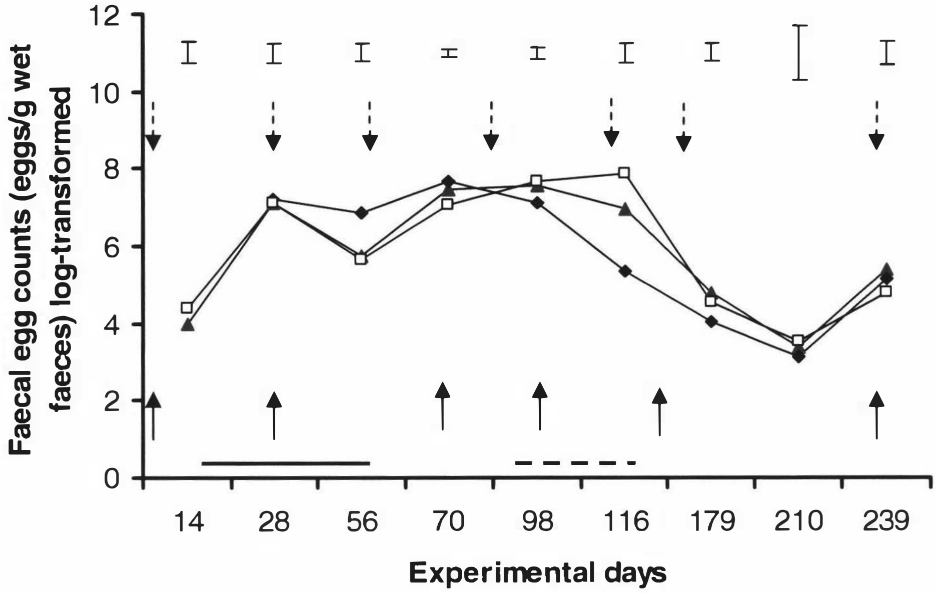
	Control pasture[1]		Willow fodder blocks[2]		Pooled
	Regularly drenched	Trigger drenched	Trigger drenched		S.E.M
			Herbage	Tree	
Second + Third growth					
Total N	35.6	35.3	33.2	24.3	1.78
OMD[3]	0.69	0.68	0.68	0.74	0.009
DOMD[4]	0.62	0.61	0.61	0.64	0.009
ME (MJ/kg DM)[5]	10.1	9.9	9.9	10.4	0.13
Total CT[6]	1.6 ± 1.36	1.3 ±1.25	1.8 ± 1.42	22.9 ± 2.36	
	Pasture[7]				
Total N	38.0	36.9	35.8		2.68
OMD[3]	0.68	0.66	0.67		0.02
DOMD[4]	0.62	0.59	0.61		0.01
ME (MJ/kg DM)[5]	10.0	9.8	9.9		0.21

Pasture measurements made on hand plucked samples of diet selected. Willow tree measurements made on hand cut samples from trees (stem diameter<5 mm) of diet selected.
[1] n = 8 samples per treatment
[2] n = 10 samples per treatment
[3] OMD: organic matter digestibility *in vitro*
[4] DOMD: digestible organic matter in the dry matter *in vitro*
[5] ME: metabolisable energy = DOMD x 16.3
[6] CT: condensed tannin; n= 4 samples per treatment
[7] All lambs grazed on these pastures for 28 days between second and third grazing of the willow fodder blocks and adjoining control pasture. n=4 samples per treatment

2.3.3. Dag scores and faecal egg counts

DS increased with time ($P<0.001$) in all three treatment groups, with time x treatment interactions ($P<0.001$; Fig 2). DS was similar for trigger drenched and regularly drenched hoggets grazing control pasture. Grazing of willow fodder blocks tended to lower DS, particularly towards the end of the second and third growth grazing period, when DS of the fodder block hoggets was significantly lower than that of hoggets grazing control pasture ($P<0.01$).

(a)



(b)

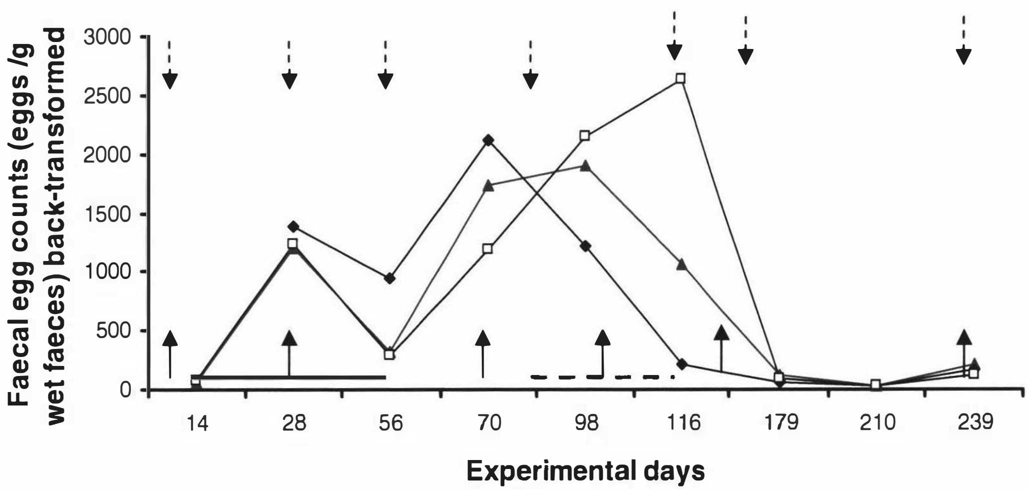


Figure 3 Change in (a) log-transformed and (b) back transformed least square mean values of FEC (eggs/g wet faeces) in trigger drenched groups grazing control pasture (□) and willow fodder blocks (▲); and the regularly drenched group grazing control pasture (♦). The solid line indicates the second growth grazing period (56 days); the broken line indicates the third growth grazing period (32days); and in between is the grazing period (28days) when all three groups grazed on pasture. (I) standard error of the mean. ↓↑ Indicates drench administration in the regularly and trigger drenched groups respectively. Pasture and willow fodder block trigger drenched groups were both given the same trigger drenches on the same days.

experiment. Both the pasture and willow fodder block trigger drenched groups were drenched on the same days.

2.3.3. Live weight and reproductive rate

LW gain (Table 2.3) was consistently greater (P<0.0001) in lambs grazing willow fodder blocks during the 116 day experimental feeding period, compared to hoggets grazing control pasture (97 vs 85 g/day; Table 1.3). At the start of the mating period with entire rams, ewe hoggets grazing willow fodder blocks were significantly heavier than the two control pasture groups (35.8 vs 34.8 kg). LW continued to increase after the groups were joined together at the conclusion of mating (Fig 4), with no differences between the three groups at the beginning of the lambing period.

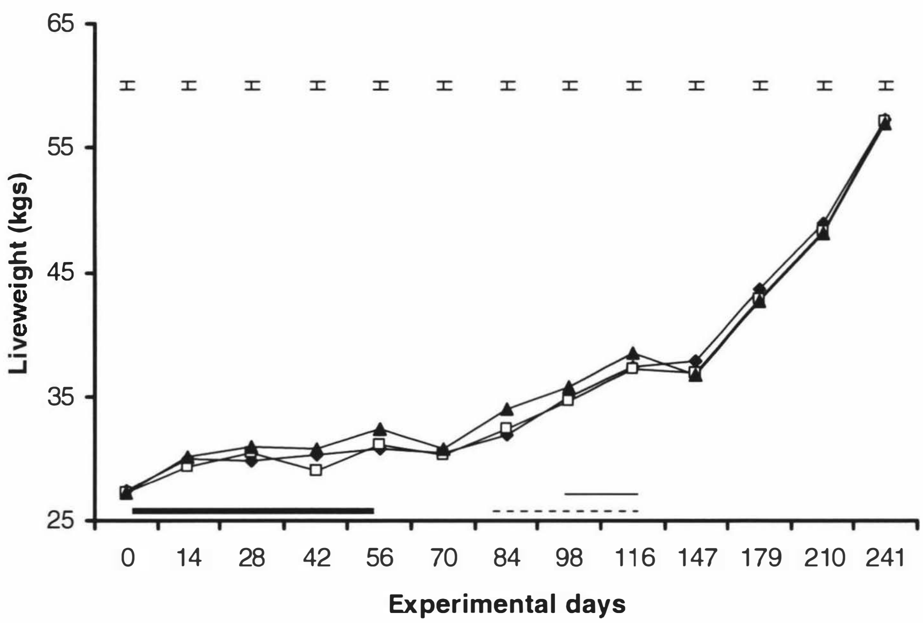


Figure 4: Changes in mean ewe hogget live weight in trigger drenched groups grazing control pasture (□) and willow fodder blocks (▲); and the regularly drenched group grazing control pasture (♦). The thick solid line indicates the second growth grazing period (56 days); the broken line indicates the third growth grazing period (32days); and in between is the grazing period (28days) when all three groups grazed on pasture. The thin solid line indicates period of mating (17 days); and (I) represents standard error of the mean.

Table 2.3 Live weight (LW) and LW change (g/day) during the 116 day experimental grazing period and reproductive rate in regularly drenched and trigger drenched ewe hoggets grazing control pasture and willow fodder blocks (mean values with standard errors).

	Control pasture		Willow fodder block	Pooled
	Regularly drenched	Trigger drenched	Trigger drenched	S.E.M
n	115	114	115	
Initial live weight (kg)	27.4	27.2	27.3	0.31
Final live weight (kg)	37.3^{a}	37.3^{a}	38.5^{b}	0.31
Change in live weight (g/day)	85.4^{a}	85.5^{a}	96.7^{b}	1.8
Oestrus activity (%)[1]				
Unadjusted				
mean	36.0^{a}	51.3^{b}	71.3^{c}	
range	(27-45)	(42-60)	(62-79)	
Adjusted[2]				
mean	35.2^{a}	52.8^{b}	71.0^{c}	
range	(26 - 44)	(43 - 62)	(61 – 78)	
Reproductive rate (%)[3]				
Scanning	42.2^{a}	45.9^{a}	61.9^{b}	0.06
Lambing	36.9^{a}	43.8^{ab}	56.3^{b}	0.06
Docking	25.5^{a}	29.1^{a}	43.5^{b}	0.05
Weaning	25.5^{a}	29.1^{a}	43.5^{b}	0.05

Means within rows with different superscripts (a, b,c) differ significantly (P<0.05)

[1]% of ewe hoggets mated in the 17 day mating period

[2, 3]Adjusted to equal LW at the start of mating.

[3]expressed as foetus or lambs/100ewe hoggets mated.

Oestrus activity of trigger drenched hoggets grazing willow fodder blocks was greater (P < 0.01) than that of regularly drenched hoggets grazing control pasture during mating, with the trigger drenched hoggets grazing control pasture being intermediate (Table 2.3). The reproductive rate of regularly and trigger drenched hoggets grazing control pasture was low from scanning to weaning, with no differences between the two groups (Table 2.3). Hoggets mated on fodder blocks showed increased (P<0.05) reproductive rates compared to control groups mated on pasture. Table 2.4 shows that grazing willow fodder blocks increased reproductive rate by increasing conception rate (hoggets pregnant /100 hoggets mated; $P<0.05$) and not fecundity (lambs born/100 ewes lambing). Adjusting all reproductive data to equal LW at mating had no effect on the response to grazing on willow fodder blocks. Mean lambing date was similar in all treatment groups. Total post natal-lamb mortality (mortality between birth and weaning) tended to be lower in the willow fodder block group compared with the two control pasture groups although the difference between the means was not statistically significant (Table 2.4). There were no consistent differences between treatments in birth weight and weaning weight of lambs (Table 2.5). Greasy fleece weight were generally similar for all groups with no treatment effects (Table 2.6)

Table 2.4 The effect of grazing regularly drenched and trigger drenched ewe hoggets for 116 days, including mating, on control pasture and willow fodder blocks on conception rate, fecundity, mean lambing date and total lamb mortality from birth to weaning (mean values with standard errors)

	Control pasture		Willow fodder block	Pooled
	Regularly drenched	Trigger drenched	Trigger drenched	SEM
Conception rate[1]				
Unadjusted. mean	33^{a}	33^{a}	49^{b}	
range	(25-43)	(25-43)	(40-58)	
Adjusted. mean	32^{a}	33^{a}	47^{b}	
range	(24-42)	(25-43)	(38-56)	
Fecundity[2]				
Singles	80	67	72	0.07
Twins	20	33	28	0.07
Mean lambing date	29 August	30 August	28 August	
Total post-natal lamb mortality (%)				
mean	34.1	33.3	25.8	
range	(21.7-49.1)	(21.5-47.7)	(16.6-37.5)	

Means within rows with different superscripts (a, b) differ significantly ($P<0.05$)
[1]expressed as ewe hoggets pregnant/100 ewe hoggets mated (adjusted to equal LW at start of mating)
[2]expressed as ewe hoggets/100 ewe hoggets lambing

Table 2.5 The effects of grazing regularly drenched and trigger drenched hoggets for 116 days, including mating, on control pasture and willow fodder blocks on lamb birth weight and weaning weights (kilograms; mean values with standard errors)

	Control pasture		Willow fodder block	Pooled
	Regularly drenched	Trigger drenched	Trigger drenched	S.E.M
Birth weight				
Single male	3.9	4.4	4.4	0.23
Single female	3.8	4.0	4.1	0.24
Twin male	3.5	3.4	3.2	0.32
Twin female	2.6	3.1	3.2	0.46
Weaning weight				
Single male	33.7	33.2	35.6	1.33
Single female	30.4	31.8	32.0	1.20
Twin male	28.7	31.9	30.0	1.45
Twin female	27.6	30.9	27.6	2.32

Table 2.6 The effects of grazing regularly drenched and trigger drenched hoggets for 116 days, including mating, on control pasture and willow fodder blocks on whole year wool production (mean values with standard errors).

	Control		Willow fodder block	Pooled
	Regularly drenched	Trigger drenched	Trigger drenched	S.E.M
Greasy fleece weight (kg)				
Single bearing hoggets	3.2	3.3	3.4	0.01
Twin bearing hoggets	3.5	3.3	3.3	0.02
Average for all hoggets	3.4	3.3	3.4	0.01

2.5 Discussion

The objectives of this study were to evaluate the effects of grazing willow fodder blocks, during the pre-mating and mating periods, on reproductive rates and on GI parasite control in mated ewe hoggets. Grazing ewe hoggets on willow fodder blocks during the pre-mating and mating periods resulted in a small increase in LW and LW gain and a substantial increase in reproductive rate of approximately 17% units, relative to ewe hoggets mated on dry summer/autumn pasture. The increase in reproductive rate was due to increases in both oestrus activity and conception rate. Judging from the amount of anthelmintic drench required to keep the FEC below 1000 epg of wet faeces, it is evident that grazing willow fodder blocks did not adequately reduce gastrointestinal (GI) parasite infection relative to grazing conventional ryegrass/white clover pastures.

Some of the higher incidence of oestrus activity and conception rate observed in hoggets grazing willow fodder blocks during the pre-mating and mating period could be partly explained by the higher LW attained at mating (35.8 kg vs. 34.8 kg), compared with the two control pasture groups. LW is positively associated with the incidence of oestrus, conception rate and subsequent reproductive rate in mated hoggets (Gavigan and Rattray, 2002; Kenyon *et al.*, 2005). Kenyon *et al.*, (2005) observed that hoggets weighing at least 36 kg prior to the introduction of rams are more likely to be mated in the first 17 days of mating and have increased conception rates and lambing percentages. McMillan and Moore (1983) found that as LW increases, the percentage of ewe hoggets exhibiting oestrus increases at about 6% for each unit (kg) increase in LW. However, correcting oestrus activity and reproductive performance to equal live weight at the start of mating had little effect on either of these, suggesting that the higher LW of hoggets grazing willow fodder block accounted for only a small proportion of the increases in oestrus activity and reproductive rate in this study.

Calculated DM and ME intake (Table 2.7) were generally similar for all three groups. However, hoggets grazing willow fodder blocks had a higher calculated CT intake, a slightly lower CP intake and a substantially higher calculated CT intake/100 g CP intake (Table 2.7). Relative to hoggets grazed on pasture, the increase in reproductive rate of hoggets grazing willow fodder blocks was associated with a greater ratio of CT/CP

Table 2.7 Calculated dry matter (DM; kg/hogget/day), metabolisable energy (ME; MJ /hogget/day), crude protein (CP; g/hogget/day) and condensed tannin intakes (CT; g/hogget/day) of ewe hoggets grazing ryegrass/white clover pasture and willow fodder blocks for 116 days during the summer/autumn, including mating (mean values with standard errors).

	Control		Willow fodder block
	Regularly drenched	Trigger drenched	Trigger drenched
DM intake[1]			
Herbage	1.40 ± 0.170	1.44 ± 0.144	1.20 ± 0.137
Willow	0	0	0.19 ± 0.018
Total	1.4 ± 0.170	1.44 ± 0.144	1.39 ± 0.133
ME intake[2]			
Herbage	14.1 ± 1.70	14.2 ± 1.40	11.7 ± 1.35
Willow	0	0	2.0 ± 0.19
Total	14.1 ± 1.70	14.2 ± 1.40	13.7 ± 1.16
CP intake[3]			
Herbage	321.0 ± 4.48	324.4 ± 3.76	249.3 ± 2.93
Willow	0	0	29.5 ± 2.81
Total	321.0 ± 4.48	324.4 ± 3.76	278.8 ± 2.64
CT intake[4]			
Herbage	2.2 ± 0.27	1.9 ± 0.19	2.0 ± 0.25
Willow	0	0	4.0 ± 0.42
Total	2.2 ± 0.27	1.9 ± 0.19	6.0 ± 0.41
g CT intake/100 g CP intake	0.7 ± 0.01	0.6 ± 0.01	2.2 ± 0.22

[1] estimated from pasture mass measurements before and after grazing

[2] DM intake x ME concentration in MJ/kg DM

[3] DM intake x CP concentration in g/kg DM

[4] DM intake x CT concentration in g/kg DM

in the diet, and with lower dead matter and slightly higher legume content in fodder block herbage. The latter two would be expected to increase nutritive value (i.e. OMD and ME), but there is no evidence of this in the diet selected (Table 2.2); whilst they could have been responsible for the slightly higher growth of the hoggets grazing fodder blocks, they are unlikely to have affected reproductive performance. CT reduces forage protein solubility and degradation in the rumen (Jones and Mangan, 1977; Barry and McNabb, 1999; Min *et al.*, 2001), thus increasing rumen outflow of non ammonia nitrogen (NAN) and the net absorption of essential amino acids (EAA; Waghorn *et al.* 1987), especially branched chain amino acids (BCAA; Min *et al.*, 1999) from the small intestine. Previous studies have shown a strong correlation between ovulation rate (OR) and the plasma concentration of BCAA (r=0.95) and EAA (r=0.61; Waghorn *et al.*, 1990) and this has been confirmed by the findings that intravenous infusion of a BCAA mixture (33.1 g total BCAA/ewe per day) over a 5 day period in the late stages of the oestrus cycle (before luteolysis), produced an increase in OR (2.4 vs. 1.5; Downing and Scaramuzzi, 1991; Downing et al., 1995). Studies by Min *et al*., (2001, 1999), with ewes grazing CT- containing *L. corniculatus* versus ewes grazing perennial ryegrass/white clover pasture during the pre-mating and mating periods, showed increases in reproductive rate of 20 to 30% due to the protein binding action of CT. It therefore seems possible that the increased intake of CT of hoggets grazing willow fodder block in this study, may have increased the supply of undegraded dietary protein to the small intestine and plasma BCAA concentration, leading to the increase in reproductive rate relative to hoggets grazing ryegrass-based pastures. This could be investigated in a future experiment by mating hoggets in willow fodder blocks, with or without PEG supplementation (MW 3,350), to inactivate the CT and measuring blood plasma BCAA concentration.

Hogget fertility and conception rates are lower and much more variable than for mature ewes especially if the mating period is restricted to less than four weeks (Smith and Knight 1998). In this study, conception rate adjusted for LW at start of mating was 32, 33 and 47 ewe hoggets pregnant/100 ewe hoggets mated (Table 2.4), for the control regularly drenched, control trigger drenched and willow fodder block trigger drenched hoggets, respectively. This is consistent with the observation by Gavigan and Rattray (2002) that hogget conception rates are often less than 50%. It has been concluded that poor egg quality is the major factor responsible for low conception rates in hoggets. However, conception rates appear to improve after the first hogget oestrus cycle, probably due to higher levels of circulating progesterone (Gavigan and Rattray 2002). Therefore, the low conception rates observed in this study, in both the control and treatment groups, are likely to be a result of the short mating period (17 days; first oestrus cycle), due to early autumn leaf fall of the willow trees. Future studies of this type should include longer mating periods of not less than two mating cycles (34 days) to achieve higher conception rates. Kenyon *et al.* (2004) recommended a mating period of 40 days for hoggets.

Increases in reproductive rate are usually accompanied by increases in lamb mortality, with losses of approximately 15% for single born lambs, 25% for twins and 35% for triplets under New Zealand pastoral farming conditions (Barry *et al.*, 2004). Grazing ewes on CT-containing forages during mating not only increased reproductive rate, but also reduced postal-natal lamb mortality (mortality between birth and weaning) in all but one experiment (Table 2.8 Pitta *et al.*, 2005; McWilliam *et al.* 2005c; Ramirez-Restrepo *et al.* 2005). In the present study, grazing willow fodder blocks during the pre-mating and mating periods appeared to reduce post-natal lamb mortality (main cause of lamb mortality) from approximately 34 to 26% despite the increase in lambing percentage, but this failed to reach statistical significance ($P>0.05$). The mechanism for the apparent reduction in post-natal lamb mortality is unknown, although it has been suggested that it may be due to increased intestinal absorption of EAA, due to the action of CT, at a critical point in early embryonic development (Barry et al., 2004). The

Table 2.8 Comparative mortality rate (%) of lambs conceived on perennial ryegrass/white clover pasture, *L. corniculatus*, poplar, willow cuttings and willow fodder blocks between birth and weaning at Riverside farm on the East Coast of New Zealand.

	Control pasture	*L. corniculatus*	Poplar or willow supplementation
L. corniculatus			
Ramirez-Restrepo *et al.* 2005			
Experiment 1	23	12	
Experiment 2	24	21	
Tree supplementation[1]			
McWilliam *et al.* 2005c			
Poplar			
2001 Experiment	20		16
Willow			
2002 Experiment	17		12
2003 Experiment	16		8
Combined poplar + willow (3 Experiments)	18		12
Grazing willow fodder blocks[1]			
Pitta *et al.* 2005 (full access)	24		18
Pitta *et al.* 2007 (full access)	20		28
Current experiment	34		26

[1]adjusted for year, treatment, sex and birth rank effects.

higher post-natal lamb mortality observed in this experiment, relative to previous experiments is probably due to the wet weather conditions experienced during the lambing period and to lower birth weights from lambs born to hoggets.

Failure to detect significant treatment differences in post- natal lamb mortality in this experiment may be related to the low hogget numbers used. Using the data generated in this study, the minimum number of hoggets required to detect treatment differences in post-natal lamb mortality with two animal groups at the 5% level of probability with a power of 80%, is 1000/group. Similarly, Ramirez-Restrepo *et al.*, (2005) calculated that the number of mature ewes needed to detect a 20% reduction in lamb mortality from mating ewes on *L. corniculatus* was 700 ewes/group. In future experiment of this type, much larger hogget numbers/group are needed, if the effects of grazing willow fodder blocks on post- natal lamb mortality are to be detected.

The approximate "in utero" losses (scanning rate minus lambing rate; Table 2.3) were similar for all groups, with values of 5.3, 2.1 and 5.6% for the control anthelmintic regularly drenched, control anthelmintic trigger drenched and willow fodder block groups, respectively. These values show no effect due to nutritional treatments.

One of the most consistent findings in this experiment was the lower dag score of ewe hoggets grazing willow fodder blocks, compared to both anthelmintic regularly drenched and trigger drenched hoggets grazing conventional ryegrass/white clover pastures, supporting previous observations (Leathwick *et al.*, 1995; Ramirez-Restrepo *et al.*, 2004; Diaz Lira *et al.*, 2007) on reduced dag formation in both lambs and ewes grazing CT-containing forages (Table 2.9). The relatively small effect of grazing willow fodder blocks on dag formation observed in this experiment is probably because the lambs were taken off the fodder blocks after 56 days of grazing and then brought back after 28 days of grazing pasture only, for a further 32 days grazing on willow fodder blocks. This compares to the work by Diaz Lira *et. al.*, (2007) in which lambs grazed willow fodder blocks continuously for 98 days, where the reduction in dag score was understandably much greater than observed in the present study. The mechanism by which CT-containing forages reduces dags is not fully understood, although it probably involves the effect of CT on FEC in sheep (Ramirez-Restrepo *et al.*, 2004). However, in this experiment, although anthelmintic drenching reduced FEC in the regularly drenched group, it was not as effective as grazing willow fodder blocks in reducing dags, suggesting that other factors may have influenced the reduction in dag formation in hoggets consuming the willow. Similar results have been found previously (McEwan *et al.*, 1992; Larson *et al.*, 1994; Leathwick *et al.*, 1995). In future experiments, measuring changes in faecal DM and correlating this with changes in dag formation in sheep grazing both CT-containing forages and ryegrass/white clover pastures may help to explain the mechanism of dag reduction.

Table 2.9 The effect of grazing condensed tannin-containing forages (*L. corniculatus*, willow fodder block) on dag formation in regularly anthelmintic drenched (D), trigger drenched (TD) and undrenched (UD) ewes and lambs/hoggets.

	Control Pasture			*L. Corniculatus*			Willow fodder block		
	D	UD	TD	D	UD	TD	D	UD	TD
	Final dag scores (units)								
Ramirez- Restrepo *et al.*, 2004									
Experiment 1 (86 days)									
Ewe		2.43			1.65				
Lamb		1.97			1.09				
Experiment 2 (91days)									
Ewe		3.53			2.60				
Lamb		1.72			1.36				
Diaz *Lira et al.* 2007									
(98 days)									
Lamb	1.48	1.72					1.12	1.37	
Current experiment									
(116 days)									
Hogget	1.72		1.70						1.58

D: lambs drenched at 4 weekly intervals

TD: all lambs in the group drenched when mean FEC exceeded 1000 eggs / g wet faeces

Previous studies have shown a high correlation between dag weight and the incidence of fly strike, indicating that the presence of dags is a prerequisite for fly strike, or at least significantly influences the suitability of the host for oviposition by flies (Leathwick *et al.*, 1995). Therefore, grazing CT-containing forages such as willow fodder and *L. corniculatus* to reduce dag formation may offer a sustainable alternative to the control of fly strike by reducing use of insecticide dips.

One of the management issues encountered with willow fodder blocks is the control of volunteer grasses, particularly in spring (Barry *et al*., 2006), which leads to high pre-grazing herbage masses and an accumulation of dead matter in the sward (Pitta *et al*., 2005; Diaz Lira *et al*., 2007). It is essential to exclude livestock from willow fodder blocks in the spring to prevent damage to tree leaf buds and to allow for tree growth. Pitta *et al*., 2005 observed that early closure (i.e., exclusion of livestock) of the fodder blocks in late winter (mid-August) resulted in an accumulation of herbage over a six month period and greatly contributed to the decline in nutritive value. Closing the willow fodder blocks in spring (7 October) followed by a light grazing with non-experimental lambs in early summer (December) controlled tree height, reduced pasture mass and improved the nutritional value of the fodder block herbage compared to previous studies (Table 2.10). A summary of information from five experiments (Table 2.10) shows that increasing the frequency of grazings per season from 1 to 3 (including those with non-experimental sheep) considerably improved the nutritive value of volunteer fodder block herbage, while having little effect on the nutritive value of edible willow which was consistently higher in ME than fodder block herbage.

Willow fodder blocks were developed with the objective of livestock doing the harvesting by browsing (Barry *et al.*, 2006). However, defoliation of trees due to browsing influences the productivity and quality of the forage and long term persistence of the browse trees (Oppong, 1998). A transect of the four willow fodder blocks of different ages at Riverside Farm in this study, showed that death rate of trees increased with age (Fig 5). After 6 years of grazing by sheep, at the frequency described above, tree death rate was approximately 15%. The oldest (7 years; block 1) fodder block had a death rate of 31 % (Fig 5). The higher death rate of trees in this block could also be attributed to management factors such as the use of Gardoprim (Terbuthylazine; a long acting herbicide with at least nine months of residual soil activity) to kill the rushes at establishment, the effect of tree damage by cattle used to clean up in autumn (May) as well as pugging of soil by cattle.

Current management practices are to use glyphosphate, a herbicide with no residual soil activity for the control of rushes at establishment and to graze fodder blocks with sheep only. The persistence of the trees under the current management system, of three grazings of the fodder blocks at 8 week intervals during the growing season, are unknown and will be determined in future work. A survival rate of 85% after 6 years of sheep grazing is considered to be promising.

Table 2.10 The effect of grazing frequency per season upon the nutritive value of the diet selected by sheep grazing willow fodder blocks

	No. of grazings per season	Closure of willow fodder block	Willow fodder block herbage			Trees		
			OMD	ME (MJ/kg DM)	Total N (g/kg DM)	OMD	ME (MJ/kg DM)	Total N (g/kg DM)
Pitta *et al.* (2005)[1]	1	15 August 2002	0.54	8.0	18.0	0.72	10.7	15.5
Pitta *et al.* (2007)[2]								
Experiment 1	1	7 October 2003	0.64	8.8	20.0	0.67	9.9	18.6
	2		0.74	10.6	38.2	0.57	8.5	16.3
Experiment 2	1	7 October 2003	0.63	9.0	25.3	0.73	10.9	18.0
	2		0.66	9.4	33.4	0.80	11.9	35.3
Diaz Lira *et al.*, (2007)[1]	1	15 October 2003	0.64	9.4	22.3	0.72	10.7	16.0
	2		0.67	9.8	24.2	0.68	10.2	16.2
Current experiment[2]	2	7 October 2006	0.68	9.9	28.1	0.74	10.4	22.5
	3		0.68	9.9	38.2	0.74	10.4	26.2

Samples taken from exclusion cages as done in this study

[1] Exclusion of livestock at the time when tree growth commenced in August (spring).

[2] Experimental grazing commenced mid-February (late summer)

[3] Experimental grazing commenced early December (early summer)

[4] Experimental grazing commenced in mid-January (mid summer)

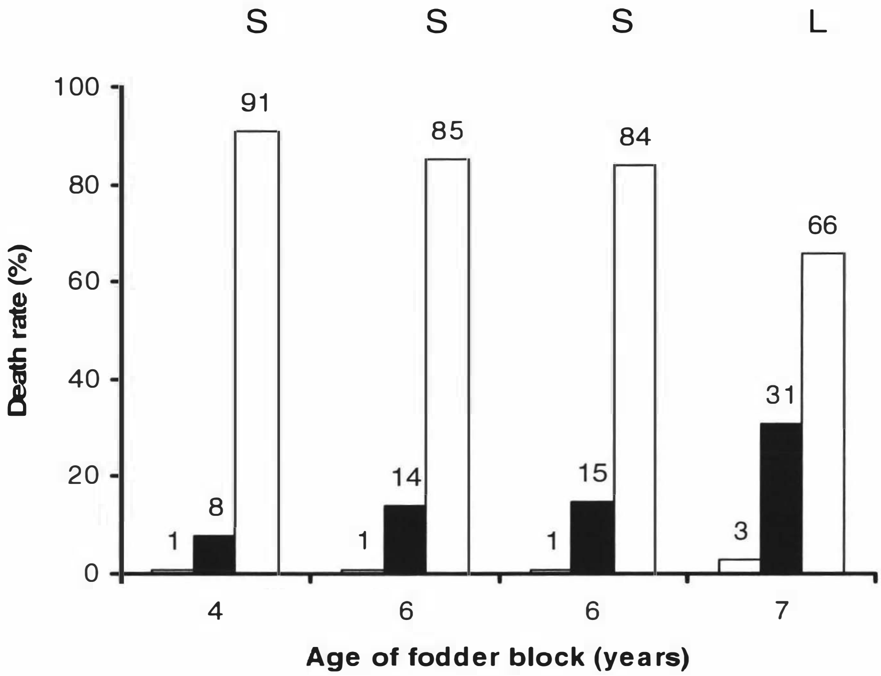


Fig 5 The effect of browsing willow fodder blocks on death rate (partially dead ░, dead ■, alive □) of willow trees over time, at Riverside farm near Masterton, on the North Island East Coast of NZ. In each fodder block, approximately 10% of the total number of trees were counted. S, short acting herbicide with no residual soil activity used at tree establishment; L, long acting herbicide with residual soil activity used at establishment.

One of the objectives of the experiment was to determine if browsing CT-containing willow could lower internal parasite infection in ewe hoggets by comparing the willow fodder block group with the trigger drenched group grazing control pasture. For logistical reasons (i.e. high cost of establishing willow fodder blocks and the long period of time (3 years) required to get the willow fodder blocks ready for grazing) it was not possible to have a fodder block group that was regularly drenched in this experiment as was on control pasture. Nevertheless, a valid assessment of the effects of grazing fodder blocks was gained by comparing the trigger drenched group grazing willow fodder block with the trigger drenched control pasture group, given that the anthelmintic drenching regimes of these two groups were identical; this defined the effects of nutrition on internal parasitism.

The epidemiology of parasitism in grazing ruminants is influenced by several factors such as seasonal variations in rainfall, temperature, stocking rate, grazing pressure, pasture species, grazing management, sward dynamics, botanical composition, parasite species etc. The current experiment was designed such that most of these were similar for all treatments such as climate, daily herbage allowance, grazing management during the experiment, and pre- grazing all areas with parasitised sheep to ensure similar herbage parasite status. Therefore the criteria evaluated in this experiment were frequency of anthelmintic drenching and the effect of grazing willow fodder blocks. In the latter comparison, the botanical composition differed from that of control pasture, with the most obvious aspect being the presence of small willow trees.

Grazing willow fodder blocks (willow 23 g CT/kg DM) was not successful in lowering internal parasite infection relative to grazing conventional ryegrass in the present study, as the number of anthelmintic drenches required to keep the FEC below 1000 epg wet faeces was the same in both groups (Fig 3). In contrast, Diaz Lira *et al.*, (2007) found that grazing willow fodder blocks full access (continuous grazing of willow fodder block; willow 42 g CT/kg DM) was effective in maintaining FEC below 1000 epg wet faeces in lambs without the need for anthelmintic drenching. A reduction in egg output has also been found previously in sheep and goats grazing tanniferous plants (Table 2.11), due to reduced female worm fecundity (Hoste *et al.*, 2006), failure of eggs to hatch and reduced L1 larvae development into infective L3 larvae, attributed to the action of CT (Molan, 2002). This can contribute towards reducing contamination of the pasture with infective larvae and consequently slowing down the dynamics of animal infection (Hoste *et al.*, 2006).

In addition to FEC, some studies have also looked at worm burdens and the most consistent finding is that parasitized lambs grazing the legume sulla (*Hedysarum coronarium*; 100 to 120g CT/Kg DM) had lower total worm burdens and increased growth rate (Niezen *et al.*, 1995; 1998). This may be due to the tall plant morphology (Moss and Vlassoff, 1993) and the presence of an astringent CT in sulla (Terrill *et al.*, 1992b; Douglas *et al.*, 1999). Grazing *Lotus corniculatus* (31 to 40g CT/kg DM) or *Lotus pedunculatus* (80g CT/kg DM) did increase growth rate of parasitized lambs but was not associated with lower worm burdens (Niezen *et al.*,1998; Ramirez-Restrepo *et al.*, 2005). Diaz Lira *et al.*, (2007) showed that grazing parasitized lambs on willow

Table 2.11 Summary of results of *in vivo* experiments with sheep and goats grazing tanniferous forages, compared with non-tanniferous forages.

Plant	Host species	Condensed tannin content (g/kg DM)	Effect on FEC	Reference
Sulla (*Hedysarum coronarium*)	Sheep	31-35	Reduced FEC	Niezen *et al.* 2002[a]
	Sheep	16	No effect	Athanasiadou *et al.* 2005[a]
Sainfoin (*Onobrychis viciifolia*)	Sheep	15	No effect	Athanasiadou *et al.* 2005[a]
	Goat	32	Reduced FEC	Paolini *et al.* 2003[a]
Big trefoil (*L.pedunculatus*)	Sheep	80	No effect	Niezen *et al.* 1998[a]
	Sheep	56	Reduced FEC	Niezen *et al.* 1998[a]
Willow fodder block	Sheep	42 (18.3[b])	Below 1000 epg wet faeces	Diaz Lira *et al.* 2007
	Sheep	23 (4.3[b])	No effect	Current experiment

[a] From Hoste *et al.* 2006.

[b] Calculated CT concentration (g/kg DM) in complete diet

fodder blocks was associated with lowered burdens of some parasites of economical importance (Table 1.16). The authors deduced that a reason for these effects was likely to be reduced re-infection rates in the willow fodder blocks. However, these effects are unlikely to have occurred in the present study. While these experiments provide some indications that feeding plants containing CT to parasitized lambs may help to lower worm burdens, failure by CT-plants to lower worm burdens in some instances, show that there is much that is not fully understood about the complex interactions between these plants, ruminants and their nematode parasites (Niezen *et al.*, 2002).

The concentration and structure of CT present in different plant species seem to be a major factor modulating efficacy against nematodes (Foo *et al.*, 1996; Hoste *et al.*, 2006). Hoste *et al.*, (2006) observed that a threshold of 30 to 40g of CT/kg DM has to be reached to observe antiparasitic activity. The relatively high FEC in hoggets grazing willow fodder blocks in this experiment could be attributed to the low CT concentration in the willow fodder (23 g/kg DM vs. 42 g/kg DM) and the low calculated CT concentration in the complete diet consumed (4.3 g/kg DM vs. 18.3 g/kg DM) compared to that consumed in the work by Diaz Lira *et al.* (2007). Studies have also shown that the nature of CT, in particular the relative proportion of prodelphinidin to procyanidin could influence their efficacy, with the highest level of activity against gastrointestinal nematodes occurring in plants presenting the highest prodelphinidin to procyanidin ratio (Hoste *et al.*, 2006). The structure of CT in willow has not been determined. It is also possible that the larval challenge may have been greater in the 2006 summer (current experiment) compared to 2005 summer (Diaz Lira *et al.*, 2007) due to greater rainfall.

Table 1.16 also shows that the effect of grazing parasitized lambs on willow fodder blocks on burdens of different GI parasites may be dose dependent. Intermittent grazing (restricted access i.e. grazing willow fodder blocks for one in every four weeks) was associated with lower burdens of some abomasal parasites, whilst continuous grazing (i.e. full access) was associated with lower burden of other small intestine parasites. Therefore, it would appear that the frequency of feeding fodder blocks to lambs in a grazing rotation can be used as a control strategy for some GI parasites.

CT may also indirectly reduce GI nematode activity in lambs by increasing the proportion of undegraded dietary protein (UDP) reaching the small intestine, thus improving the amount of amino acids absorbed (Waghorn *et al.*, 1994; Aerts *et al.*, 1999) and consequently increasing the immunocompetence in young sheep (Coop and Holmes, 1996; Bown *et al.*, 1991). The positive response of the immune system to protein intake has been shown in previous metabolism studies with lambs (Abbott *et al.*, 1988) and ewes (Houdijk *et al.*, 2000). In the current experiment ewe hoggets grazing willow fodder blocks showed that despite increased FEC values, they coped with nematode infection and continued to achieve higher LW and reproductive rates (resilience), compared to drenched hoggets grazing conventional perennial ryegrass/white clover pasture.

The steadily increasing FEC in this experiment in the pasture regularly drenched group (the conventional faming system in NZ) up to day 70 indicates that there were abundant parasite larvae in the pasture, providing a regular challenge to grazing animals and were infecting the lambs faster than the short acting drench could control them. However, the decline in FEC in the regular drenched control pasture group after day 70 indicates that the drenching regime was controlling parasite infection from this point onwards. Both trigger drenching and regular drenching had almost similar effects on FEC up to day 70. Pasture trigger drenching was less effective towards the end of the experiment and there was some evidence that the trigger drenched fodder block group better controlled FEC over this time.

Considering the results of this experiment and that of Diaz Lira *et al.* (2007), grazing willow fodder blocks is beneficial for parasitized lambs, as it is associated with lower GI parasite burdens in some instances, sustains good rates of LW gain, reduces DS and increases reproductive rates in ewe hoggets. These increases in productivity are associated with reduced dead matter content and increased legume content in fodder block herbage and with increased intake of secondary compounds from the trees. Ramirez-Restrepo and Barry (2005) concluded that responses in parasite management to grazing CT-containing legumes were variable and the same seems to apply to grazing willow fodder blocks.

Conclusions and future research priorities

This study has shown that grazing willow fodder blocks has a role to play in sustainable farming systems, as it can be used to increase both LW gain and the efficiency of reproduction in mated hoggets compared to similar hoggets grazing low quality summer/autumn pasture, with more lambs being born per /100 hoggets mated, despite relatively high FEC. Lower levels of dag formation in hoggets grazing willow fodder blocks may also reduce the need for insecticide treatment to control fly strike. Increased intake of CT from trees is likely to be responsible for these responses. However, further research is needed to establish CT as the causal mechanism. This can be investigated in two ways. Firstly by mating hoggets in willow fodder blocks for at least 40 days, with or without PEG supplementation (molecular weight; MW 3,350) to inactivate CT and studying the responses obtained. Secondly, by studying the effects of grazing willow fodder blocks planted with Tangoio (*S. matsudana x alba* clone; 25 to 50 g CT/kg DM) or Kinuyanagi (*S. kinuyanagi*; 90 to 110 g CT/kg DM) upon parasite management and hogget reproduction, relative to similar animals grazing control pastures (2 to 4 g CT/kg DM).Research on the structure and MW of CT in willow and its effects on internal parasite control are also needed and part of this can be obtained using the second approach.

This study also confirmed that increasing the frequency of grazing of willow fodder blocks from 1 to 3 times during the growing season, at 8 week intervals, is necessary to improve the nutritive value of the volunteer herbage growing within the willow fodder blocks, while maintaining the above-ground height of trees. However, it is important to determine the persistance of willow trees under this grazing system.

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