The Effect of Poplar (*Populus spp.*) and Willow (*Salix spp.*) Supplementation on the Reproductive Performance of Ewes Grazing Low Quality Drought Pasture During Mating

A thesis in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Animal Science in the Institute of Veterinary Animal and Biomedical Science, Massey University

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This is to certify that the research carried out in the Doctoral Thesis entitled: "The Effect of Poplar (*Populus*) and Willow (*Salix*) Supplementation on the Reproductive Performance of Ewes Grazing Low Quality Drought Pasture During Mating", in the Institute of Veterinary, Animal and Biomedical Sciences at Massey University, New Zealand:

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ABSTRACT

A series of grazing experiments was conducted, in the summer/autumn of 2001, 2002 and 2003, to investigate the effects of poplar (*Populus spp.*) and/or willow (*Salix spp.*) supplementation, during mating, on ewe production and reproduction when grazing drought pasture. Each experiment involved a rotational grazing system with 300 mixed-age Romney ewes, divided into three groups of 100 ewes each. In each year, all ewes were offered low quality simulated drought pasture, containing more than 60% dead matter, at an allowance sufficient to provide a potential desired intake of 0.70 kg dry matter (DM)/day, for periods of 9 to12 weeks, including two mating cycles. Mean pre-and post-grazing pasture masses averaged over the three years were 1100 and 600 kg DM/ha. The pasture consumed in all years was typical of pasture available to grazing livestock in a drought; it was high in neutral detergent fibre (NDF; approximately 600 g/kg DM), low in organic matter digestibility (OMD; approximately 0.52) and metabolisable energy (ME; approximately 7.5 MJ/kg DM) and contained approximately 20 g nitrogen (N)/kg DM. The supplementary poplar and willow diets were always superior to drought pasture consumed by the ewes, being higher in OMD (approximately 0.67), ME (approximately 10 MJ/kg DM) and total N (approximately 26 g/kg DM) and lower in NDF (approximately 383 g/kg DM). Tree fodder diets also contained substantial concentrations of the secondary compounds condensed tannin (CT; range 7 to 52 g/kg DM), salicin (approximately 2 g/kg DM) and other phenolic glycosides (approximately 21g/kg DM), with willow (27 to 52 g/kg DM) containing greater concentrations of CT compared with poplar (7 to 19 g/kg DM). Mean diameter of the tree fodder stem consumed during the series of experiments was approximately 7 mm for poplar and 4 mm for willow with the diameter increasing over the experimental periods in four cases out of five ($P<0.05$). After the supplementation period, the three groups were joined together and grazed on perennial ryegrass/white clover pasture until the conclusion of each experiment at weaning. In all years, the effect of poplar and/or willow supplementation on ewe live weight (LW) and body condition score (BCS) change; the proportion of lambs (reproductive rate) at pregnancy scanning, lambing, docking and weaning; and wool production and staple length from ewe fleeces with approximately 11 months growth, were measured.

Experiment 1 was designed to determine how much poplar fodder needed to be fed to increase ewe production and reproduction over a 71-day supplementation period. The experiment involved a high supplementation group, offered 1.5 kg fresh poplar/ewe/day; a low supplementation group, offered 0.75 kg fresh poplar/ewe/day; and a control group that was offered no tree fodder. Ewes in the high and low treatments lost less LW (-67 and -71 vs. -82 g/day; P<0.05) and BCS (-0.78 and -1.27 vs. -1.31 units; P<0.05) compared with unsupplemented ewes. Reproductive rate was relatively low in the control group (121 lambs born/100 ewes mated), with poplar supplementation increasing ewe reproductive rate by approximately 20% units (P<0.05) and 30% units (P<0.001) for the low and high treatment groups, respectively, at scanning, lambing, docking and weaning. The increase in reproductive rate in supplemented ewes was due to increases in both conception rate (number of ewes pregnant/100 ewes mated) and fecundity (number of lambs born/100 ewes mated).

Experiment 2 was designed to determine if production and reproduction varied between ewes fed poplar versus willow at the same rate of supplementation, 1.4 kg fresh forage/ewe/day, for 87 days. Again, reproductive rate was relatively low in the control group (133 lambs born/100 ewes mated), with willow supplementation reducing LW loss (-86 g/day vs. -103 g/day; P<0.01) and increasing reproductive rate by 15%, 17% 21% and 20% units at ultrasound scanning (P=0.097), lambing (P=0.087), docking (P<0.05) and weaning (P=0.058), respectively. The increase in reproductive rate was due to an increase in fecundity; supplementation did not affect conception rate in this experiment. Unlike the previous experiment, poplar supplementation showed no effect on reproductive rate, despite the increase in DM intake and the apparent reduction in LW loss of 9 g/day (P=0.11). It is likely that severe contamination of the poplar fodder with *Melampsora larici-populina*, or poplar leaf rust, confounded the results.

Building on the results of the first two grazing trials, the next step was to determine the period (days) of tree fodder supplementation necessary to achieve a response in reproductive rate. Experiment 3 involved ewes fed 1.3 kg fresh willow/ewe/day for a 'long' period, 63 days including 6 weeks of mating, and a 'short' period, 31 days including 3 weeks of mating. The mating period commenced on the same day for all groups and lasted for 6 weeks. Willow supplementation for 63 days reduced ewe LW loss (-96 g/day vs. -147 g/day; P<0.05) and BCS (-0.79 VS. -1.09; P<0.05) loss, compared with unsupplemented ewes; however, it did not increase reproductive rate at scanning and lambing. The lack of response in willow-supplemented ewes was likely to be due to toxic concentrations of zearalenone (1.5 mg/kg DM), an oestrogenic mycotoxin, in the drought pasture during mating, which confounded the results by negating any potential benefits due to increased nutrient intakes. Willow supplementation for 63 days did increase reproductive rate at weaning by 13% units, due to a 9% unit (P<0.05) reduction in post-natal lamb mortality, from 17.1 to 8.4%. Supplementation for 31 days did not appear to influence ewe reproduction and production parameters. Overall, the rate of LW loss was greater in Experiment 3 compared with the first two experiments.

Seven indoor *in vivo* digestibility experiments were conducted at the following times; early April 2001 (poplar), February, March and April 2002 (all poplar), and December, March and April 2003 (all willow). Each 14-day trial involved 6 male cryptorchid lambs, individually fed in metabolism cages. The experiments showed that the digestibility of poplar and willow tree fodder declined from late spring to autumn (P<0.05), but that the decline was much smaller than the decline in digestibility of grass-based pastures in New Zealand over the same time period. The experiments also showed that mean ME and digestibilities were generally higher for willow than for poplar. The seven *in vivo* digestibility coefficients were then used to develop a standard curve for *in vitro* prediction of *in vivo* digestibility; this standard was used to analyse all unknown tree fodder samples from the three grazing experiments.

Results from the three grazing experiments showed that supplementing ewes grazing drought pasture during mating with poplar and willow tree fodder consistently increased DM intake by 0.25 to 0.33 kg DM/ewe/day for ewes offered 1.3 to 1.5 kg fresh willow or poplar each day and increased calculated total DM intakes from 0.67 to 1.03 kg DM/ewe/day in Experiment 1, from 0.59 to 0.86 kg DM/ewe/day in Experiment 2 and from 0.47 to 0.75 kg DM/ewe/day in Experiment 3. Supplementation also consistently reduced LW loss and loss in BCS and substantially increased lambing rate through increased conception rate and fecundity and reduced post-natal lamb mortality. The effects on LW and BCS gradually declined in the post-treatment period and were no longer evident by commencement of lambing. There was no effect of supplementation on wool production or staple length in any of the experiments. One of the unexpected results of the experiments was an average 34% reduction in post-natal lamb mortality over three years, due to willow/poplar supplementation of ewes during mating. Initial results showed that despite significant increases in fecundity in supplemented ewes in 2001 and 2002, post-natal lamb mortality was not increased. This result, combined with a statistically significant reduction in lamb mortality in Experiment 3 ($P<0.05$), in the absence of any differences in fecundity between the groups, suggested that tree fodder supplementation during mating may have reduced lamb mortality in all three years, but that the effect was masked by the increase in reproductive rate in the first two experiments. Therefore, data from the three field trials were combined and analysed by adjusting all mortality data to equal birth rank and sex; this showed a significant reduction due to supplementation ($P<0.05$) with no treatment-year interaction.

The increase in ewe production and reproduction in supplemented ewes was likely due to increases in nutrient intake, through increased DM, ME and CP intakes, prior to and during mating and to increased outputs of undegradable dietary protein and microbial protein from the rumen, per unit of crude protein consumed, thus increasing amino acid absorption. An increase in ovulation rate of 1.5 % units/MJ of digestible energy consumed (Smith 1985) should result in increases in ovulation rate due to tree fodder supplementation of only 5 and 4% units in 2001 and 2002, respectively; however, the increases in scanning rate were substantially greater at 41 and 16% units. Therefore, it is possible that the majority of the increase in reproductive rate was due to increased essential amino acid absorption, which is consistent with increases found in ewes mated on CT-containing forages such as *Lotus corniculatus* (Birdsfoot trefoil).

Gross margin analyses using actual data from unsupplemented ewes in each of the three grazing trials compared with Riverside Farm's commercial ewes from the same years showed that drought reduced scanning rates by an average of 22.4% and wool production by 20% and that this reduction decreases sheep production income by approximately $14/ewe. Further analysis showed that almost half the cost ($6/ewe) could be recovered by supplementing ewes with tree fodder in a drought. On a whole farm basis this represents $58/hectare cost benefit due to tree fodder supplementation.

Fungal contamination was a significant factor in the results obtained in Experiments 2 and 3. In all years, simulated drought pasture contained metabolites of zearalenone and the trichothecenes nivalenol and deoxy-nivalenol, produced by *Fusarium* fungi, while in Experiment 2 the poplar was severely contaminated with *Melampsora larici-populina*, or poplar leaf rust. Zearalenone concentrations in pasture were at their greatest in Experiment 3 and increased to over 2 mg/kg DM during the mating period. This may explain the lack of increase in reproductive rate expected in willow-supplemented ewes in Experiment 3, which was a feature of previous experiments; however, it did not explain the much greater loss in ewe LW in Experiment 3. Nivalenol (NIV) and deoxy-nivalenol (DON) are common trichothecene toxins found in New Zealand pasture and were found in pasture samples from all three experiments; however, the concentration in Experiment 3 was three- to four-fold greater than in previous experiments. Reports have suggested that trichothecenes may be partly responsible for the reduced growth of otherwise healthy livestock grazing dry autumn pasture, often referred to as 'ill thrift'. However, based on evidence from dosing experiments, it is unlikely that the quantities of NIV and DON present in pasture in Experiment 3 accounted for all of the greater LW loss seen in this experiment. This suggests that these toxins are likely to be indicators of other more potent fungal toxins, which have a much bigger impact on livestock health and production. It is likely that fungal toxins contribute more to reduced reproduction in breeding ewes and to ill thrift in young stock grazing dry autumn pastures in East Coast regions than is currently acknowledged.

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ADF	Acid detergent fibre
BCS	Body condition score
Ca	Calcium
CHO	Carbohydrate
cm	Centimetre
CP	Crude protein
CT	Condensed tannin
D	Diameter (mm)
DBH	Diameter at breast height
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
DM%	Dry matter percentage
DOMD	Digestible organic matter (g)/100 g DM
DON	Deoxy-nivalenol
EAA	Essential amino acids
ELISA	Enzyme linked immunosorbent assay
FA	Feed allowance (DM/ewe/day)
g	Gram
GLM	General linear model
ha	Hectare
HCL	Hydrochloric acid
HM	herbage mass (kg DM/ha)
IPO	Interdecadal Pacific Oscillation
IRI	International Research Institute
K	Potassium
kg	Kilogram
kph	Kilometres per hour
LIG	Lignin
LW	Live weight
m	Metre
M	Million
MAF	Ministry of Agriculture and Forestry
M/D	MJ ME/kg DM
ME	Metabolisable energy
Mg	Magnesium
MJ	Megajoule
mm	Millimetre
MW	Molecular weight
MWI	Meat and Wool Innovations
N	Nitrogen
NAN	Non-ammonia nitrogen
ND	Not determined
NDF	Neutral detergent fibre
NIV	Nivalenol
NV	Nutritive value

$NZ	New Zealand dollar
OM	Organic matter
OMD	Organic matter digestibility
P	Phosphorous
P	Probability
P.	*Populus*
PA	Paddock/grazing area
PG	Phenolic glycoside
pH	Measure of acidity
RDN	Rumen degradable nitrogen
S.	*Salix*
SAS	Statistical Analysis System
SE	Standard error
SO	Southern Oscillation
SOI	Southern Oscillation Index
t	Experimental period (days)
TGD	total grazing days
UDP	Undegradable dietary protein
VFA	Volatile fatty acids
VFI	Voluntary feed intake
WSC	Water-soluble carbohydrate
Z	Zearalenone
Zn	Zinc
µg	Micrograms

CHAPTER 1

REVIEW OF LITERATURE

1.1 New Zealand Sheep Production and the Significance of Drought

Pastoral production has long been the backbone of the New Zealand economy and the importance of pastoral farming can be seen in its substantial contribution to New Zealand export earnings (Table 1.1). Figures for the year-end March 2002 from the New Zealand Ministry of Agriculture and Forestry (MAF) show that pastoral exports totalled $14 billion (B), accounting for almost half of total export revenue (Table 1.1). Sheep product exports accounted for 23% of total pastoral exports at $3.2 B (Table 1.1; MAF Information Bureau 2003).

Table 1.1 New Zealand exports for years 1997-2002 in NZ$ billion (MAF Information Bureau 2003).

	1997	1998	1999	2000	2001	2002
Total Agricultural Exports	10.90	11.44	11.63	12.43	16.31	16.62
Pastoral based exports	9.29	9.65	9.61	10.36	13.91	14.05
Other agricultural exports	1.61	1.79	2.02	2.07	2.40	2.57
Non-agricultural Exports	9.50	10.05	10.15	12.45	14.68	14.49
Total NZ Exports	20.40	21.49	21.78	24.88	30.99	31.11
Total sheep product exports[1]	2.54	2.51	2.35	2.62	3.13	3.20
Meat and meat products (lamb, hogget, mutton)	1.50	1.49	1.50	1.70	2.13	2.26
Total wool	1.04	1.02	0.85	0.92	1.00	0.94

[1] Data does not include income from sheep by-products (i.e. hides and skins, etc)

Sheep production in New Zealand is based on the grazing of temperate pastures predominantly consisting of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) and the performance of the industry is affected by a large spatial and seasonal variability in patterns of pasture production. In the summer and autumn, yield and quality of these pastures declines due to moisture stress, which is a major factor limiting pasture production in New Zealand. This decline can result in feed shortages, which are a common occurrence during the summer and autumn in the dry East Coast regions of Gisborne, Hawke's Bay, Wairarapa, Marlborough, Canterbury and Otago.

Severe periodic summer/autumn droughts are also a feature of farming in the East Coast regions of both the North and South Islands and usually occur every 7 to 10 years (Salinger 2000). Droughts are defined in terms of the duration of days without rain and result from the persistent absence of rain producing systems (Mosley & Pearson 1997). From a pasture production point of view, drought commences when lack of soil moisture causes the grass plants to wilt (wilting point; Crump 1984). The severity of a drought is controlled by the duration of the dry period and the effects of temperature (evaporation) and air movement (evapotranspiration) on soil moisture levels and pasture growth.

In the Wairarapa region, dry spells and drought significantly reduce pasture growth in late spring, summer and autumn and potential evapotranspiration is usually greater than average rainfall from November to March, although soil moisture deficits are most common in February (Radcliffe 1975). Radcliffe (1975) recorded no pasture growth in February in 4 out of 5 years of data collection in the Wairarapa region. On a typical beef and sheep farm in Wairarapa, average pasture masses in a drought are less than 1000 kilogram (kg) dry matter (DM)/hectare (ha), with little or no pasture growth (Baker & Associates, Masterton, Unpublished). Figure 1.1 shows average pasture covers on a Wairarapa hill country farm during the 1997/98 drought. In November and December 1997, pasture covers were adequate for livestock production at 1650 and 1350 kg DM/ha, respectively. However, poor rainfall and hot dry northwesterly winds from November 1997 to April 1998 stopped pasture growth and led to a continuous decrease in pasture quantity and quality. 141 mm of rain from 6 March to 30 April and 23 mm at the end of May did result in some pasture growth on southerly facing country, but by June 1998 there still was not enough rainfall to allow northwesterly facing country to recover from the drought (Baker & Associates, Masterton, Unpublished).

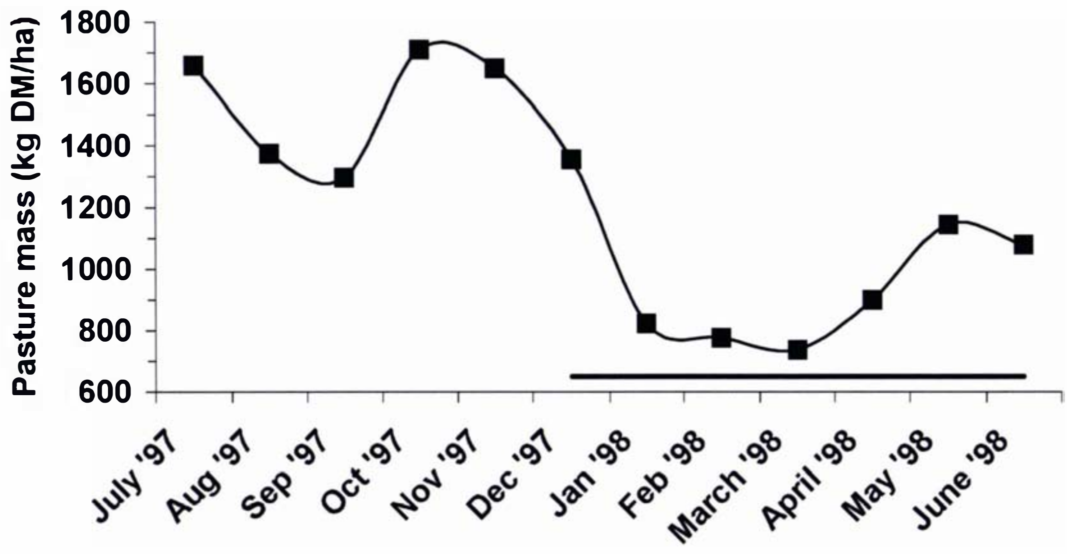


Figure 1.1 Average pasture masses (kg DM/ha), during the 1997/98 East Coast drought, on a typical Wairarapa hill country farm (Baker & Associates Unpublished). The solid line indicates drought conditions.

1.1.1 Impact of Drought on Livestock Productivity

A farm can be classified as being under drought conditions when the available feed supply is less than the feed demand, due to dry conditions, resulting in livestock receiving less feed than is required to maintain production targets (Crump 1984). Dry conditions reduce pasture growth rate, resulting in lowered predicted pasture covers (i.e. herbage mass/ha) and increased dead matter content in the sward. The reductions in pasture mass and quality lead to feed shortages that result in decreased feed and nutrient intakes and potentially large losses in livestock productivity. Loss of animal live weight and body condition is common during short-term dry spells and is more severe in drought situations. In sheep production, loss of live weight in the critical pre-mating and mating months of February, March and April severely reduces ovulation rate and subsequent lambing percentage (Rattray *et al.* 1983).

1.1.2 Financial Impact of Drought

Losses in livestock productivity, due to drought conditions, reduce farm income and potential profitability. However, the cost varies significantly between farms, depending on the drought management strategy used and the severity of drought conditions. The reduction in individual farm income in drought-affected rural areas reduces the capital resources of these areas and their industries, which in turn reduces their potential economic activity.

A severe drought can impact on farms financially for one to two years following the end of the drought (Crump 1984, Ward 1999). In the first year, capital livestock are sent to slaughter as farmers reduce stocking rates. Livestock production is affected in subsequent years, as pasture and animal production take time to return to pre-drought levels. In this period, a higher proportion of livestock tend to be retained as replacements to build up capital livestock levels following drought culling. This, in turn, affects industry throughput by reducing the number of sheep and cattle carcasses that would have normally been put through the meat processing chain and sold on the export market (Crump 1984).

On 5 February 1999, the New Zealand Ministry of Agriculture and Forestry (MAF) estimated the likely farm-gate cost of the 1997/98 and 1998/99 droughts to total $NZ 800 million (M; Ward 1999). This figure takes into account losses in production for all agricultural sectors, not only during the 1997/98 and 1998/99 financial years ($500M), but also production losses in 1999 ($240M) and 2000 ($60M) due to the follow-on effects of drought. Estimated losses in the sheep and beef industries were $101.5 M for 1997/98 and predicted to be $147 M in 1998/99 (Basher 1998), which is a significant proportion of the total farm-gate losses. It is important to note that downstream value-added agricultural products whose value is about three times the on-farm returns will also be affected (Basher 1998).

1.1.3 Climate Variability and Climate Change in New Zealand and their Impact on Future Climate and the Occurrence of Droughts

Global and regional climates have shown large fluctuations over the past million years and there is clear evidence that the climate in New Zealand has experienced considerable change and variability since climate records were started in the 1850s. Climatic variability refers to the short-term deviations of monthly, seasonal and annual values from the mean value of the climatic state established over a reference period. Climate change refers to the long-term difference between mean values of a climatic component, or the difference between climatic states (Salinger 1992).

1.1.3.1 Systems that Influence Climate Variability and Change

Three major systems, operating on different time scales, influence climate variability and trends in New Zealand. On a seasonal basis, climate variability is significantly affected by the Southern Oscillation (SO) cycle. Recently, an Interdecadal Pacific Oscillation (IPO) has been identified, which is similar to the SO, but operates on a time scale of approximately two decades. The third system, global warming, influences worldwide long-term climate changes (Salinger 2000).

1.1.3.1.1 The Southern Oscillation and Southern Oscillation Index

The Southern Oscillation (SO) is a weather pattern centred in the eastern Pacific that is caused by a cyclical warming and cooling of the ocean surface, which influences major shifts in the patterns of winds, cloudiness and rainfall, especially in the Pacific Basin (Basher 1998; Harkness 2000). The SO has a major influence on the occurrence of drought in New Zealand; however, at less extreme SO fluctuations there may be other controlling factors (Harkness 2000).

The cyclical warming and cooling of the eastern Pacific, characteristic of the SO, leaves its distinctive fingerprint on atmospheric pressure. The difference between air pressure at Darwin and air pressure at Tahiti can be used to generate an index number, called the Southern Oscillation Index (SOI; Figure 1.2; Harkness 2000; Salinger 2000).

A strongly positive SOI indicates a La Niña weather pattern and a strongly negative SOI indicates an El Niño weather pattern.

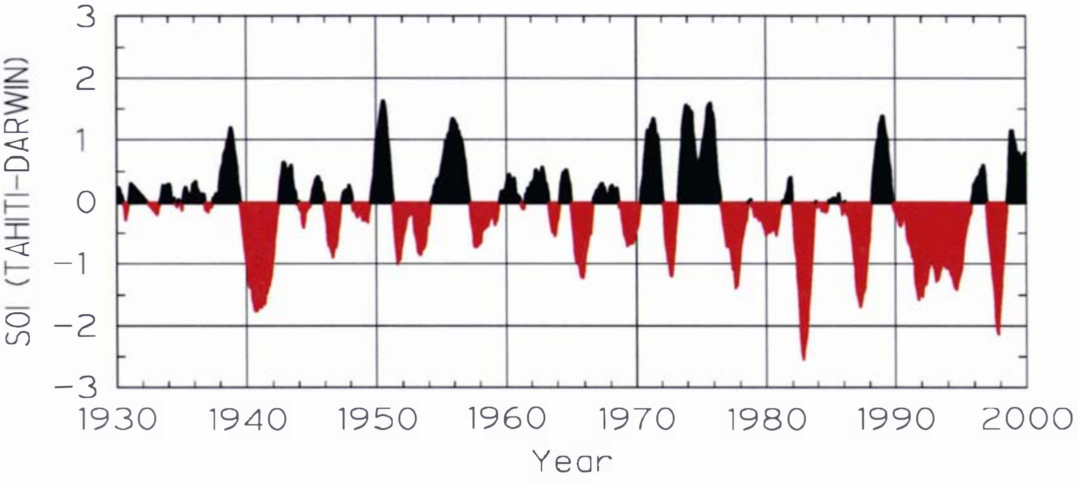


Figure 1.2 The Southern Oscillation Index 1930–2000. Low values represent El Niño and high values of the index La Niña conditions (Salinger 2000).

1.1.3.1.1.1 El Niño and La Niña Southern Oscillations

A strongly negative SO, or El Niño, is associated with more frequent southwesterly flows over New Zealand and a ridge of high pressure to the north. In the summer, stronger or more frequent than normal westerly winds lead to cooler conditions and more rain in western areas and below average rainfall in eastern districts. El Niño events occur about three to seven years apart, typically becoming established around April or May and persisting for about a year thereafter. (Basher 1998; Harkness 2000). It is important to note that, although East Coast droughts are common during El Niños, they can also happen in non El Niño years (for example the severe drought in 1988-89) and that serious East Coast droughts do not occur in every El Niño (Salinger 2000).

La Niña events occur at the extreme positive end of the SOI and result in more northeasterly winds, which bring moister, rainy conditions to northeastern regions of the North Island and drier conditions in the southeast of both the North and South Islands (Harkness 2000; Salinger 2000). The severe drought in Otago and South Canterbury in 1998/99 was caused by a La Niña cycle of the SO (Salinger 2000).

In the Wairarapa region, the presence of an El Niño event increases the chance of a summer drought and a La Niña event increases the chance of an autumn drought (Harkness 2000). The prevalence of summer/autumn droughts in eastern regions of New Zealand, due to the cycles of the SO, make drought management a serious issue for farmers in these areas and for the entire New Zealand pastoral industry.

1.1.3.1.2 Interdecadal Pacific Oscillation

Interdecadal Pacific Oscillation (IPO) is a newly described climate feature that involves climate shifts every one to three decades. IPO is similar to the SO as it involves a tight coupling between the ocean and the atmosphere with the main centre of action in sea surface temperatures in the north Pacific, with an opposing weaker centre just south of the equator in the eastern Pacific (Salinger 2000).

IPO phases can be indexed (Figure 1.3) with a positive phase indicating more frequent southwesterly winds and a negative phase bringing more frequent northeasterly winds to New Zealand. Three phases have been identified during the 20^{th} century, with two well-documented climate shifts in New Zealand during this time period that can be linked to the IPO. The first climate shift (a negative IPO index) occurred in 1947 and brought more anticyclones to the east of the South Island and more easterly winds over the north. Temperatures rose slightly, rainfall increased in the north and east, and decreased in the west and south. The second climate shift (a positive IPO index) occurred in 1977 and resulted in more anticyclones over northern areas of the country, with westerly winds strengthening over southern regions. This shift had only a small effect on temperatures, but rainfall increased in the north, west, south and southeast of the South Island, and decreased in the north of the North Island (Salinger 2000).

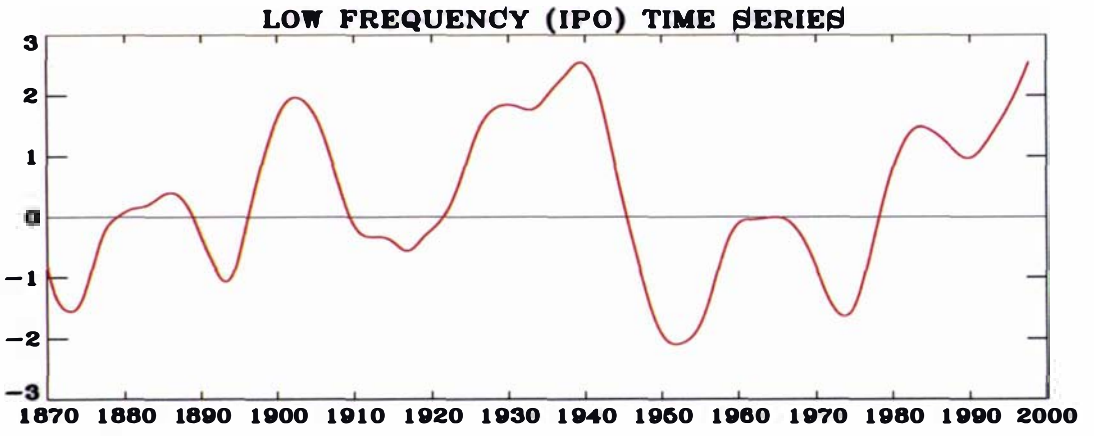


Figure 1.3 Index denoting the phases of the Interdecadal Pacific Oscillation (IPO) Index (Salinger 2000).

1.1.3.1.3 Global Warming

Global warming is believed to be caused by an accumulation of radiatively-active trace gases in the upper atmosphere, including carbon dioxide, methane, nitrous oxide and man-made chemicals such as chlorofluorocarbons. Increasing concentrations of these gases in the upper atmosphere reduce its ability to dissipate heat into space, thus raising the temperature of the lower atmosphere and the earth's surface (Reid 1992; Salinger 1992).

Global warming has resulted in increases in global mean surface temperature between 0.4 and 0.8°C since the second half of the 19^{th} century (Reid 1992; Salinger 1992). In New Zealand, the observed regional surface temperature variations and trends have been documented for the years 1871-1998 (Figure 1.4). There is a good relationship between the variations in marine data and surface air temperatures on time-scales down to a season (Salinger 1992). These document a warming trend of 0.7°C over the period.

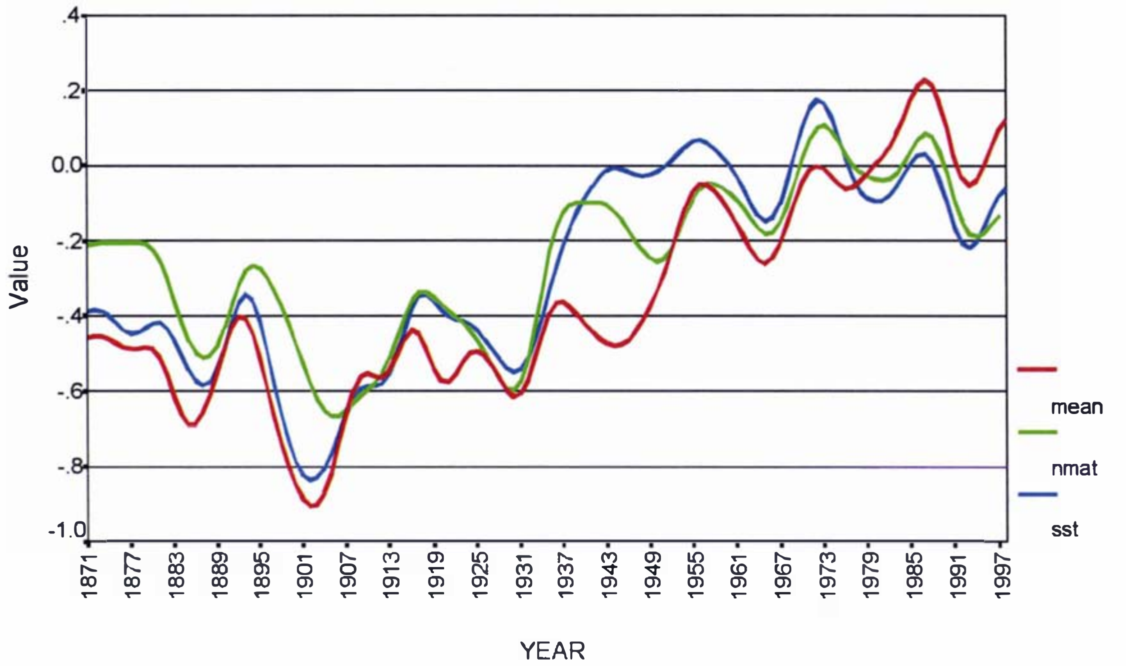


Figure 1.4 Smoothed New Zealand surface air and surrounding marine temperatures 1871-1998 (°C) compared with the 1961-1990 reference period. Mean = surface air temperature, nmat = night marine air temperature, sst = sea surface temperature (Salinger 2000).

1.1.3.2 Future Climate Predictions

The New Zealand climate will continue to vary on a short-term basis due to the effects of El Niño and La Niña Southern Oscillation and Interdecadal Pacific Oscillation cycles. Research indicates that the frequency and intensity of El Niños will increase under future climate change and that the relatively more frequent El Niños of the last two decades are related to the slow rise in global temperatures this century (Basher 1998).

Predictions indicate that significant climate warming is likely to happen by the middle of this century (Salinger 1992, 2000). Temperature increases due to global warming in New Zealand are expected to be similar for both the North and South Islands, but evidence points to more rapid increases in winter temperatures than summer temperatures and in more southern parts of the country (Salinger 1992). Predictions of likely changes in rainfall patterns are still uncertain; however, the regions of Hawke's

Bay and Wairarapa, the eastern slopes of the Southern Alps and the foothills from Canterbury to Southland are likely to receive less rainfall in the future (Salinger 1992). Increases in the duration of days without rain and increases in evapotranspiration, due to the combination of higher soil temperatures and lower soil moisture content, increase the probability of drought conditions occurring in these regions (Salinger 1992, 2000). The East Coast of the North Island will be particularly prone to increased drought and its associated hazards in the future (Salinger 2000)

1.1.3.2.1 Tools for Future Climate Prediction

The potential increase in the frequency and intensity of SO cycles and the apparent trend in global warming could result in increased dry periods and long-term droughts in some regions of New Zealand. Therefore, accurate short-term and long-term climate prediction is necessary for farmers to put management strategies into place to minimise the, often negative, impact of climate variations and long-term climate change on pastoral production.

A range of tools exists for predicting future climatic conditions, including seasonal climate forecasting models, IPO climate shifts and 21st century trends based on a combination of global climate models and scenario building, using global warming hypotheses (Salinger 2000).

The International Research Institute (IRI) for Climate Prediction was formed in late 1996 to foster the improvement, production and use of global forecasts of seasonal to interannual climate variability (Mason *et al.* 1999). The Institute collaborates with international climate research communities to develop and implement mathematical climate models, better techniques for forecasting seasonal to interannual variations in the climate system, techniques for monitoring variations and for disseminating climate monitoring and forecasting information to potential users. The Experimental Forecasting Division of the IRI successfully produced and issued climate forecast information during the height of the 1997/98 El Niño and 1998/99 La Niña events (Mason *et al.* 1999). The IRI, along with local and regional climate research bodies, will continue to be important in the forecasting of regional climate events, such as the

SO, and anomalies in New Zealand and around the world, thus helping livestock producers to prepare for negative climate variations.

1.1.4 Counteracting the Effects of Drought on Livestock Production

Farm management strategies to counteract the effects of drought on pastoral production can be divided into two categories; reduce feed demand or increase feed supply. A flexible livestock policy is essential to achieve a reduction in feed demand during drought. A reduction in livestock numbers can be achieved using a combination of management strategies, which will vary depending on the type of farm and its management policies. Strategies include selling surplus livestock using a priority culling or selling list, lambing earlier in the season, selling lambs earlier at lighter live weights and selling replacement ewe hoggets as lambs to the freezing works (Batey 1982, Crump 1984, Kinnell 1995).

Traditional strategies to increase feed supply include preserving high quality feed, such as hay, silage and grains, from years of lush growth to supplement livestock in drought years, or purchasing supplementary feeds from outside sources (Crump 1984, Leng 1992, Batey 1982, Kinnell 1985). Special purpose fodder crops and greenfeed can also be grown. Many eastern hill country farms have little or no flat land to grow and harvest supplementary feeds, therefore hay, silage or grains must be purchased from outside sources. If a farm is unable to grow or buy supplementary feed, livestock can be sent to other districts, not affected by drought, for grazing. During a drought, supplementary feeds and off-farm grazing are purchased at a premium as demand often outstrips supply. The cost-effectiveness of all drought management strategies must be critically analysed before a decision is made to implement a particular management regime (Leng 1992). The amount of supplement to be fed is also a critical consideration that depends on the level of production desired (Leng 1992).

1.2 Poplar and Willow Trees in New Zealand

Willow (genus *Salix*) and poplar (genus *Populus*) trees are members of the *Salicaceae* family, a mainly Northern Hemisphere family of deciduous trees and shrubs with soft, light wood (Van Kraayenoord *et al.* 1995). Willow and poplar trees are exotic to New Zealand and have been introduced and cultivated over the last 160 years for aesthetics, soil erosion control on pastoral hill country and riverbanks, woodlot forestry and animal welfare (shade and shelterbelts) (Van Kraayenoord *et al.* 1995; Wilkinson 1999). Only in relatively recent times have pastoral farmers and scientists considered willow and poplar trees planted for soil conservation and shelterbelts as a potential summer feed source. The browse on wide-spaced soil conservation trees can provide an abundant feed source for livestock during feed shortages, particularly during drought years, in the summer dry regions on the East Coast of New Zealand. Also, fodder blocks of densely planted willow and/or poplar trees can be managed as a summer crop to provide a bank of green feed when pastures have senesced.

1.2.1 Soil Erosion Control

A substantial proportion of land currently under pastoral farm management was previously covered by dense native forest and scrub that was cleared by early settlers. Problems with lowland flooding and hillside erosion as a result of the removal of the native forest and scrub led to the development of Regional Catchment Boards in the late 1940s. Regional Catchment Boards were constituted to implement a programme of gully control, hillside stabilisation and riverbank protection. One of the key strategies of the Regional Catchment Boards for soil conservation on hill country pastoral land in New Zealand was the extensive planting of willow and poplar trees (Wilkinson 1999).

During the 1960s and 70s, Regional Catchment Boards planted two million willow and poplar trees, in government-subsidised erosion control schemes (Wilkinson 1999). The planting of conservation trees on unstable pastoral land allowed farmers to graze livestock in areas that had previously been under-productive and where farming would not have been sustainable in the long term. On pastoral hill country, trees planted at a spacing of 12 metres or closer have been shown to reduce mass movement (i.e., slipping) of pasture by 50 to 80%. Increases of approximately seven livestock units/ha in annual livestock carrying capacity have been recorded on spaced-planted, previously unstable ground in the East Coast and Wairarapa (Hicks 1995).

Regional Catchment Boards planted willow and poplar trees for several reasons. The principal reasons for their use on pastoral land are the easy vegetative propagation of clones of known quality, the quick establishment of trees from un-rooted poles in the presence of domestic livestock on grazing land, the superior early growth rate of willow and poplar trees compared with all other cool temperate tree species, the extensive root system that is capable of rapidly stabilising large soil masses, high evapotranspiration rates during the growing season (to dry out water-logged soils), the benefit of shade and shelter for grazing livestock and the potential of poplar trees as timber (Wilkinson 1999).

In 1969, a willow and poplar breeding and selection programme was also initiated in New Zealand, with the development of the National Plant Materials Centre at Aokautere in Palmerston North (Van Kraayenoord 1971; Van Kraayenoord *et al.* 1995). The objective of the programme was to provide a range of improved, locally adapted clones and hybrids suitable for soil conservation and river protection planting (Van Kraayenoord 1971; Van Kraayenoord *et al.* 1995). Between 1992 and 1994, Landcare Research (a Crown Research Institute), formerly the National Plant Materials Centre, was responsible for most aspects of poplar and willow research and cultivation in New Zealand (Bulloch & Wilkinson 1993). Since 1994, another Crown Research Institute, HortResearch, has taken over these functions.

This programme has been reasonably successful, particularly in regard to the development of interspecific hybrids between *Salix matsudana* and various *S. alba* willow clones (Van Kraayenoord *et al.* 1995). These hybrid willows have the advantage of rapid establishment from stem cuttings, resistance to diseases, extensive root development, narrow crown form and adaptability to extreme site conditions. *S. matsudana* × *S. alba* clones have quickly gained popularity as soil conservation trees in New Zealand (Van Kraayenoord *et al.* 1995). The first three *S. matsudana* × *S. alba* hybrid clones (Aokautere, Cannock and Te Awa) were released in 1975, in response to the arrival of poplar leaf rusts in 1973, which left willow as the main tree for slope stabilisation planting until rust resistant poplars became available. In 1980, a further series of *S. matsudana* × *S. alba* willow hybrids was released for general soil conservation planting as well as for use in farm and horticultural shelterbelts (Van Kraayenoord *et al.* 1995). These clones included Tangoio, Hiwinui, Adair, Wairakei, Makara and Moutere.

Intensification of the poplar breeding and selection programme in New Zealand commenced in 1975, with the establishment of an 8 ha poplar gene pool plantation by the National Plant Materials Centre at Brookfield, Napier (Van Kraayenoord 1984; Wilkinson 1984). The purpose of the development of this plantation was to establish a new gene pool of disease resistant poplar species and hybrids, in response to the introduction of *Melampsora larici-populina* (poplar leaf rust) and *Marssonina brunnea* (poplar leaf-spot disease). The aim of the breeding programme was to select and release 20-25 poplar clones with a wide genetic base suitable for erosion control, shelter and farm forestry in the various climatic regions of New Zealand (Van Kraayenoord 1984; Wilkinson 1984). By 1988, after 15 years of poplar introduction, breeding and selection, 100% of the species released for use were considered rust-resistant and of those, 48% were resistant to browsing by possums (Wilkinson 1988). There are approximately 50-70 million wild Australian Brushtail possums (*Trichosurus vulpecula*) in New Zealand (Cowan 1991). Cowan (1991) estimates that poplar and willow poles planted to alleviate erosion are subject to severe and persistent possum damage, which may cost $320,000 to $800,000/annum. In the period from 1984 to 1988, the poplar clones/cultivars Eridano (*Populus deltoides* × *P. maximowiczii*), Tasman (*P. deltoides* × *P. nigra*), Yunnan (*P. yunnanensis*), Kawa (*P. deltoides* × *P. yunnanensis*) and Yeogi 1 (*P. alba* × *P. glandulosa*) largely replaced Flevo (*P. deltoides* × *P. nigra*) as a conservation tree (Wilkinson 1988). Breeding and selection of poplars in this period focused on crosses with *P. nigra* to expand the gene pool of parents for future crosses to produce disease-resistant, low possum palatability clones with a narrow crown form (Wilkinson 1988). These provided a new range of clones for horticultural and farm shelter and amenity planting. Clones derived from crosses between *P. deltoides* and *P. nigra*, also known as *P.* × *euramericana*, are historically, and currently, the most commonly used clones from poplar breeding programmes (L. Fung, Scientist, HortResearch, Palmerston North, personal communication).

Poplar and willows continue to be the primary trees for soil erosion control along with several other species, including *Pinus radiata*, *Eucalyptus* and *Acacia*. In New Zealand, it is estimated that significant soil conservation measures are necessary on 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 & Newsome 1992). For conservation purposes the poplar (*P. x euramericana*) clones, Veronese, Otuhoua and Weraiti, and Kawa (*P. deltoides x yunnanensis*) dominate current nursery pole production, while *S. matsudana x alba* clones are the most common willow pole produced (Table 1.2; Wilkinson 1999; P.N. Cameron, Greater Wellington Regional Council Akura Conservation Centre, personal communication). The relatively recent development of disease and possum resistant poplar clones has resulted in a reduction of willow trees being planted (Wilkinson 1999). In the Wanganui-Manawatu and Greater Wellington Regional Council divisions, which include the Wairarapa region, over 58% of the farmland is erosion-susceptible (Hicks 1995). Akura Nursery, near Masterton in central Wairarapa, supplies between 25 and 55 thousand willow and poplar poles (all sizes) to the region annually (Figure 1.5; P.N. Cameron, personal communication). In 2002, the nursery sold 21,000 three-metre willow and poplar poles for conservation planting (Figure 1.6), with the number of conservation poles sold since establishment of the nursery in 1954, totalling 1.36 million (P.N. Cameron, personal communication).

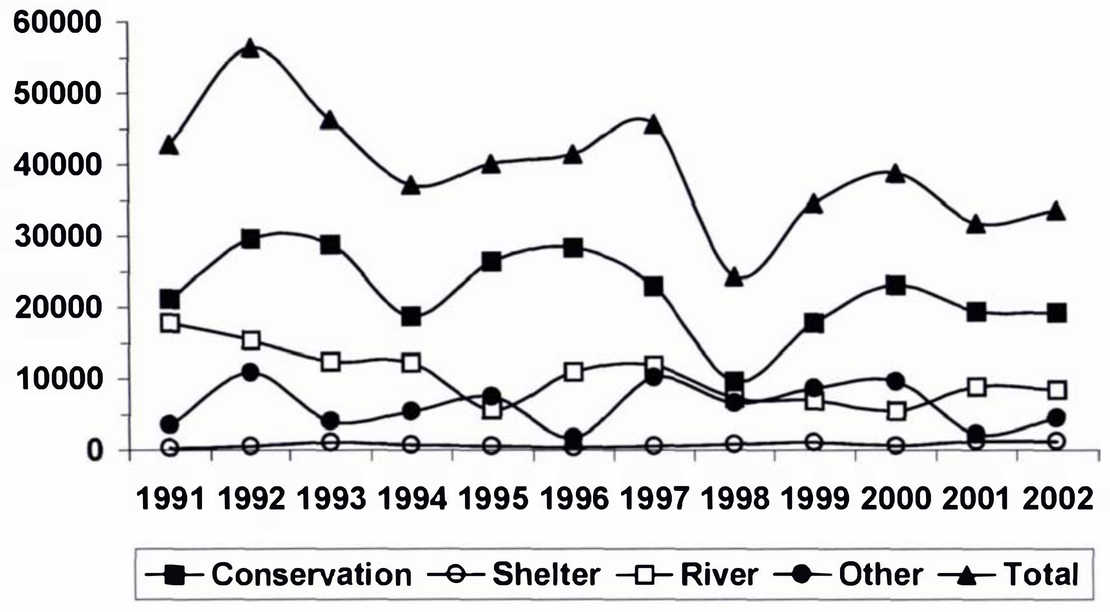


Figure 1.5 Willow plus poplar poles sold for conservation, shelter, and riverbed planting by Akura Conservation Centre, Masterton, Wairarapa (P.N. Cameron, Greater Wellington Regional Council Akura Conservation Centre, personal communication).

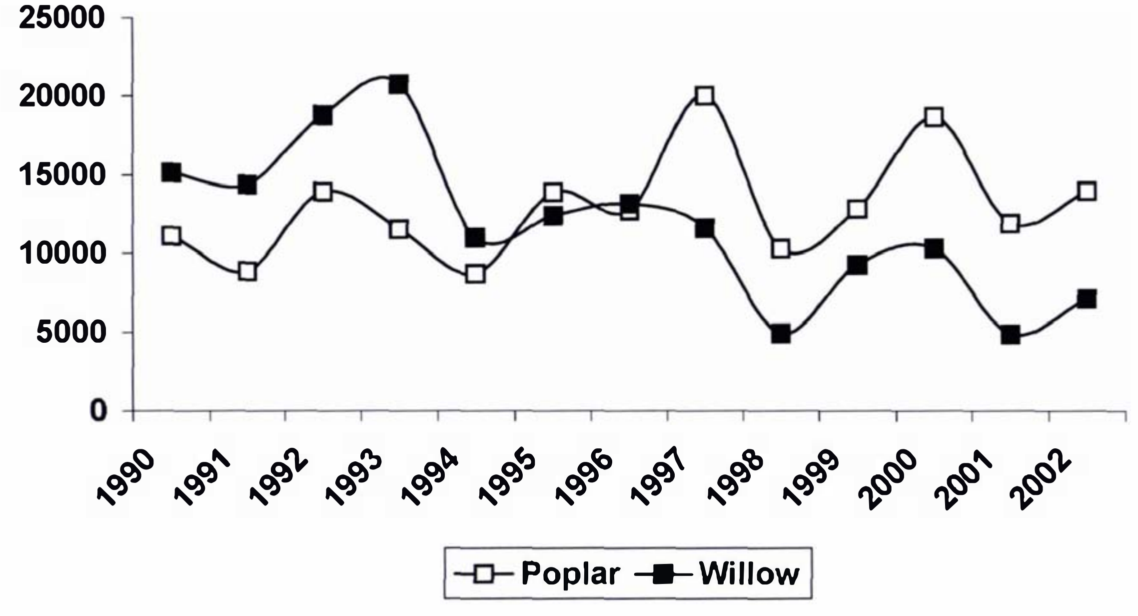


Figure 1.6 Total number of three-metre willow and poplar poles sold for conservation planting on farmland by Akura Conservation Centre, Masterton, Wairarapa (P.N. Cameron, personal communication).

Table 1.2 Poplar and willow tree hybrids and clones grown at Akura Conservation Centre, Wairarapa, New Zealand. Names marked with an asterisk indicate clones most commonly planted on pastoral farms from 1998-2003 (P.N. Cameron, personal communication).

Willow	
Salix matsudana x alba	
Tangoio*	Dry upper slope planting
Moutere*	Wet lower slope and gully planting
Poplar	
Exposed Sites – mid to upper slope planting/dry slope planting	
Populus deltoides x nigra (P. x euramericana)	
cv. Veronese*	
cv. Argyle*	
cv. Selwyn	
cv. Taueru	
Populus nigra	
cv. Crow's Nest*	
Semi-exposed Sites - lower slope planting/wet slope planting	
Populus deltoides x nigra (P. x euramericana)	
cv. Tasman*	
cv. Pakaraka	
cv. Weraiti*	
cv. Otahoua*	
cv. Toa	
Populus deltoides x yunnanensis	
cv. Kawa*	

1.2.2 Animal Welfare

Trees provide shade and shelter for grazing animals, which reduces their exposure to direct ultraviolet radiation, temperature extremes, high winds and driving rains. Willow and poplar 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 shelterbelts (Gregory 1995). Shade and shelterbelts, planted in the mid 1970s, were usually planted with willow (*S. matsudana x alba*) trees. This is because early poplar clones, such as Italica (*P. nigra*), which were commonly used for this purpose, were highly susceptible to the leaf rust *Melampsora larici-populina* that arrived in New Zealand in the mid 70s (Wilkinson 1999). In recent times, poplar trees have become more common as disease resistant clones have been developed. Currently, poplar trees are more desirable for shade and shelterbelt planting as they have a narrower more upright form compared with willow trees (P.N. Cameron, personal communication).

The East Coast regions of New Zealand are particularly prone to extremes in climatic conditions. Drying northwesterly winds and intense heat are typical in the summer and driving southerly winds and cold, wet weather are characteristics of winter. The combination of cold, wet, and windy weather is particularly conducive to excessive heat loss (hypothermia) and hot, dry weather can lead to hyperthermia, or overheating, in livestock (Gregory 1995). Climatic stress caused by extreme weather conditions has been shown to reduce pasture and animal production and is a significant cause of animal suffering (Gregory 1995). From an animal welfare point of view, the provision of 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 and hyperthermia (Gregory 1995).

Protection from the chilling effects of the wind is important in pastoral production, as cold stress leads to losses in efficiency of production and at worst can lead to hypothermia and death. Cold exposure in ewes can also result in failure in the expression of oestrus, a reduction in ovulation rate, a delay in the onset of oestrus, and even failure to come into oestrus altogether (Doney *et al.* 1973, 1976; MacKenzie *et al.* 1975). In a comprehensive five-year study on lamb mortality, Alexander *et al.* (1980) found that at least 40% of lamb deaths were associated with hypothermia. This was consistent with a study by Arnold & Morgan (1975), which found that 52% of all lambs born on rainy days died, accounting for 41% of all losses. Obst & Day (1968) observed that lamb mortality started to increase when winds rose above 8 kph and were accompanied by 0.25 to 5 mm of rainfall/day, with extensive losses occurring with winds of 24 to 56 kph accompanied by rainfalls of more than 5 mm/day.

Studies on the effects of shelter availability on animals suffering cold stress have shown an increase in growth rate in cattle and an increase in growth rate, ovulation rate and wool production in sheep (Table 1.3; Gregory 1995). Shelter has also been shown to reduce lamb mortality and abortions induced by hypothermia (Table 1.3).

Table 1.3 Research on the beneficial production and reproduction effects of animals sheltered from cold climatic conditions (Gregory 1995).

	Shelter from Cold Conditions
Cattle production	150 kg dairy heifers grew faster when provided with access to a shed shelter in their paddock (Holmes *et al.* 1978).
	Providing shelter in beef feedlots during wintertime improved growth rate without adversely affecting feed conversion efficiency (Hoffinan & Self 1970; Leu *et al.* 1977).
Ewe ovulation rate	Protection from cold with a shed shelter for 17 days before and 25 days after chemically synchronised mating has helped to raise ovulation rate (Griffiths et al. 1970).
Wool production	Mean daily growth rate of wool was higher in sheltered ewes throughout a 5-year period (Lynch & Donnelly 1980).
Lamb mortality	Lamb mortality during the first 48 hours decreased from 20% to 7% when a 5 to 8 m high *Cupressus macrocarpa* shelterbelt was available in windy conditions (Egan *et al.* 1972).
	Lamb mortality decreased from 17 to 9% in single-born and from 51 to 36% in multiple-born when phalaris grass shelters were provided (Alexander *et al.* 1980).
Lamb growth rate	Lamb growth rate to 21 days of age in lambs from sheltered paddocks was 7% greater than for unsheltered lambs (Alexander & Lynch 1976).

Protection of livestock from heat stress by providing shade and shelter is also important for pastoral farms. Persistent high ambient temperatures plus direct solar radiation will suppress growth rate in lambs and wool production in older sheep. Heat stress can also depress fertility in rams and bulls and can reduce the number of breeding females conceiving and maintaining a concepta (Gregory 1995). Alexander & Williams (1971) and Brown *et al.* (1977) concluded that severe heat stress during the last third of pregnancy inhibits the growth of the placenta and foetus. In hot conditions, shade/shelter has been shown to improve reproductive performance in cattle and growth rate in fattening livestock (Gregory 1995; Table 1.4). The availability of shade and shelter is especially important for livestock grazing perennial ryegrass based pastures, particularly old pastures, which contain high concentrations of the wild-type endophyte strain *Neotyphodium lolii* (Easton 1999; Fletcher *et al.* 1999). Endophyte is a fungus, which produces alkaloid metabolites that are beneficial to the grass plant in providing protection against insect and livestock over-grazing and enhancing persistence (Easton 1999). However, endophyte also 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).

Table 1.4 Research on the beneficial production and reproduction effects of animals sheltered from hot climatic conditions (Gregory 1995).

	Shelter from Hot Conditions
Cattle reproduction	Temperature decreases during autumn were found to improve breeding efficiency in year-round calving herds (Stott & Williams 1962).
Growth rate	Beef cows and calves grazing in wooded pasture grew faster than those grazing in open pasture (McDaniel & Roark 1956).
	Shade has been shown to benefit growth rate in both grazing (Alexander 1967) and feedlot cattle (Garrett *et al.* 1960).

1.2.3 Trees as Livestock Feed

It is well recognised around the world that some varieties of trees and shrubs are a valuable source of feed for grazing or browsing livestock, especially in environments with extreme climatic oscillations (Sankary & Ranjhan 1989). Many regions of New Zealand are characterised by low rainfall and high evapotranspiration rates during the summer. However, in the eastern regions of the country, southern oscillations can increase temperatures and severely reduce rainfall. Consequently, summer droughts are a regular occurrence. Summer/autumn droughts are particularly detrimental in hill country environments where there may be no land to grow supplementary feeds and feeding on steep hillsides can be difficult. In New Zealand, willow and poplar trees have been used successfully as a source of emergency fodder for sheep and cattle during summer/autumn feed shortages and droughts in the past (Treeby 1978; Charlton *et al.* 2003; Moore *et al.* 2003). However, most New Zealand pastoral farmers have never considered tree fodder to be a useful or valuable feed source and few farmers know how to manage the trees as a fodder crop. Recently however, anecdotal evidence has shown an increase in the use of tree fodder as a supplement to livestock grazing dry summer pasture, in response to recent droughts and the predicted increase in drought incidences in the eastern regions of New Zealand. Evidence shows that farmers in the North Island are successfully integrating tree fodder into intensive beef, sheep and deer farming (Charlton *et al.* 2003).

There are several convincing reasons for the suitability of poplar and willow as a livestock feed. First, poplar and willow trees are inexpensive and easy to establish in a range of soil types and climates. Second, they will produce a renewable feed source, year after year, at no monetary cost to the farmer. Finally, the foliage and primary growth is palatable and nutritious.

1.2.3.1 Methods of Fodder Production

There are two primary management systems for willow and poplar browse production. The first is a willow/poplar-pasture system, in which trees are planted on hill country pastoral land at a low density, primarily for soil conservation and animal shelter. The second system is a coppiced tree plantation or fodder block, in which trees are densely planted, coppiced or browsed at a height of 0.3 to 1.3 metres annually and managed as a fodder crop.

1.2.3.1.1 Willow/Poplar-Pasture System

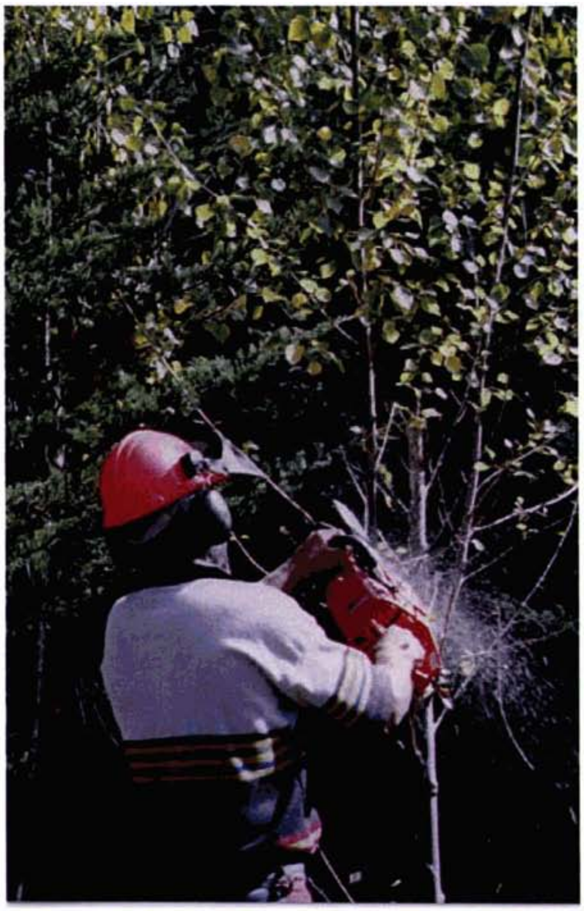
Wide-spaced tree planting is suited to hill farm operations where high soil water levels lead to slipping, and involves trees planted at an erosion control density of 25 to 150 trees/ha (Plate 1.1; Wilkinson 1995; Wall *et al.* 1997; Wilkinson 1999). Management of a poplar/willow-pasture system does not differ from open pasture except that planted poles need to be individually protected from farm livestock for up to three years using fencing and/or plastic sleeves so their production potential is not compromised (Wilkinson 1999; Charlton *et al.* 2003). Nylon sleeves are ideal for preventing sheep, deer, hares and rabbits from ring-barking young trees and fencing helps to reduce damage from mature cattle.

Several feeding options exist with this production method. The first option involves mechanically pruning the lower branches and foliage from the tree and feeding grazing livestock on the fallen fodder (Plate 1.2). Alternatively, young trees (5 to 10 years) can be pollarded above cattle browsing height; 2.0 to 2.5 m (Plate 1.3; Charlton *et al.* 2003). Regrowth from the pollarded trees will then form a 'pruning nest', which allows easy and safe pruning access for farmers (Plate 1.4). Pollarded trees that are pruned regularly, every two to three years, have the added benefit of reducing the impact of shading on pasture growth (Douglas *et al.* 2001) and managing mature trees so they do not become too large and dangerous to livestock and farmers (Charlton *et al.* 2003). In a willow/poplar-pasture system the trees can be planted at a higher density than actually desired. Therefore, young thinned trees that are not needed for soil erosion control can be felled for livestock fodder. Another feeding option is, simply, to allow livestock to graze underneath the trees in late summer and early autumn to utilize the fresh leaf fall. Leaves shed are fresh and palatable, compared with most pasture available in summer/autumn. From 25 February to 20 May Guevara-Escobar (1999) recorded leaf fall of 3.1 tonnes DM/ha from widely spaced (37 stems/ha) mature poplars (>30 years) in Manawatu. This equated to 84 kg DM/tree. In the study, leaf fall peaked on 30 March at 1.2 tonnes of DM/ha. In times of drought, trees will shed leaves prematurely as a defence against transpiration loss, providing much needed fodder when pasture is scarce (McGregor *et al.* 1999).

Plate 1.1 Willow and poplar trees planted for soil erosion control in the East Coast region of Wairarapa, New Zealand, that are suitable for livestock fodder.

a b

Plate 1.2 Poplar trees planted for erosion control in the East Coast regions of Wairarapa (North Island; a) and North Otago (South Island; b) and pruned using a long handled saw for livestock fodder.



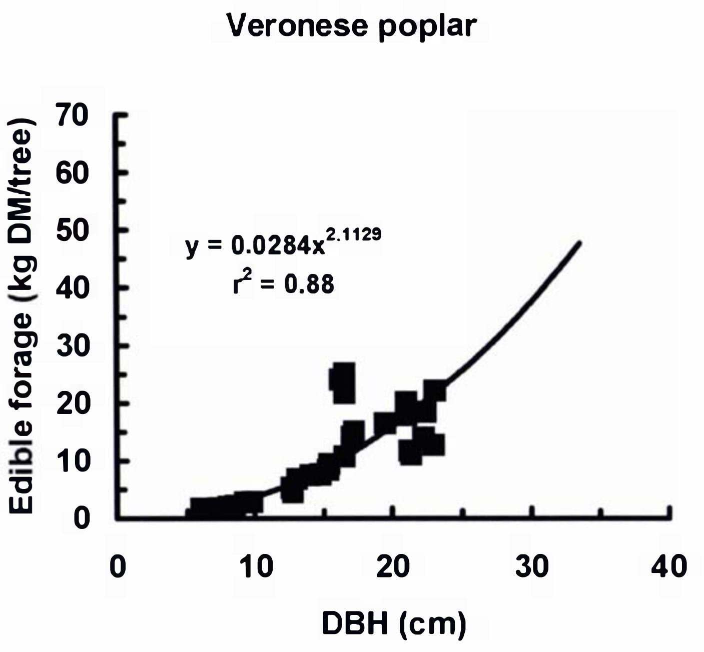
a

b

Plate 1.3 Farmers in the North Island pollarding a young poplar tree at a height of approximately 1.8 metres above ground level (a) and a six to nine year willow tree at a height of greater than 2 metres above ground level (b), for livestock fodder, using a petrol-powered chainsaw.

Plate 1.4 12 months re-growth on previously pollarded (at a height of 1 metre above ground level) Flevo poplar trees, on the East Coast of the South Island.

To incorporate poplar and willow fodder into a farming system, it is important to have a reasonably accurate and non-destructive method of estimating the edible forage yield of trees of various size and age. The edible portion of poplar and willow fodder refers to all of the leaves plus stems less than or equal to approximately 5 to 7 mm in diameter; livestock preferentially select the leaves and soft stems and are unable and unlikely to consume lignified stem material with a large diameter. Recent research has shown that seven-year-old Tangoio willow (*S. matsudana x alba*) and Veronese poplar (*P. deltoides x nigra*) trees grown on Wairarapa hill country will produce 9.5 kg and 7.5 kg edible DM (leaves + stems ≤ 5 mm), respectively (Kemp *et al.* 2001). Kemp *et al.* (2003) found that the quantity of edible DM/tree in a previously un-harvested willow and poplar was related exponentially to the diameter of the tree trunk at a height of 1.4 m above the ground, also called breast height (DBH). Figure 1.7 shows that the general relationship is similar for both willow and poplar; however, at any given DBH, Tangoio willow has more edible DM/tree than Veronese poplar and this difference increases as DBH increases (Kemp *et al.* 2003). From Table 1.5, a willow tree with a circumference of 47.1 cm, or a DBH of 15 cm, will yield 12 kg edible DM. Thus, a farm with 20 ha planted at a density of 50 Tangoio willow trees/ha, with a DBH of 15cm (breast height circumference = 47 cm), would have an edible willow supply of 12 tonnes DM (Table 1.5).



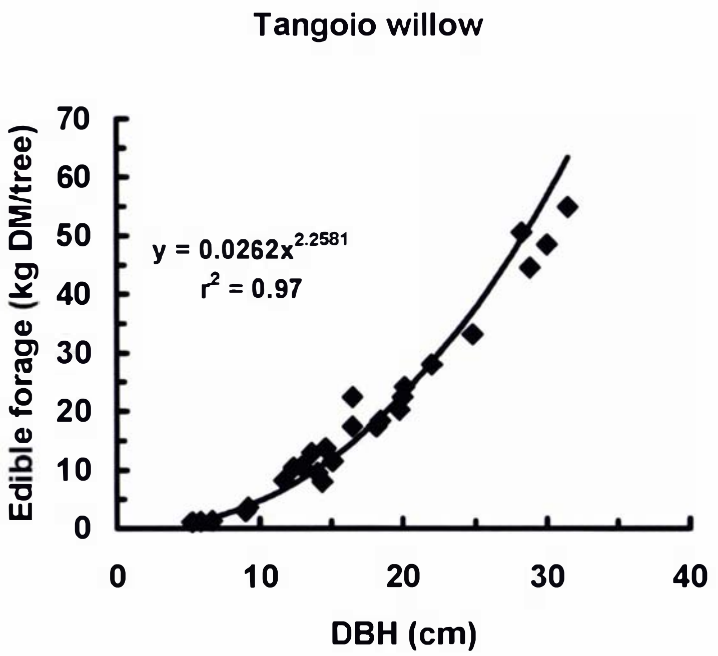


Figure 1.7 Relationship between diameter at breast height (1.4 m; DBH) of the tree trunk and edible dry matter (DM)/tree based on leaves plus stems ≤ 5 mm diameter for Veronese poplar and Tangoio willow (Kemp *et al.* 2003).

Table 1.5 Predicted edible dry matter (DM)/tree for Tangoio willow and Veronese poplar using either trunk circumference or diameter at breast height (DBH) measured 1.4m above ground level (Kemp *et al.* 2003).

Circumference (cm)	**DBH** (cm)	**Tangoio willow** (kg DM/tree)	**Veronese poplar** (kg DM/tree)
15.7	5	1.0	0.9
31.4	10	4.9	3.7
47.1	15	12.0	8.7
62.8	20	22.9	15.9

The edible DM yield of a willow or poplar tree branch can also be predicted using a linear equation (below) based on the basal diameter (mm) of the branch, if the branch is less than 10 cm in diameter (Kemp *et al.* 2001). If the branch is greater than 10 cm in diameter, a curvilinear function is necessary.

$$\text{kg edible dry matter} = 0.04 * \text{basal diameter} - 0.6$$

It is important to consider that the prediction equation and data presented by Kemp *et al.* (2001, 2003) was based on trees that had not been previously harvested for livestock fodder. Douglas *et al.* (2003a) reports that average regrowth from six Tangoio willow trees (DBH = 29 cm), in Hawke's Bay, New Zealand, after one year was 0.8 kg DM/tree (0.4 kg edible DM/tree). However, there are few data available on the regrowth production of harvested trees and more research is required in this area.

1.2.3.1.2 Fodder Tree Plantations

Suitable areas for fodder tree plantations have been defined as those that are currently unproductive on the farm. These could include rush-infested wasteland or unproductive hill country areas, such as gullies. Fodder tree blocks are established by planting poplar or willow wands/stakes (1.0 to 1.2 metres in length) at a density of 1,500 to 30,000 stems/ha (Douglas *et al.* 2003b), with a boundary fence surrounding the area to facilitate tree establishment and subsequent management. After the wands/stakes are established (usually 1 to 2 years), they are coppiced at a height of 0.3 to 1.3 m to create a stump from which future shoots can grow (P.N. Cameron and P.D. Kemp, personal communications).

Two feeding options exist for fodder tree plantations; the primary growth and foliage can be mechanically pruned ('coppiced') and fed to livestock or the trees can be grazed directly by livestock ('browsed'; Plate 1.5; Douglas *et al.* 2003b). Mechanical pruning is labour intensive, therefore direct grazing of fodder tree blocks is probably the most efficient means of using poplar and willow trees as a feed source. There is an initial cost to set up and plant fodder tree blocks, but afterwards there is little cost or labour required and the blocks can be break fed or rotationally grazed several times annually.

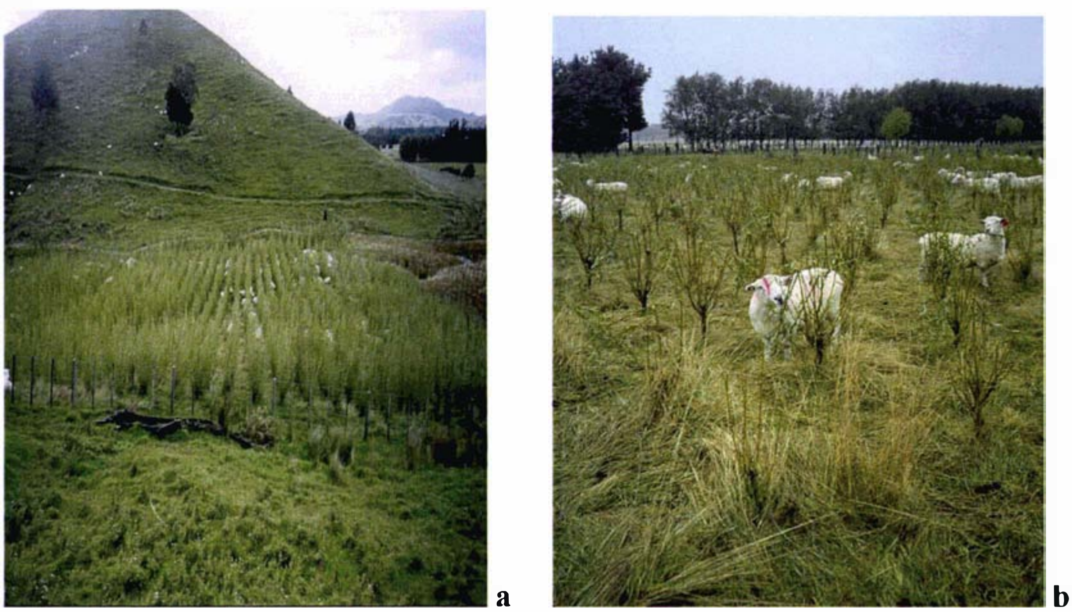


Plate 1.5 Willow browse blocks, planted with 6000 trees/ha on previous unproductive wasteland, at Massey University Riverside Farm, Wairarapa, at early (a) and late (b) stages of grazing by sheep.

Research in the area of willow bioenergy production (wood as a fuel for electricity production) concluded that the productivity of willow clones in a coppiced tree system increases steadily until the fifth growing season, when the trees reach a maximum in annual biomass production (Kopp *et al.* 2001). In coppiced fodder tree production the DM yield of trees such as *Gliricidia sepium* increased with tree age (Adejumo 1992), and in a range of other species, older trees often had higher edible forage yields due to increased coppiced stump diameter (Blake 1983), enhanced root development, and more potential growing points (Adejumo 1992). Variations in DM yield are common in tree coppicing systems due to year-to-year variation in growing season temperatures and rainfall (Kopp *et al.* 2001).

Results from coppice trials show that willow and poplar trees vary in total edible DM yield because of differences between tree species or clones, tree age, site and planting density (Hathaway 1986; Douglas *et al.* 1996; Oppong *et al.* 1996, 2001; Douglas *et al.* 2003b). The annual edible DM yield of coppiced fodder trees is 1 to 6 tonne DM/ha for hybrid tree willow (*S. matsudana x alba*) clone 'Tangoio' (Table 1.6), which is about 0.3 to 2.5 kg DM/tree, and approximately 2.5 tonne DM/ha for the poplar clone Flevo (*P.* x *euramericana*; Hathaway 1986; Douglas *et al.* 1996; Oppong *et al.* 1996, 2001). This is consistent with results from a study with cattle grazing willow fodder blocks where researchers found that the animals browsed 0.7 to 2.4 kg DM/tree, depending on the willow clone and the height of the tree (Kemp *et al.* 2001).

Some studies on the cutting management of willows have concluded that the total edible forage yields for the same species/clone are significantly affected by frequency of harvest; however, results are conflicting (Douglas *et al.* 1996; Oppong *et al.* 1996). Oppong *et al.* (1996) found that harvesting twice during the growing season increased edible forage yield by 27%. In contrast, Douglas *et al.* (1996) found that a single harvest at stump (stool) height at the end of the growing season yielded up to twice as much edible forage as two or three harvests at the same height during the growing season. To further confuse the issue, Oppong *et al.* (2001) reported no effects on DM yields due to frequency of harvest. It is clear that there is a lack of definitive information on harvesting strategies that will produce the most edible fodder. However, Douglas *et al.* (1996) suggested that multiple and single harvest strategies at varying stump heights all produced useful quantities of edible forage and that management programmes could differ depending on requirements. During an extended requirement, fodder could be harvested multiple times; alternatively the resource could be stockpiled and harvested at the end of the growing season. It is important to note, however, if the trees are not grazed until mid-late summer, there will be a quantity of edible forage that grazing animals will not be able to reach (Douglas *et al.* 1996).

Oppong *et al.* (1996, 2001) reported that the height of the willow stump (0.3 m vs. 0.8 m vs. 1.2 m) had no effect on the total edible forage yield. This contrasts with findings by Douglas *et al.* (2003a; 2003b) who found that trees cut at 0.5 m produced greater total yields than those cut at 0.25m. Cutting height of the stump is an important aspect of fodder block management as the stump needs to be maintained at a height that will enable safe and easy harvesting in a coppice block or will keep current growth within the reach of animals in a browse block.

Table 1.6 Total edible dry matter (DM) production (t DM/ha) from Tangoio (*S. matsudana* x *alba*) willow coppiced-managed plantations at Aokautere Soil Conservation Centre, lower North Island, New Zealand.

	Age of stools est. years	**Density** stems/ha	**Total Edible DM** t DM/ha
Hathaway (1986)	5	16,000	3.2 - 5.7
Douglas *et al.* (1996)	2-3	2,670	1.38
Oppong *et al.* (1996; 2001)	3 - 4	2,670	2.9 - 3.2

Accessibility is an important factor when providing tree fodder to grazing animals. Fallen leaves and mechanically pruned limbs and foliage are easily accessible methods of feeding all classes of livestock. The accessibility of fodder in browse blocks, however, may vary between ages and classes of livestock. Adult sheep, for example, have an effective grazing height of 1.2 to 1.3 metres and would, therefore, not have access to foliage and primary growth above that height. Adult cattle, on the other hand, have an effective grazing height of approximately 2 metres (Kemp *et al.* 2001). They also have a size advantage, because they can push down tree fodder to gain access to feed that may have been out of their grazing range. Furthermore, certain clones may grow more accessible fodder than others (P.D. Kemp, Massey University, Palmerston North, personal communication). Poplar and willow clones with highly branched stems may have more inaccessible fodder than unbranched stems with a straight line of leaves. This is because livestock tend to strip the foliage by running their mouth down the stem. Highly branched stems may be hard to strip, thus requiring the animal to remove each leaf individually. This may require more time and limit overall consumption.

1.2.3.2 Feeding Value

The feeding value of any forage ultimately determines the usefulness of that forage as a source of livestock fodder, and poplar and willow tree trimmings are no exception. Ulyatt *et al.* (1980) defined feeding value as the animal production achieved from a particular forage fed under unrestricted conditions, with its components being voluntary feed intake (VFI), the digestion process (digestibility) and the efficiency of utilisation of digested nutrients. The nutritive value (NV) of a forage is defined as the nutrient concentration per unit of feed and can be expressed as megajoules (MJ) of metabolisable energy (ME)/kg DM, or M/D, metabolisable protein/kg DM and in concentration of major trace elements/kg DM (Ulyatt *et al.* 1980).

Two common methods for estimating VFI are the animal and the pasture sampling techniques. The animal-based method involves indirect measurement of intake from forage digestibility of the diet selected and faecal output of the animals, using the following equation (Mayes & Dove 2000).

$$\text{Voluntary Feed Intake} = \text{Faecal Output} / (1 - \text{Forage Digestibility})$$

Faecal output is usually measured either directly by bagging the animal or indirectly with the use of an indigestible marker, such as chromium sesquioxide (Cr_2O_3) or naturally occurring alkanes (Mayes & Dove 2000). Forage digestibility can be obtained from direct animal measurement (*in vivo*) or estimated from the *in vitro* digestibility of forage samples plucked to grazing height or indirectly from the relative concentration of an indigestible component in the feed and faeces. The advantage of the animal-based method is that separate estimates of intakes for individuals within a group can be made and the data can be statistically analysed. However, the method also has a high requirement for resources, i.e. labour and cost. The pasture-based or 'Difference' method is used to measure mean apparent intake or pasture disappearance for groups of animals (Walters and Evans 1979). This involves determination of pre- and post-grazing pasture mass from mechanically harvested pasture samples, or by use of pasture meters calibrated against these measurements. Estimates of DMI (kg/animal/day) are based on the equation from Walters and Evans (1979).

$$\text{DMI} = (\text{Pre-grazing DM} - \text{Post-grazing DM}) / \text{number of animal grazing days}$$

The pasture sampling method has a lower resource requirement and is generally considered a reliable method of herbage intake over short grazing intervals, when pasture growth is minimal and stocking densities are high (Walters & Evans 1979). The disadvantage is that the method only allows for calculation of DMI for the entire group and does not provide individual animal intakes.

Digestion is the key process controlling both intake and utilisation of feeds (Ulyatt *et al.* 1980). There is a strong positive relationship between digestibility and VFI; as digestibility increases, intake increases (Ulyatt *et al.* 1980). The chemical and physical composition of a feed determines the passage rate of feed through the digestive tract. Therefore, higher quality (more digestible) feeds break down more quickly, thus increasing passage rate of feeds and encouraging a higher VFI. It is important to note that very high VFIs can decrease feed digestibility.

In ruminant animals, the rumen is the first and largest organ encountered by ingested feed and accounts for about 60% of digestion (Ulyatt *et al.* 1980). Digestion in the rumen is via microbial fermentation, which is important for the breakdown of the complex plant carbohydrates, cellulose and hemicellulose. The major products of digestion of feed by rumen microorganisms are volatile fatty acids (VFA), microbial cells (the most important component of which is protein), methane and carbon dioxide. VFA and microbial protein supply a substantial proportion of the energy and protein requirements of ruminants. However, inefficient digestion of protein and carbohydrates can occur based on the chemical composition of a particular feed. Therefore, processes occurring within the rumen dictate to a large extent the nature of the nutrients available to the animal and the subsequent utilisation of those nutrients (Ulyatt *et al.* 1980).

There are few published data on the feeding value of willow and poplar trees. Nutritive value analyses have been conducted on relatively few willow and poplar species and clones and there is only one reported *in vivo* digestibility trial (McCabe & Barry 1988). However, sources agree that the total nitrogen (N) and ME content of willow and poplar fodder is within the range (16-24 g/kg total N; > 7.5 MJ ME) that will support moderate growth in livestock (Ulyatt *et al.* 1980). Willow and poplar tree fodder is moderately digestible and highly palatable for livestock and is superior to dry summer pasture (McCabe & Barry 1988; Smith 1992).

1.2.3.2.1 Chemical Composition, Nutritive Value and Digestibility of Willow Tree Fodder

The following diagram describes the composition of poplar and willow tree fodder (Figure 1.8).

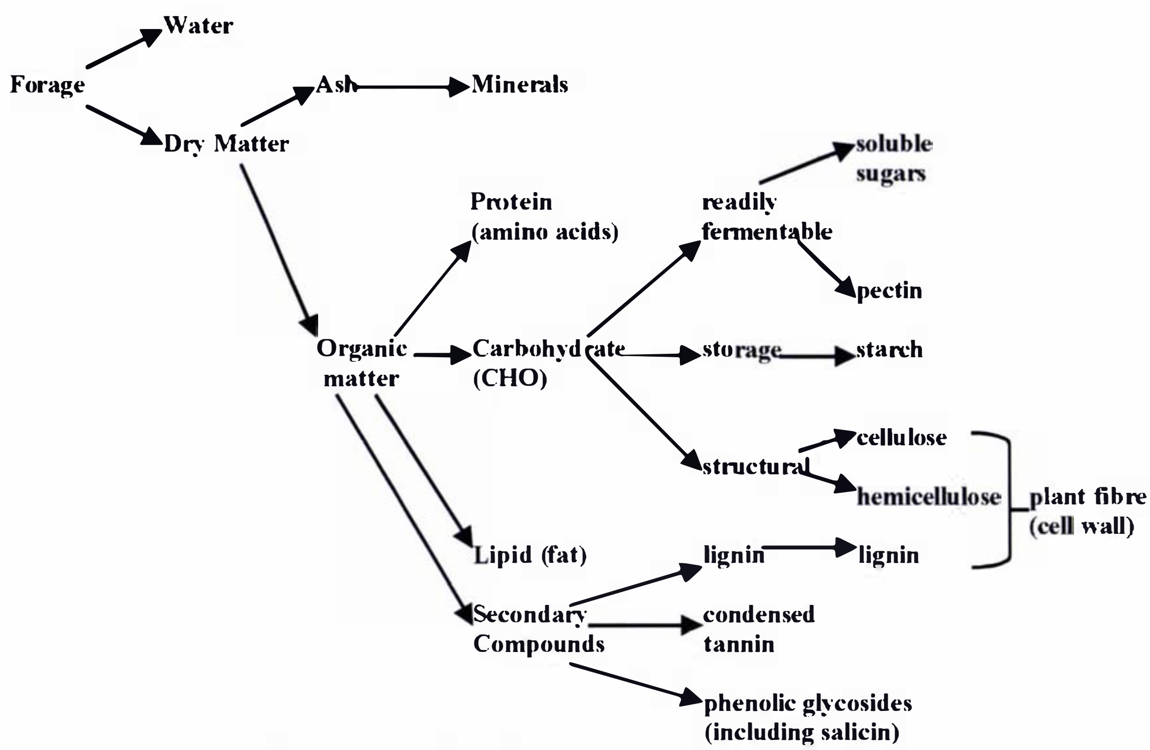


Figure 1.8 Composition of animal feeds.

McCabe & Barry (1988) conducted the first comprehensive nutritive value and digestibility analyses of tree willow tree fodder. The authors compared willow (*S. matsudana x alba*, cv. 'Wairakei') tree fodder (leaf + stem ≤ 5 mm) to a variety of other common temperate forages (i.e. white clover, perennial ryegrass, kale, etc.; Table 1.7). The study found that willow tree fodder has a substantially lower ratio of readily fermentable to structural carbohydrate than forage kale and vegetative white clover, but was greater than fresh or dried ryegrass. The total N content was low but was substantially above the levels where N concentrations limit voluntary intake of adult ruminants (< 13 g N/kg DM). A noticeable difference between willow tree fodder and the temperate forages in Table 1.7 is the very high concentration of lignin. This suggests that the digestibility of DM is lower in a willow tree fodder diet than the other temperate forage diets in the trial.

Table 1.7 Carbohydrate (CHO) ratio, lignin and total nitrogen (N) content and nutritive value (M/D) of willow (*S. matsudana x alba*), cv. 'Wairakei', compared with other temperate forages (McCabe & Barry 1988).

	CHO ratio*	**Lignin** g/kg DM	**Total N** g/kg DM	**M/D value** MJ ME/ kg DM
Tree willow	0.51	182	17.8	10.0
Forage kale	2.60	32	26.3	12.8
White clover (summer/autumn average)	1.26	25	39.0	11.9
Perennial ryegrass (summer/autumn average)	0.34	20	42.0	11.5
Dried ryegrass (seed setting)	0.24	73	15.4	9.9
Lucerne hay	0.38	105	31.2	ND

*Ratio of readily fermentable carbohydrate (CHO) to structural carbohydrate.

Overall, the limited data available on the chemical composition and *in vitro* digestibility of willow tree fodder is consistent with the figures reported by McCabe & Barry (1988; Table 1.7). Reports show that that DM content of willow tree fodder is approximately 300g/kg (Table 1.8). Matheson (2000) and Moore *et al.* (2003) found that the DM content of Tangoio willow tree fodder is significantly higher in summer than in spring, with ranges of 238-337 g/kg and 300-520g/kg, respectively. Lignin concentrations vary between reports with McCabe & Barry (1988) documenting the highest concentrations in Wairakei willow (Table 1.8). Douglas *et al.* (1996) reported varying crude protein (CP) concentrations, from 106 to 231 g/kg DM; all other reported data fell within that range. Smith (1992) and Moore *et al.* (2003) reported organic matter digestibility (OMD) of approximately 60%, while other sources reported OMD digestibility of 64% or higher (Table 1.8). ME values were approximately 9 to 10 MJ/kg DM. Both the CP content and digestibility of willow tree fodder declines from early spring to leaf fall in autumn with slight, but insignificant, variations between cultivars (Matheson 2000; Oppong *et al.* 2001). The reported condensed tannin (CT) concentration of willow is approximately 30 g/kg DM; however, Oppong *et al.* (1996,

2001) found significantly higher concentrations of CT. Willow cultivars have shown significant variation in CT concentration (Matheson 2000). Matheson (2000) found ranges of CT concentrations from 12 to 54 g/kg in the spring and 18 to 42 g/kg in the summer. It is important to note that not all chemical composition values were obtained using the same methods and that some variation is likely to be due to the differing methods used by the authors.

Table 1.8 Chemical composition, in g/kg DM, of willow tree fodder (leaf + stem ≤ 5 mm).

	DM	OM	Lignin	CP	CT	OMD	ME
	g/kg wet	g/kg DM				*in vitro*	MJ/kg DM
McCabe & Barry 1988 Cv. 'Wairakei'	299	904	182	111	29	-	10.0
Smith 1992 Cv. 'Aokautere'	290	924	-	143	-	.58	8.7
Douglas *et al.* 1996 Cv. 'Tangoio'			59	106-231		.64 -.81	
Oppong *et al.* 1996 Cv. 'Tangoio'	-	-	-	126	60	.67	-
Kemp *et al.* 2001 **Matheson 2000** Cvs. 'Tangoio', 'Moutere' & 'Matsudana' (mean)	323	937	-	142	33	.64	9.8
Oppong *et al.* 2001 Cv. 'Tangoio' (Spring, Autumn)	-	-	-	119, 138	65, 53	.70, .64	-
Moore *et al.* 2003 Cv. 'Tangoio'	300-520	946	117	113	27	.60	9.3
Mean	**333**	**928**	**119**	**137**	**45**	**.66**	**9.5**

Variations in the chemical composition and digestibility of tree fodder are most likely due to species/clonal differences and stage of growth of the willow fodder analysed. Site climate and soil fertility affects the growth pattern of willow trees and could also affect the nutritional value of the edible DM available for grazing livestock. However, it is important to note that the total quantity of nutrients each clone can provide is determined by the concentration of nutrients and by the quantity of forage that each clone is capable of producing (Smith 1992).

Smith (1992) reports that concentrations of the four major nutrient elements, calcium (Ca), phosphorous (P), magnesium (Mg) and potassium (K), in Tangoio willow leaf and stem less than 5 mm in diameter, are above the minimum requirements for sheep and cattle (Table 1.9). Concentrations (on a DM basis) in early summer (5 February) were documented as 14.7 g/kg, 3.1 g/kg, 2.0 g/kg and 13.0 g/kg, respectively. This is consistent with concentrations reported by Douglas *et al.* (1996), in Tangoio willow fodder in February, although the authors reported slightly lower Ca concentrations and a lower Ca:P ratio. In the trial conducted by Smith (1992), early March regrowth (4 week regrowth) after the full harvest of edible material in February showed higher P, Mg and K concentrations and lower concentrations of Ca than the fodder in February. All nutrients, except for Ca, decreased as leaf fall became imminent. Ca:P ratios increased from February to April as Ca levels increased and P levels declined.

Table 1.9 Ruminant requirements and concentrations of calcium, phosphorous, magnesium and potassium, in g/kg DM, in Tangoio willow tree browse; leaf plus stem less ≤ 5 mm in diameter (Smith 1992; Grace 1983).

	Ca	**P**	**Ca:P**	**Mg**	**K**
Livestock Requirements	2.9-4.4	2.5-3.0		1.2-1.9	2-6
Typical Range in Pasture	2.3-12.3	1.1-9.9	1:1 to 2:1	1.4-3.4	20-40
Tangoio Willow					
5 February	14.7	3.1	4.7 : 1	2.0	13.0
10 March[1]	10.3	6.5	1.6 : 1	2.2	17.0
24 April[1]	16.7	2.8	6.0 : 1	1.9	8.3

[1] Regrowth from pruning after 5 February

1.2.3.2.2 Chemical Composition and *In Vitro* Digestibility of Poplar Tree Fodder

Smith (1992) conducted a trial to evaluate the differences in apparent nutritive value, using Near-Infrared Reflectance Spectroscopy, between seven poplar clones and to follow the changes in the nutritive value of poplar fodder over the summer-autumn period (Table 1.10). The author found significant variation in the composition and nutritive value of poplar cuttings (leaves and stems ≤ 5 mm diameter) between clones. In the trial, Yunnan was the lowest in all attributes relating to nutritive value and

Eridano and Kawa, overall, performed the best. Eridano and Kawa were two of the highest in terms of DM digestibility (DMD) and digestibility of organic matter (DOMD) and Kawa had relatively high CP levels (Table 1.10).

Table 1.10 Nutritive value of 7 poplar clones (Smith 1992).

	DM	OM	CP	DMD	DOMD	ME
	g/kg wet	g/kg DM		*in vitro*		MJ/kg DM
Yunnan *P. yunnanensis*	330	932	106	.554	.507	8.3
Kawa *P. deltoides x yunnanensis*	300	915	128	.643	.562	9.2
NZ 5007 *P. euramericana x yunnanensis*	320	910	111	.583	.516	8.4
Tasman *P. x euramericana*	290	920	117	.622	.557	9.1
8008-9 *P. x euramericana*	330	899	109	.640	.547	8.9
Eridano *P. deltoides x maximowiczii*	340	912	117	.663	.574	9.4
Veronese *P. x euramericana*	310	915	125	.622	.547	8.9
Mean	**317**	**915**	**116**	**.618**	**.544**	**8.9**

A similar trial by Matheson (2000) using *in vitro* methods, however, found no significant differences in DMD, CP and ME between cultivars. The means for CP, DMD and ME recorded by the authors were 149 g/kg, 0.668 and 9.9 MJ/kg DM (Table 1.11). These figures are slightly higher than those found by Smith (1992). Discrepancies between the two trials could be due to the differences in clones used in the trials and the timing of sampling. The trials only had two clones in common, Veronese and Tasman. Also, Smith's (1992) figures were adjusted over three sampling dates, 5 February, 10 March and 24 April whereas figures recorded by Kemp *et al.* (2001) were based on material cut at the beginning of March.

Kemp *et al.* (2001; Table 1.11) reported the mean CT concentration of poplar tree fodder as 14.0 g/kg, which is significantly lower than the 33.1 g/kg reported for willow tree fodder (Table 1.8).

Table 1.11 The nutritive value, in g/kg dry matter (DM), of forage (leaf + stem ≤ 5 mm) from 9 poplar cultivars during summer (Matheson 2000; Kemp *et al.* 2001).

	CP g/kg DM	**DMD** *in vitro*	**ME** MJ/kg DM	**CT** g/kg
Veronese *P. x euramericana*	179	0.698	10.4	9.8
Louisa Avanza *P. x euramericana*	136	0.670	10.2	26.1
Pakaraka	165	0.687	10.3	9.3
Selwyn	150	0.676	10.2	19.2
Toa	134	0.607	8.9	6.0
Argyle	152	0.647	9.6	11.3
Weraiti	158	0.692	10.2	11.1
Otahoua	137	0.640	9.6	9.3
Tasman *P. x euramericana*	128	0.694	10.0	23.6
Mean	**149**	**0.668**	**9.9**	**14.0**

Guevara-Escobar (1999) found that the ME and CP contents of fresh poplar leaves (11 MJ and 180 g/kg) compared favourably to that of perennial-ryegrass/white clover pasture in September-November, although feed quality of fallen leaves declines rapidly over time. Charlton *et al.* (2003) reported a decline in organic matter digestibility of 15% units after 2 to 3 days on the ground. Poplar leaves are also a useful source of minerals, particularly Zn, which is effective in preventing facial eczema symptoms (Guevara-Escobar 1999). Facial eczema, caused by the fungus *Pithomyces chartarum*, is a condition associated with sheep and cattle grazing pastures that have a low clover content and high dead matter content, which occurs between January and April during or after periods of warm humid weather (Guevara-Escobar 1999). The high zinc content of fresh (158 μg/g DM) and senesced (284 μg/g DM) poplar leaves, compared with pasture (62.3 μg/g DM), may help to control facial eczema in grazing livestock (Guevara-Escobar 1999). Senesced poplar leaves have also been found to be very high in Ca and could be used to supplement Ca in the diet of pregnant cows during lactation or young calves (Guevara-Escobar 1999).

Table 1.12 Ruminant requirements and calcium, phosphorous, magnesium and potassium concentrations in g/kg DM of poplar browse; leaf plus stem less ≤ 5 mm in diameter (Smith 1992).

	Ca	P	Ca:P	Mg	K
Livestock Requirements	2.9-4.4	2.5-3.0		1.2-1.9	2-6
Typical range in pasture	2.3-12.3	1.1-9.9	1:1 to 2:1	1.4-3.4	20-40
Poplar Tree Fodder	17	2.3	7.4 : 1	2.3	9

Smith (1992) reported that, similar to willow tree diets, the levels of Ca, Mg and K in poplar were all above the minimum requirements for sheep and cattle (Table 1.12). However, P levels were marginal. The ratio of Ca:P in poplar browse was well above that found in pastures. Smith (1992) pointed out that high dietary Ca levels depress P absorption and may exacerbate any P deficiency. However, there is no evidence that willow or poplar tree fodder diets will cause a P deficiency in grazing animals.

Various studies have reported the nutritive value of leaf versus poplar stem and all studies have found that the leaves of both poplar and willow trees have a much higher nutritional value than the stem (Smith 1992). Thus it is important to remember that as a higher proportion of stem is consumed, the value of the feed will be diluted.

1.2.3.2.3 Voluntary Intake and *In Vivo* Digestibility of Willow and Poplar Tree Fodder

McCabe and Barry (1988) found that sheep voluntarily consume (voluntary feed intake; VFI) 69.6 g/kg $W^{0.75}$ of primary spring growth (leaf plus stem ≤ 5 mm in diameter) each day, on an adjusted live weight basis, from the tree willow species *S. matsudana x alba*, cultivar Wairakei (Table 1.13). With a reported digestibility of 64.2%, the digestible intake was 44.4 g/kg $W^{0.75}$/day (Table 1.13). The trial also showed that the

VFI of willow tree fodder is 29% lower than that of lucerne hay, but can still provide significantly more than the maintenance requirement of sheep. Expressed as a function of the quantity of intake required for maintenance, McCabe & Barry (1988) concluded that Wairakei could provide 22% more than maintenance level nutrition.

Table 1.13 Voluntary intake and *in vivo* digestibility of dry matter in primary spring growth of *Salix matsudana x alba*, 'Wairakei' (McCabe & Barry 1988).

	'Wairakei'
Voluntary intake (g/kg $W^{0.75}$ /day)	69.6
Digestibility	0.642
Digestible intake (g/kg $W^{0.75}$/day)	44.4

VFI trials conducted, by McKinnon *et al.* (2000), with sheep fed sole diets of the poplar cultivars Kawa, Argyle or Eridano showed that the intakes of Argyle and Kawa were similar (Table 1.14). However, intake/day of the cultivar Eridano was approximately 50% less than that of either Kawa or Argyle (Table 1.14).

Table 1.14 Voluntary feed intake of leaves of three poplar cultivars when fed *ad lib* as the sole diet to sheep (55 kg mean live weight; McKinnon *et al.* 2000).

Poplar Cultivar	**Mean Intake**	
	g DM/sheep/day	g/kg $W^{0.75}$/day
Argyle	1408	69.7
Kawa	1305	64.6
Eridano	718	35.6

McKinnon *et al.* (2000) also conducted preference experiments with sheep offered leaves from pairs of poplar cultivars (Kawa + Argyle, Kawa + Eridano or Argyle + Eridano). The authors found that when sheep were offered Kawa + Eridano, they consumed 880 g/day of Kawa leaves and only 98 g/day of Eridano leaves (Table 1.15). Similarly, when sheep were offered Argyle + Eridano, sheep consumed a significantly greater proportion of Argyle. The trial concluded that sheep prefer fodder from cultivars Argyle and Kawa to that of cultivar Eridano and that the differences in preference could be due to differing concentrations of the secondary metabolite salicin. Therefore, it is important that farmers selecting poplar cultivars for use as a feed resource for sheep select more preferred cultivars because a poorly preferred cultivar, such as Eridano, could severely decrease sheep performance if fed as a sole diet.

Table 1.15 Voluntary feed intake of sheep (55 kg mean live weight) when offered *ad lib* diets leaves of pairs of poplar cultivars (McKinnon *et al.* 2000).

Intake	Cultivar Pair		
	Kawa / Argyle	Kawa / Eridano	Argyle / Eridano
g DM/day	546 / 628	990 / 98	976 / 121
g/kg $W^{0.75}$/day	27.0 / 31.1	49.0 / 4.9	48.3 / 6.0

1.2.3.2.4 Willow and Poplar Secondary Compounds

The family Salicaceae, which includes willow and poplar species, is characterized by the ability to synthesize low molecular phenolic glycosides and/or condensed tannins (CT; proanthocyanidins; Figure 1.9), both of which are known to influence the susceptibility of plants to grazing or browsing by herbivores (Swain 1979; Julkunen-Tiitto 1986; Nichols-Orians *et al.* 1992; Orians 1995; Orians *et al.* 2000). Plant phenolics are characterised by hydroxylated aromatic rings and are categorised as secondary metabolites. Salicin and salicortin are the most common glycosides, in the secondary metabolite group, found in willow and poplar leaves (Julkunen-Tiitto 1986). Some willow species produce only condensed tannins, others produce mostly phenolic glycosides, and others produce both classes of compounds (Orians *et al.* 2000). The negative correlation between condensed tannin and phenolic glycosides in F1 willow hybrids found by Orians *et al.* (2000) suggests that poplar/willow species and clones may not be able to produce high concentrations of both CT and phenolic glycosides.

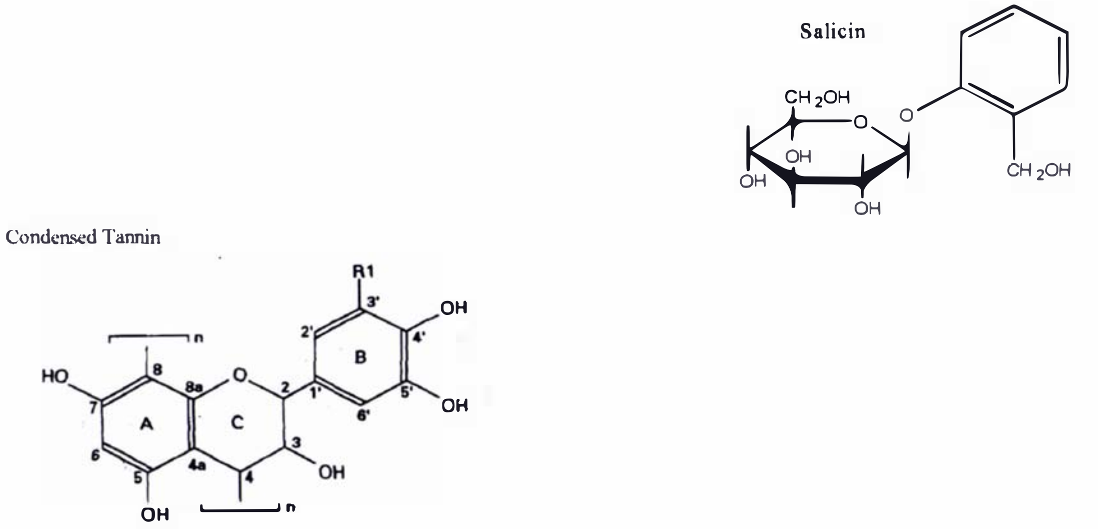


Figure 1.9 Structures of condensed tannin (MW = 1800 - 2200 for *Lotus* species) and salicin (MW=286.27) molecules.

1.2.3.2.4.1 Salicin

Table 1.16 Salicin concentration, in g/kg, in willow and poplar tree fodder.

	Salicin Content g/kg DM	
	Markham 1971	Edwards 1978
Willow		
Salix vitellina	0	-
S. viminales	0	-
S. daphnoides	15	-
S. purpurea (var. *eugenei*)	32	-
S. purpurea	43	-
S. purpurea cv. Booth	50	-
S. daphnoides (var. *acutifolia*)	52	-
S. incana	65	-
S. piperi	84	-
Poplar		
Populus euramericana cv. N.E. 378	17	28
P. euramericana cv. I-214	25	43
P. euramericana cv. Laevigiata	28	28
P. nigra cv. Sempervirens	28	26
P. yunnanensis	58	31
P. generosa	76	47

Salicin and salicin derivatives, such as populin, fragilin, tremuloidin and salicortin, (henceforth called 'salicin') are natural plant defensive chemicals found in the leaves of willow and poplar trees that cause an intensely bitter taste (Markham 1971). Salicin concentrations vary between cultivars of the same species with a recorded range of 17 to 76 g/kg DM and 0 to 84 g/kg DM in poplar and willow cultivars, respectively (Markham 1971, Edwards 1978; Table 1.16). Markham (1971) has related salicin hydrolysate concentration, determined with a rapid thin-layer chromatography method, to the palatability of willow and poplar species to possums (*Trichosurus vulpecula*), a browsing marsupial (Figure 1.10). Markham (1971) concluded that willow/poplar species with higher concentrations of salicin were generally the least palatable to possums, giving a good example of salicin as a plant defensive chemical against browsing herbivores.

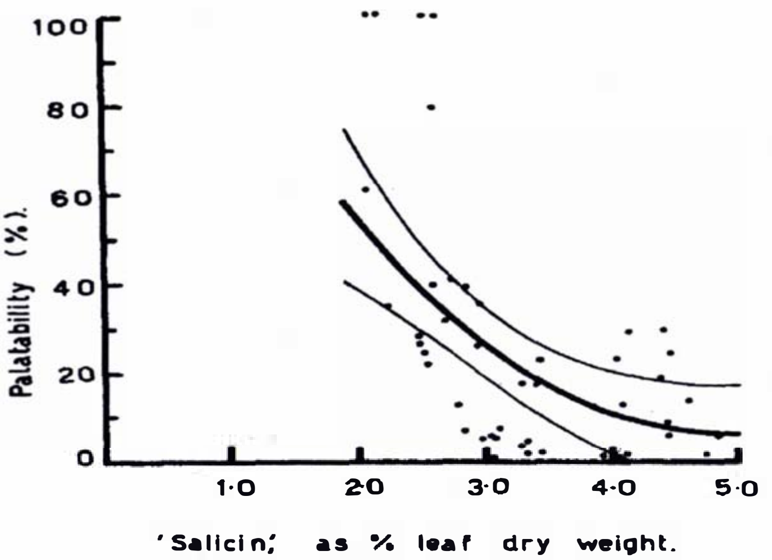


Figure 1.10 Salicin as a percentage of dry weight versus palatability as a percentage of leaves partly or wholly consumed. The upper and lower lines are 5% limits of confidence for the regression equation (Edwards 1978).

Research with caged possums and field observations has largely confirmed this result (Edwards 1974, 1978). Edwards (1978) states that it is clear that salicin is a major component in determining the palatability of *Populus* to possum; however, while high salicin levels appear to limit palatability, the presence of low levels does not necessarily indicate lower palatability. Other factors may be involved in selection and palatability such as smell and appearance (Edwards 1978). This may have implications in the use of willow and poplars as fodder trees. Willow/poplar cultivars and species that are very high in salicin content and unpalatable to possums may also be bitter and unpalatable to livestock. Therefore, offering fodder from an undesirable species/cultivar could result in very low VFI or even refusal (McKinnon *et al.* 2000).

1.2.3.2.4.2 Condensed Tannin

Condensed tannins are prevalent in tropical and temperate browse plants and in some temperate legumes, including *Lotus pedunculatus* (now called *Lotus uliginosus*; lotus), *Lotus corniculatus* (birdsfoot trefoil) *Hedysarum coronarium* (sulla) and *Onobrychus viciifolia* (sainfoin). Condensed tannins bind to plant protein by pH-reversible hydrogen bonding. Stable complexes are formed in the basic environment of the rumen (pH 6.0-7.5) and are disassociated in the acidic environment of the abomasum (pH < 3.5; Jones & Mangan 1977).

1.2.3.2.4.2.1 Effects of Condensed Tannin on Protein Digestion

The New Zealand livestock industry is based on fresh ryegrass dominant pasture and, to a smaller extent, forage crops. When ruminants are fed fresh forages there is often extensive fermentation of dietary protein to peptides, amino acids and ammonia in the rumen. A large proportion of this nitrogenous substrate is reincorporated in microbial protein. However, the rapid release of ammonia often exceeds its incorporation into microbial protein, resulting in 20-35% of the N being lost as ammonia absorbed from the rumen (Barry *et al.* 2001). Thus, for ruminants grazing typical New Zealand pastures of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), duodenal non-ammonia nitrogen (NAN) flow is only about 75% of N intake (Barry & McNabb 1999). Duodenal NAN can be used as an index of protein-N leaving the rumen. With *Lotus* species, duodenal NAN flow increases linearly with increasing CT concentration and equals N intake at a CT concentration of approximately 40 g/kg DM (Figure 1.11; Barry & McNabb 1999; Barry *et al.* 2001). This is due to the binding action of CT to forage protein in the rumen reducing the rates of both solubilization and degradation by rumen microorganisms (Barry & McNabb 1999; Barry et al. 2001). The total CT concentrations in birdsfoot trefoil and lotus are approximately 30 to 40 and 75 to 85 g/kg DM, respectively (Barry & McNabb 1999).

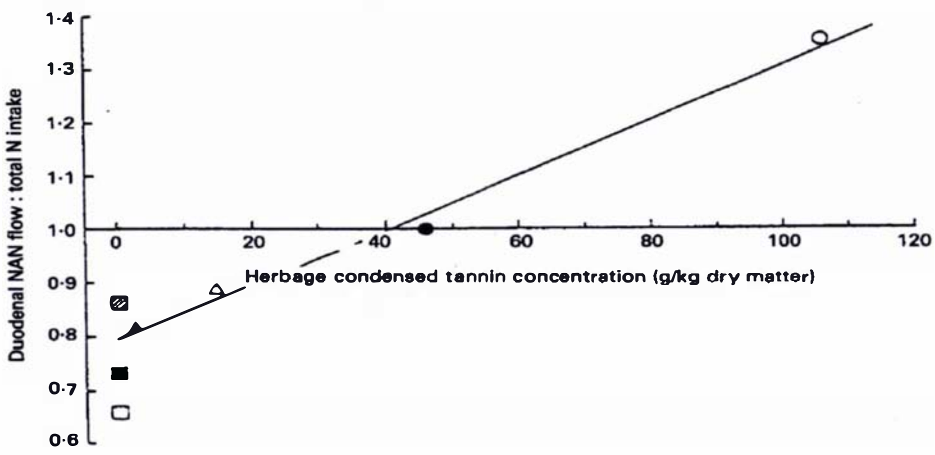


Figure 1.11 Duodenal non-ammonia nitrogen (NAN) flow per unit total nitrogen (N) intake as a function of herbage condensed tannin (CT) concentration in sheep fed *Lotus* species (Barry & McNabb 1999).

Dietary CT always increases the proportion of protein-N passing from the rumen to the acidic abomasum (Waghorn & McNabb 2003). A number of studies have shown that low to medium concentrations of CT, found in forages like birdsfoot trefoil, in the diet increase the efficiency of protein digestion by increasing the flow of protein-N to the intestine, relative to N intake, by increasing the flow of essential amino acids (EAA) out of the abomasum (abomasal flow) by 50-53% and by increasing the net absorption of EAA from the small intestine by 59-63%, with no effect on apparent digestibility in the small intestine (Barry & McNabb 1999; Waghorn *et al.* 1999; Barry *et al.* 2001). However, while action of CT increased abomasal flow in sheep fed lotus, which contains relatively high concentrations of CT, by 30%, this was counteracted by reduced apparent digestibility in the small intestine, with only a 10% increase in apparent absorption of EAA from the small intestine.

The differences between birdsfoot trefoil and lotus are due to differences between these species in the concentration, structure, molecular weight (MW) and hence reactivity of the CT. No information is available on the MW, structure and reactivity of the CT in willow and poplar tree fodder; however, the CT concentration is within the range to have beneficial effects on protein digestion in grazing ruminants.

1.2.3.2.4.2.2 Effects of Condensed Tannin on Carbohydrate Digestion

When a ruminant consumes CT-containing forages, CT reacts with all available protein in the host plant until the binding capacity of the system has been saturated. At this point, any excess CT is considered 'Free'. It is proposed that any free CT then reacts with and inactivates microbial enzymes (Barry & McNabb 1999). This may explain the report by Barry & McNabb (1999) that high concentrations of CT in lotus (95 and 106 g/kg DM) depress rumen digestion of readily fermentable carbohydrate (soluble sugar + pectin) and hemicellulose. Sources report that concentrations of CT in excess of about 45 g/kg DM markedly depress rumen digestion of structural carbohydrate, apparent digestibility and voluntary intake. It is important to note that the chemical structure and molecular weight of CT in lotus and birdsfoot trefoil differ; therefore CT concentration alone may not mediate carbohydrate digestion in ruminants.

1.2.3.2.4.2.3 Effects of Condensed Tannin on Voluntary Feed Intake

CT does not affect VFI of ruminants grazing forages with moderate concentrations of CT (34 to 45 g/kg DM). In contrast, Barry & Duncan (1984) report a decrease in VFI of -27% in sheep grazing lotus with high CT concentrations (63 and 106 g/kg DM). Smaller depressions in VFI of -12% were reported in sheep grazing lotus with only 55g CT/kg DM (Waghorn *et al.* 1994). This is consistent with plant CT production being a defensive mechanism against pathogenic microorganisms, insects and grazing herbivores (Barry & McNabb 1999).

1.2.3.2.4.2.4 Effects of CT on Livestock Production

In a summary report of literature published before 1997 on the responses of livestock to CT in a wide range of temperate and tropical diets, Waghorn *et al.* (1999) reported that CT in birdsfoot trefoil always benefited performance. In contrast, the CT in lotus, when fed alone, did not benefit performance and sometimes had substantial negative impacts (Waghorn *et al.* 1999). Trials with sulla and sainfoin also most often show a positive production response to CT (Waghorn *et al.* 1999). However, in one experiment, Douglas *et al.* (1999) reported a reduction in carcass weight and yield in sheep fed sulla for a period of 17 weeks. Waghorn & McNabb (2003) report that the CT content of sulla varies widely from a beneficial 20 g/kg DM to an anti-nutritional affect at 110 g/kg DM, which could help explain the results of Douglas *et al.* (1999).

The benefits of temperate forages containing low to moderate amounts of CT (20 to 40g/kg DM) are probably due to improved efficiency of protein digestion, notably increased absorption of essential amino acids from the intestine and reduction in NH_3 absorption, which reduces the need for metabolism to urea (Barry & McNabb 1999; Barry *et al.* 2001; Waghorn & McNabb 2003). Livestock productivity gains include increases in wool growth and ovulation rate in sheep and milk yield and milk protein secretion in sheep and dairy cows, (Table 1.17; Barry & McNabb 1999; Barry *et al.* 2001; Waghorn & McNabb 2003).

Table 1.17 Livestock production responses to condensed tannin action in birdsfoot trefoil (*Lotus corniculatus;* Barry *et al.* 2001).

	Production Responses
Wool production	12 and 19% increase in fleece weight for lambs and ewes, respectively. Wang *et al.* (1996a)
Ovulation rate	21-32% increase in ovulation rate in ewes. Min *et al.* (2001)
Lactation - Ewes	21% increase in milk production and 14% increase in milk protein production in mid and late lactation. Wang *et al.* (1996b)
Lactation - Cows	Increase in milk and milk protein yield, and milk protein concentration during late lactation. Woodward *et al.* (1999)

CT has also been shown to reduce the burden and establishment of gastrointestinal parasites in growing lambs and weaner deer (Niezen *et al.* 1995, 1998a,b; Barry *et al.* 2002). Barry *et al.* (2002) report that forage secondary compounds, notably CT present in certain specialised legumes, inhibit the motility of both lungworm (*Dictyocaulis eckerti*) and gastrointestinal nematode larvae *in vitro*. Corresponding *in vivo* studies demonstrated reduced establishment of gastrointestinal parasites in young deer fed CT-containing sulla, and a reduced need for anthelmintic drenching in young deer grazing chicory. Data demonstrate that CT in plants probably reduces internal parasite burdens by direct inhibition of larvae and indirectly by increasing protein absorption, supporting the immune system and helping the animals to cope with the demands of infection. However, the mechanism is not fully understood.

CT is beneficial to grazing livestock; however, very high concentrations of CT in forages, such as lotus (80-100 g/kg DM), reduce VFI and rates of body and wool growth in grazing sheep, which is consistent with CT being a plant defence against herbivores (Barry & McNabb 1999; Barry *et al.* 2001).

Willow tree fodder has significantly higher concentrations of CT than poplar tree fodder (Matheson 2000). However, the CT content of both poplar, 14 g/kg DM (Table 1.11), and willow, 45 g/kg DM (Table 1.10), tree fodder is within the optimum range and should improve the efficiency of protein digestion in grazing ruminants, thus counteracting the somewhat lower content of total N they provide (McCabe & Barry 1988). The role CT plays in the digestion of poplar and willow tree fodder in grazing livestock is unknown and needs further research.

1.3 Feeding Ewes During Mating

1.3.1 Ewe Nutrition and Fecundity

Nutrition is the major environmental factor influencing fecundity of ewe flocks (Rattray *et al.* 1983; Smith 1991; Smith & Knight 1998). 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, which sets the upper limit for the flock, and pre-natal mortality, which determines what proportion of the ova ovulated and fertilised actually develop into lambs born.

The reproductive response to ewe nutrition is divided into two factors, the static and the dynamic effects (Rattray *et al.* 1983; Smith 1991; Smith & Knight 1998). The static effect involves the nutritional management of ewes throughout the year, which relates to weight and body condition at the time of mating. For example, heavier, fatter ewes tend to be more fecund, thus for every 10kg in live weight at the time of mating there is an increase in ovulation rate of about 0.2 to 0.3. However, mating weight alone is not the major factor controlling ovulation rate, as the pattern of live weight change immediately prior to mating can also have a large effect. The dynamic effect of nutrition involves the direction of weight change that takes place during the six-week period before mating. For example, heavier, fatter ewes that lose live weight and body condition during the six weeks before mating will have a lower percentage of multiple ovulations than lighter ewes that are gaining live weight during the same period (Rattray *et al.* 1983). An increase in ewe nutrition during the pre-mating period, resulting in increased ovulations, is commonly known as the "flushing" effect.

1.3.2 Feed Requirements During Mating

The ovulation rate response of ewes grazing pasture is controlled by the quantity and quality of the feed eaten by the ewe, which 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/ewe/day) and the botanical composition of the pasture (ratio of grass to legume; Rattray *et al.* 1983).

Figure 1.12 shows the influence of the pasture quantity offered and of pasture mass/ha pre-grazing and post-grazing on ovulation rate. Pasture masses are shown as kg "green" DM, which is fresh green herbage measured in a dry state. Ewes preferentially select the green content of the sward in preference to brown, dead herbage. In Figure 1.12a, ovulation rate increased in a curvilinear manner, as the amount of pasture fed increased, reaching a peak at allowances around 3 to 4 kg green DM/ewe/day. Figure 1.12b also shows an increase in ovulation rate with increasing post-grazing residuals, with a peak around 1000 kg green DM/ha. These relationships show the importance of providing both a high proportion of green material in the sward and an adequate amount of DM/ha (>1000 kg green DM/ha) and the negative effects on reproductive rate of feeding at lower nutritional levels.

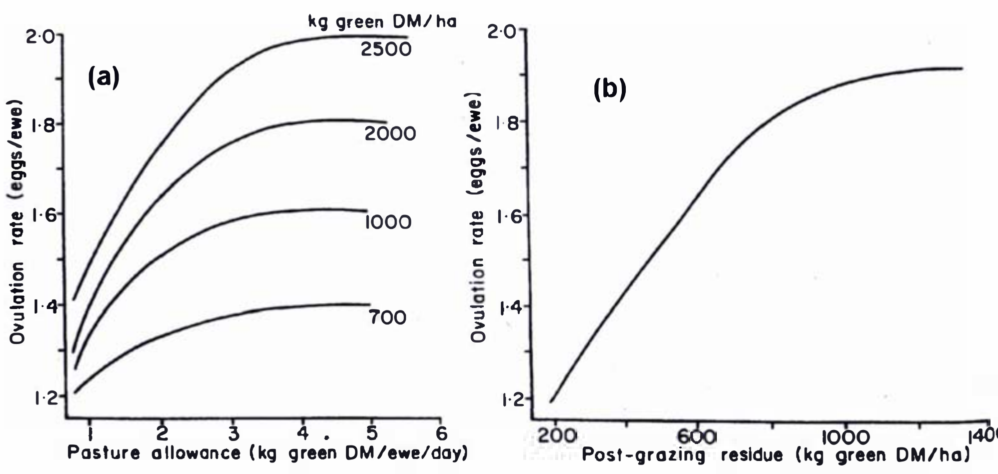


Figure 1.12 Influence of the amount of pasture offered and the level of pasture herbage mass/hectare (ha) pre-grazing (a) and post-grazing (b) on the ovulation rate of ewes. Pasture refers to perennial ryegrass/white clover pasture (Rattray *et al.* 1983).

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). Figure 1.13 highlights the relationship between green material and *in vitro* digestibility of autumn pasture and shows that for every one percentage unit increase in green matter, average sward digestibility increases by about 0.5 percentage units.

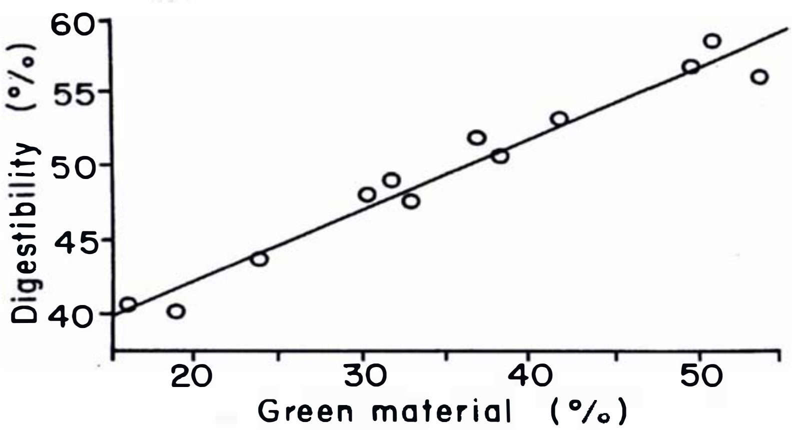


Figure 1.13 Relationship between *in vitro* digestibility and proportion of green material in autumn pasture (Rattray *et al.* 1983).

The benefits of legumes over grass species are well known in lamb finishing systems; however, only relatively recently have legumes been shown to be superior to ryegrass-dominant pastures for flushing ewes. Rattray *et al.* (1983) reports that at any particular allowance, clover-fed ewes showed significant increases in ovulation rate above those grazing ryegrass pastures.

The mechanisms through which nutrition influences ovulation rate is unknown; however, both energy and protein intake are known to be critical components of the ovulation rate response to different levels of nutrition during the pre-mating period (Smith 1985, 1991). The effect of energy is linear with increases in ovulation rate of 1.5% for every additional 1 MJ ME consumed per day (Smith 1985). Protein seems to have a threshold effect with marked increases in ovulation rate when the digestible protein intake increases above 125 g/ewe/day (Smith 1985). Figure 1.14 illustrates the significant responses that were obtained, by Smith (1985), with increasing protein intakes; numbers 1 and 3 represent results from two different years. In both years, the percentage of ewes with multiple ovulations was higher when the digestible protein intake was greater than 125 g/day, compared with ewes consuming less than 125 g/day at the same level of energy intake. Cruickshank *et al.* (1988) also found significant increases in ovulation rate (1.77 and 1.75 vs. 1.61) and the percentage of ewes with multiple ovulations (72% and 74% vs. 55%), with abomasal infusions of lactalbumin and soy protein isolate, compared with control ewes. However, the threshold level may vary with the level of rumen degradation of the diet, type of diet, and also for ewes of different breeds and live weights (Smith 1985). The duration of the period of increased nutrition is also important, with a minimal period of three weeks feeding required for most diets with additional responses occurring with up to six weeks of feeding (Smith 1985).

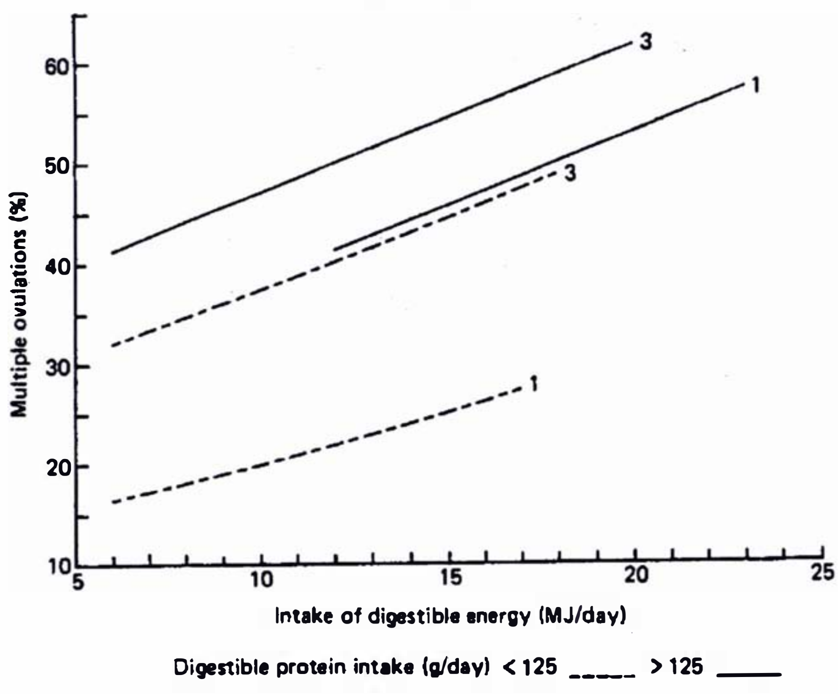


Figure 1.14 Effect on intake of digestible energy (MJ/day) and digestible protein (g/day) on the percentage of ewes with multiple ovulations. Numbers 1 and 3 represent results from two different years (Smith 1985).

It is clear that weight loss leading up to mating must be avoided at all costs, as feeding at nutritional levels below maintenance will severely reduce ovulation rate and subsequent fecundity (Rattray *et al.* 1983). Flushing ewes adequately to produce some live weight gain or to reduce weight loss, is essential for high reproductive rates in ewe flocks.

1.3.3 Anti-nutritional Factors in Herbage and Ewe Fecundity

It is well known that certain forage species contain anti-nutritional factors that can affect ewe fecundity (oestrogenic compounds). Red clover species (*Trifolium pratense*), for example contains the isoflavone formenonetin at a concentration of approximately 1.5% DM. Formenonetin is only slightly oestrogenic; however, it is metabolised in the rumen to equol, a much more oestrogenic compound. Equol has been shown to reduce ovulation rate and fertilisation rate in ewes and can lead to permanent infertility (Barrett *et al.* 1965; Shutt *et al.* 1970; McCall & Smith 1998). Recent selection trials with red clover cultivars have identified cultivars, with lower formononetin, levels that when grazed by ewes can increase ovulation rate (Rumball *et al.* 1997). Lucerne can also affect reproduction in sheep. When insects or fungi attack lucerne, during the summer, it responds by producing a defensive chemical called coumestan. Studies have shown that as the concentration of coumestan increases in lucerne consumed by ewes, ovulation rate decreases (Smith & Jagusch 1979; McCall & Smith 1998).

Grass/clover pastures in both the North and South Islands of New Zealand can contain a number of *Fusarium* fungi capable of producing the oestrogenic mycotoxin zearalenone (Smith *et al.* 1990; Towers 1997; McCall & Smith 1998). Fungal growth and zearalenone production is highest in the months of February, March and April, which correspond to the pre-mating and mating period of ewes. Di Menna *et al.* (1987) reports concentrations of zearalenone in typical New Zealand pastures from January to April of 0.4 to 4.0 mg/kg DM. However, the authors pointed out that the factors determining zearalenone production in pasture could be site-related, as *Fusarium* numbers did not correlate with zearalenone concentrations in their study. Dosing trials have established that daily intakes of more than 1 mg zearalenone depress ovulation rates of ewes, with the decrease in ovulation rate increasing as both the daily zearalenone intake (Figure 1.15) and the duration of exposure to the toxin increases (Smith *et al.* 1990, 1992).

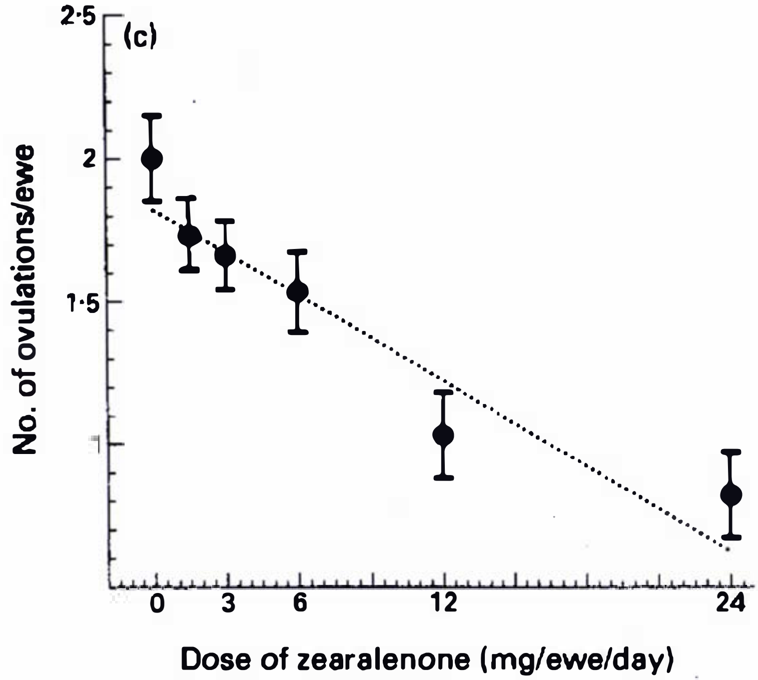
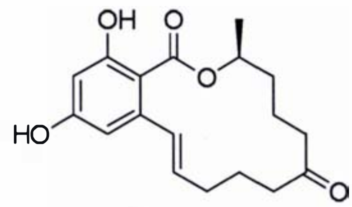


Figure 1.15 Effect of dose of zearalenone (mg/ewe/day) before mating on the number of ovulations/ewe (Smith *et al.* 1990).

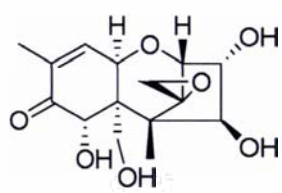
Adult sheep usually ingest 1 to 2 kg DM/day of pasture, therefore intakes in excess of 1 mg would be expected whenever pasture zearalenone concentrations are higher than 0.5 to 1.0 mg/kg dried pasture (Towers 1997). Most of the zearalenone in pasture is found on the dead material, thus ewes grazing short drought pastures with a high dead matter content would consume sufficient quantities of zearalenone to depress ewe reproductive rate and fecundity. Analysis of pasture samples collected from throughout New Zealand over several years (Sprosen *et al.* 1995), during autumn, showed that 23 to 51 % of the samples contained zearalenone levels greater than 1 mg/kg DM prior to and during mating, and the authors concluded that many ewe flocks were grazing pastures with concentrations of zearalenone that were likely to depress reproduction. (Towers 1997).



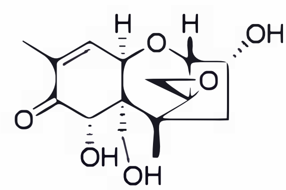
Zearalenone

Figure 1.16 Chemical structure of the *Fusarium* mycotoxin zearalenone.

Pasture fungi, particularly *Fusarium*, also produce trichothecene toxins that are known to cause a variety of human and animal toxicities (Ueno 1977; Fink-Gremmels 1999); however, little is known about the effects of trichothecenes found in New Zealand pasture on grazing animals and the amount of toxin necessary to impact on animal health and production. Sources suggest that trichothecenes may be involved in animal 'ill-thrift' disorders (failure to grow or produce), which often occurs in the autumn under New Zealand grazing conditions (Lauren *et al.* 1988, 1992; Towers 1997). Nivalenol (NIV) and deoxy-nivalenol (DON) are two common trichothecene toxins produced by *Fusarium* sp. in New Zealand pasture (Lauren *et al.* 1988, 1992).



Nivalenol



Deoxynivalenol

Figure 1.17 Chemical structure of the *Fusarium* mycotoxins nivalenol and deoxynivalenol.

Another anti-nutritional factor in New Zealand pasture is Sporidesmin-A, a mycotoxin produced by the fungus *Pithomyces chartarum*. Sporidesmin-A is not oestrogenic; however, when it is ingested it concentrates in bile where it can cause mild to severe liver damage and photosensitization; symptoms of the disease commonly referred to as 'facial eczema' (Smith 2000). *Pithomyces chartarum* grows and produces spores on pasture litter under warm and humid conditions, usually in autumn (Smith 2000; Smith & Towers 2002). Facial eczema can have serious production consequences for ewes during mating, which ultimately affects reproduction.

The impact of mycotoxins on ewe reproduction can be lessened through management designed to reduce or eliminate intake of feeds containing the compounds (Smith & Towers 2002). In the case of zearalenone, this can be achieved by reducing the amount of toxin ingested by grazing ewes through periodic pasture monitoring for zearalenone levels in late summer and early autumn (February to May) and providing toxin-free forages when concentrations begin to approach 1mg/kg DM. Toxin-free fodder can be provided by growing summer/autumn forage crops for ewes prior to and during the mating period; legumes and brassicas are both excellent options. Conserved fodders, such as silages are also an option; however, the supplement must provide a large majority of the ewes diet to reduce the amount of pasture fungal toxins consumed. Exposure to facial eczema spores can be controlled similarly; however, other options exist such as spraying pastures with benzimidazole fungicides, which has been shown to reduce spore production by 55 to 65% (Smith & Towers 2002). If utilising pastures with high levels of toxins is unavoidable, supplementing livestock with very high doses of zinc salts (15 to 30 mg Zn/kg live weight/day) will reduce sporidesmin-induced liver damage and production losses by 60 to 90% (Smith & Towers 2002). Willow and poplar leaves also contain adequate concentrations of zinc, which may help to treat the symptoms of facial eczema (Guevara-Escobar 1999; Douglas *et al.* 1996).

1.3.4 Effect of Drought on Fecundity

Drought reduces pasture growth and increases the dead matter content of pasture resulting in a decline in mass and nutritive value of feed available to grazing ewes, which affects ewe production and reproduction. Figure 1.12 shows that at pre-grazing levels of 1000 kg DM/ha, with a pasture allowance of 1 kg DM/ewe/day and a post-grazing residual of 400 kg DM/ha, ovulation rate should be approximately 1.3 or 130%. In the 1997/98 drought that severely affected the usually summer-dry Wairarapa region, pre-grazing residuals of approximately 1300 kg DM/ha were recorded in December 1997. Pasture masses reduced to approximately 800 kg DM/ha in the critical flushing periods of February, March and April 1998 (Figure 1.1; P. Gawith, Farm Advisor, Wairarapa, personal communication). Figure 1.18 highlights the significant drop in reproductive rate on East Coast hill country farms due to the effects of drought conditions. The severe East Coast drought in 1988 resulted in a 25% unit drop in lambing rate on both classes of hill country (MWI Economic Service).

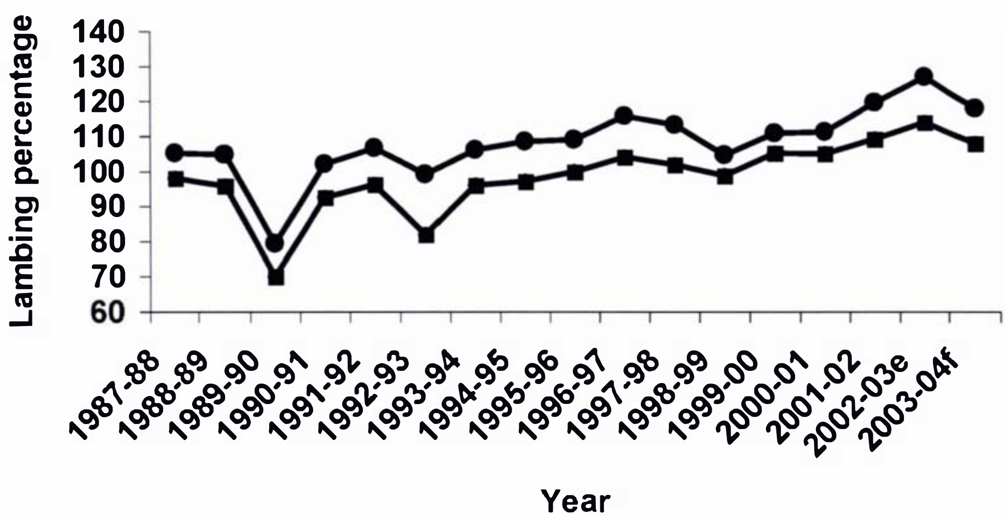


Figure 1.18 Mean lambing percentage for East Coast Hill Country Farms. Statistics from the Meat and Wool Innovation Economic Service. ■ Class 3 hard hill country; ● Class 4 hill country.

It is clear that summer-dry and drought-affected regions have inadequate pasture to provide the level of nutrition necessary to increase fecundity in grazing ewes. Thus supplementary feeding is required during the critical periods, just before and during mating, to maintain acceptable reproductive rates and profitability of dry-land sheep production systems.

1.4 Conclusion

1.4.1 Severe periodic summer/autumn droughts are a feature of farming in the East Coast regions of both the North and South Islands. Lack of rainfall, due to a summer/autumn drought, reduces pasture mass and quality and can lead to feed shortages that result in decreased feed and nutrient intakes and potentially large losses in livestock productivity, including reproduction.

1.4.2 The Southern Oscillation and resulting El Niño and La Niña weather patterns have a major impact on climate in New Zealand. El Niño conditions lead to more frequent than normal westerly winds and below average rainfall in eastern districts. La Nina events bring drier conditions to the southeast of both the North and South Islands. Global warming is increasing both the mean air and sea surface temperature. Due to climate change, scientists are predicting increased incidence and variability of extreme weather patterns over New Zealand, including greater frequency and severity of droughts in the East Coast in the future.

1.4.3 Two main strategies exist for farmers to cope with a drought-induced feed deficit; reduce feed demand or increase feed supply. Feed demand can be reduced by flexible livestock policies, including early selling of livestock, and feed supply can be increased through the growth and storage, or purchase, of high quality supplements.

1.4.4 Willow and poplar trees are exotic to New Zealand and have been introduced and cultivated over the last 160 years for aesthetics, soil erosion control on pastoral hill country and riverbanks, woodlot forestry and animal welfare, i.e. shade and shelterbelts. For conservation purposes the poplar (*P. x euramericana*) clones, Veronese, Otuhoua and Weraiti, and Kawa (*P. deltoides x yunnanensis*), dominate current nursery pole production, while *S. matsudana x alba* clones are the most common willow pole produced.

1.4.5 Willow and poplar trees have been used successfully in New Zealand as a source of emergency fodder, by a small number of farmers, for sheep and cattle during summer/autumn feed shortages and droughts. The trees are easy to establish on pastoral farmland, they will produce a renewable source of fodder and the foliage and primary growth is palatable and nutritious to grazing livestock. To date, there has been no scientific experimentation on the effects of this practice upon ewe productivity.

1.4.6 There are two primary management systems for willow and poplar browse production; wide-spaced tree planting on hillsides and densely planted fodder blocks. The annual edible DM yield of coppiced fodder trees is between 1 and 6 tonnes DM/ha/year for willow and approximately 2.5 tonnes DM/ha for poplar.

1.4.7 The total N and metabolisable energy content of willow and poplar fodder is within the range that will support moderate growth in livestock. Willow and poplar tree fodder is moderately digestible and highly palatable for livestock and is superior to dry summer pasture. Willow and poplar tree trimmings are similar in feed value; however, willow tree fodder contains higher levels of the secondary compound, condensed tannin (CT). Poplar and willow tree fodder is useful source of minerals for grazing livestock, including calcium, magnesium, potassium and zinc.

1.4.8 Willow and poplar species synthesize low molecular phenolic glycosides, such as salicin, and/or CT. High levels of salicin may reduce tree fodder palatability to grazing livestock. CT in forage legumes reduces protein degradation in the rumen and increases the flow of undegraded dietary protein to the small intestine, thus increasing protein absorption and utilisation. This has been shown to increase the productivity of grazing ruminants. The effects of CT on forage digestion depend on the molecular weight, structure and reactivity of the CT. This is unknown for willow and poplar tree fodder. However, the CT concentration is below the threshold of CT concentrations that cause anti-nutritional effects, 35-45 g CT/kg DM.

1.4.9 Reproductive efficiency is the key to profitability in dry-land sheep production systems and good nutrition prior to mating is necessary to achieve this. It is clear that in summer-dry and drought-affected East Coast regions, the quantity and quality of pasture available during mating is inadequate to achieve reproductive targets in grazing ewes during drought years. Thus, supplementary feeding is a necessity, especially during drought conditions, to maintain reproductive efficiency.

1.4.10 Willow and poplar tree fodder is an abundant and nutritious feed source and is an inexpensive supplementation option for farmers in summer-dry and drought stricken regions. However, it is necessary to collect further scientific data on the nutritional value of tree fodder and to assess the value of willow and poplar supplementation on production and reproduction of ewes grazing drought pastures before and during mating.

The following studies were designed to test the hypothesis that poplar and willow tree fodder would be a beneficial supplement to ewes grazing drought pasture during the pre-mating and mating period. It is thought that tree fodder may help reduce live weight loss and the loss in reproductive rate commonly seen in ewes suffering drought conditions. The following studies sought to

- determine how ewe production and reproduction were affected by the amount of poplar and/or willow supplementation and the period of time the supplement was offered.

- compare the effects of poplar versus willow supplementation on production parameters.

- examine changes in *in vivo* digestibility of fodder over the tree growing season.

The studies focused on ewe production traits of economic importance in dry-land pastoral farming and sought to provide new information to fill the obvious knowledge gap in the feeding of poplar and willow forage trees to livestock in New Zealand.

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CHAPTER 2

2001 GRAZING EXPERIMENT

The effect of different levels of poplar (*Populus spp.*) supplementation on the reproductive performance of ewes grazing low quality drought pasture during mating

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2.1 Abstract

A grazing experiment, conducted for 71 days from 31 January to 12 April in the late summer/autumn of 2001 at Massey University's Riverside Farm, near Masterton (New Zealand), compared the effect of poplar supplementation (*Populus deltoides x nigra*, clone Veronese), during mating, on ewe production and reproduction when grazing low quality drought pasture. A rotational grazing system with 300 mixed age Romney ewes (57.1 kg ± 0.68 kg) was used, with 100 ewes per treatment. All ewes were offered an allowance of low quality pasture sufficient to provide a potential desired intake of 0.70 kg dry matter (DM)/d. Pasture offered contained 84% dead matter, with pre- and post-grazing masses of 1040 and 531 kg DM/ha. Ewes were randomly allocated to 3 treatment groups, being: high supplementation, low supplementation and control. The high and low treatment groups were offered 1.50 kg/ewe/d (fresh) and 0.75 kg/ewe/d (fresh) poplar trimmings, respectively. The effect of poplar supplementation on liveweight (LW) and body condition score (BCS) change; reproductive rate at pregnancy scanning, lambing, docking and weaning; and wool production and staple length was measured. The poplar diet selected contained 22 g/kg DM of phenolic glycosides and higher levels of nitrogen (N; 28.4 vs. 17.8 g/kg DM) and condensed tannin (CT; 7.0 vs. 1.5 g/kg DM) and was of higher organic matter digestibility (0.66 vs. 0.52) than the pasture diet selected. Voluntary DM intake of poplar progressively increased with time of supplementary feeding for both treatments ($P<0.01$), due to increases in both DM content and the diameter of stem consumed. Reproductive rate was relatively low in the control ewes (121 lambs born / 100 ewes mated), and poplar supplementation increased ewe reproductive rate by approximately 20% units and 30% units for the low and high treatment groups, respectively, compared with the control group, at scanning, lambing, docking and weaning. The increase in reproductive rate in supplemented ewes was due to increases in both conception rate and fecundity, with a higher proportion of pregnant ewes, and a higher proportion of multiple pregnancies, in the supplemented groups. Ewes in the high and low treatments lost slightly less LW (-67 and -71 vs. -82 g/d; $P<0.05$) and BCS (-0.78 and -1.27 vs. -1.31 units; $P<0.05$) as a result of poplar supplementation, but these differences did not occur in the post-treatment period. There were no treatment effects on wool production or staple length, and only small treatment effects on the LW of single- and twin-born lambs at birth and weaning. Poplar trimmings are a beneficial supplement for increasing the reproductive rate of ewes grazing drought pasture during the pre-mating and mating periods. Poplar supplementation increased intakes of DM, metabolisable energy (ME) and crude protein (CP), and increased the estimated g CP/MJ ME eaten during the mating period. Increased concentrations of total N, CT and water-soluble carbohydrate (WSC) in the diet of supplemented ewes would also be likely to increase outputs of undegradable dietary protein and microbial protein from the rumen, per unit of CP consumed. A combination of these mechanisms, especially the likely increased absorption of protein, probably explains the increased ewe reproductive rate from poplar supplementation.

Keywords: Drought feeding; Poplar (*Populus* sp.) supplementation; Reproduction; Condensed tannins; Phenolic glycosides

2.2 Introduction

Drought is a major limiting factor to livestock production on many New Zealand pastoral farms, particularly in the dry East Coast regions of Gisborne, Hawkes Bay, Wairarapa, Marlborough, Canterbury, and North Otago. Severe summer/autumn droughts occur every 7 to 10 years in these regions, and climatic predications indicate that both the frequency and severity of droughts on New Zealand's East Coast will increase in the future (Salinger 2000). Therefore, drought management will become an increasingly important issue for farms in these regions.

The most significant effect of drought on pastoral farms is the loss in livestock production due to shortages in available fodder and reductions in feed quality. In sheep production systems losses in liveweight (LW) and body condition score (BCS), due to poor quality and inadequate levels of feeding during the pre-mating and mating periods, are detrimental to reproductive rate (Smith & Knight 1998). A low reproductive rate results in fewer lambs born and compromises farm financial returns. Ward (1999) estimated that the farm gate cost of the 1997/98 drought was $NZ 800 million for the effects not only on the 1997/98 financial year, but also losses in 1999 and 2000 due to follow-on effects.

There are several management strategies pastoral farmers can employ to decrease losses in a drought. They include flexible stock policies and feeding stored supplements, such as conserved forages, like silages and hay, or concentrates such as barley grain. Many East Coast hill country farms do not have enough flat land to grow their own silage or hay, and therefore must purchase supplements, which are often very expensive during a drought due to limited supplies. In some North Island East Coast regions, hill-country farmers prune the small stems and leaves of poplar (*Populus*) and willow *(Salix)* trees to create an inexpensive drought livestock feed. Poplar and willow trees have been extensively planted in New Zealand to control soil erosion on hill country pastoral farms (Wilkinson 1999) and it is estimated that 1.44 million willow and poplar trees are available as a source of supplementary fodder on the North Island East Coast (D.J. Cameron, 2002, personal communication). At 25 kg of edible forage per tree (P.D. Kemp, 2002, personal communication), this gives a biomass of 36,000 tonnes that could be used as supplementary feed in a drought. Poplar and willow tree fodder is superior in nutritive value to typical hill pastures in dry summers (Kemp *et al.* 2001). However, there is no scientific information available on the benefits of poplar or willow fodder supplementation on sheep production.

The objective of this study was to determine effects of different levels of poplar supplementation, during mating, on reproductive performance and wool production in ewes grazing low quality drought pasture.

2.3 Materials and Methods

2.3.1 Experimental Design

A grazing trial involving 300 mixed age Romney ewes was conducted at Massey University's Riverside Farm, near Masterton, New Zealand, on the North Island East Coast. Poplar supplementation occurred over 71 days from 1 February 2001 (late summer) to 12 April (autumn) 2001, including the mating period. The experiment involved ewes grazing simulated drought pastures with poplar limbs and leaves offered daily as supplementary feed. Ewes were randomly allocated to 3 treatment groups, each of 100 being: high supplementation, low supplementation and control. The high and low treatment groups were offered 1.50 kg/ewe/d and 0.75 kg/ewe/d, respectively, of fresh poplar as a supplement to the low quality pasture. The control group was offered no poplar. All ewes were offered a pasture allowance sufficient to provide a potential desired intake of 0.70 kg dry matter (DM)/d. Mating occurred over a 6-week period, although poplar was only fed during the first oestrus cycle. Poplar supplementation ceased after 27 days of mating due to the onset of early autumn leaf fall.

2.3.2 Animals

On 31 January 2001, Romney ewes of similar age, size and LW were randomly assigned to the three treatment groups and individually tagged, scored for body condition and weighed to ensure that the initial average LW of each group was consistent. All ewes were vaccinated with Salvexin^{TM} +B (Schering-Plough Animal Health Ltd., Upper Hutt, Wellington, New Zealand) before the experiment to prevent salmonella poisoning and Eweguard^{TM} (Fort Dodge New Zealand Ltd., Auckland, New Zealand), a combination 6-in-1 vaccine and anthelmintic drench, prior to lambing. During the mating period (March 15 to April 26), two Suffolk rams were run with each group of 100 ewes. Rams were randomly re-assigned to the groups every two weeks. This was done to ensure that a ram failure did not affect reproductive results. Following supplementation, the three treatment groups were joined and managed as one group until the conclusion of the trial on 30 Nov 2001. Pasture grazed by the experimental ewes after the supplementation period gradually increased in quantity and quality to reflect pasture availability after a summer/autumn drought; during winter and spring, pasture covers under set stocking were approximately 1000 and 1500 kg DM/ha, respectively, with an estimated organic matter digestibility (OMD) of approximately 0.8. Ewes were scanned for pregnancy using ultrasound on 11 June 2001 and non-pregnant ewes were sent to the abattoir. Ewes lambed between 8 August 2001 and 17 September 2001 and reproductive data was recorded at lambing. Lamb tails were removed with a searing iron (tail docking) on 24 September 2001 and lambs were separated from their mothers (weaned) on 19 November 2001. Ewes were shorn and wool production data was collected on 30 November 2001.

2.3.3 Forages

2.3.3.1 Pasture Management

Perennial ryegrass/white clover pasture, grown on very shallow, stony soil, was prepared to simulate drought conditions. This was achieved by allowing the ryegrass to mature and develop seed heads, thus decreasing the quality of the sward, and then grazing the experimental area with cows and non-experimental ewes to reduce pasture mass. This resulted in pasture that was high in dead matter content and low in nutritive value and pasture mass, typical of drought conditions.

Pasture was rotationally grazed in eight breaks, each lasting seven to ten days, using electric fencing. All treatment groups were moved to a new break on the same day. Total grazing days (TGD) was calculated for each break, using the following equation.

$$TGD = ((HM - 500) * PA) / (n * PI)$$

HM is herbage mass (kg DM/ha) before grazing, 500 refers to the post-grazing residual expected, PA is grazing area (ha), n is the number of ewes, and PI is potential desired intake/ewe/day (0.70 kg DM/ewe/day). 'Potential desired intake' is defined in this thesis as the amount of pasture estimated to be consumed by ewes in the experiment, provided that there are no nutritional, non-nutritional or anti-nutritional factors present that could affect intake. Pasture growth rate was assumed to be zero. This management system was intended to provide similar levels of intake for each treatment group. A potential dry matter intake of 0.70 kg DM/ewe/day is below maintenance energy level for ewes grazing low quality perennial ryegrass/white clover pasture, as would typically occur in a drought. A moveable water trough was available for each treatment group, with all ewes consuming water *ad libitum*.

Plate 2.1 Simulated drought pasture before grazing.

2.3.3.2 Poplar Supply

Material of hybrid poplar (*Populus deltoides* x *nigra*), clone Veronese, was delivered daily from Greater Wellington Regional Council's Akura Nursery, near Masterton. The small stems (basal diameter < 18 mm) of poplar were cut every three days from coppiced stools and stored in a room at 4°C to reduce dehydration and weight loss. The 150 kg and 75 kg of fresh poplar trimmings were weighed and fed daily to the high and low poplar groups, respectively. This was increased to 175 kg and 87.5 kg of poplar after four weeks, as consumption increased. Poplar stems were spread out in a large area, allowing access to the supplementary fodder by all ewes in each group.

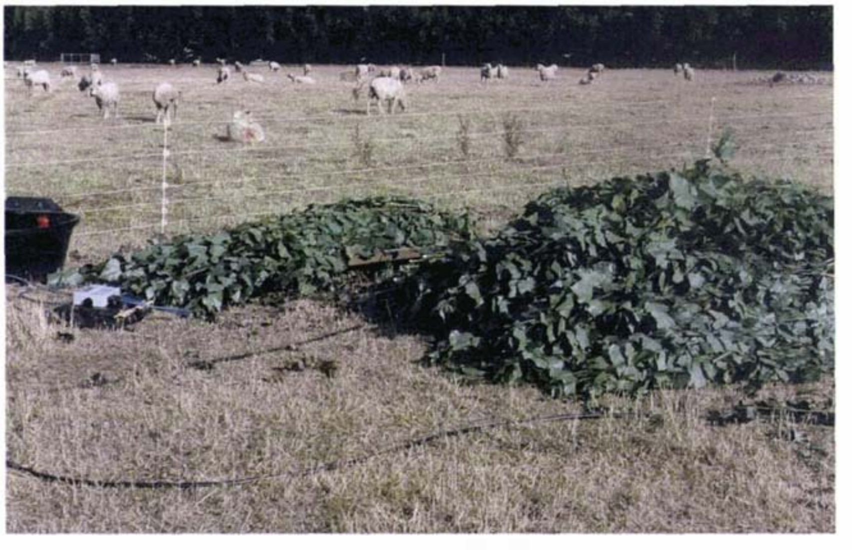

Plate 2.2 Small stems of poplar offered to ewes in the experiment.

Plate 2.3 Supplementation of ewes with poplar fodder.

2.3.4 Forage Measurements

2.3.4.1 Pasture

Pre- and post-grazing herbage mass was determined immediately before and after grazing each break respectively, by cutting eight random quadrats per treatment group per break to ground level, washing and then drying the herbage at 80°C for 18 to 24 hours. Six exclusion cages (approximately 1.4 x 0.9 m) were placed in each break before grazing. Hand-plucked diet selected samples were collected from the exclusion cages, after grazing, by simulating the diet actually consumed by the ewes. These samples were stored at -20°C for later nutritive value analysis. Samples for dead matter content of pasture offered were collected before grazing each break. Pasture dry matter intake (DMI) was calculated using the following equation (Walters & Evans 1979).

DMI (kg/ewe/day) = (Pre-grazing DM – Post-grazing DM) / (No. of ewes * Days)

This method for intake determination was used as the grazing intervals were short, approximately 7 days, and pasture growth was minimal due to very dry conditions and assumed to be zero. DMI determination for individual animals was not attempted due to the much greater resources required.

2.3.4.2 Poplar

The poplar fodder offered was weighed daily and samples were collected twice weekly to determine the DM content of feed offered. Poplar residue was collected and weighed after each break and samples taken to determine DM content. Thus, the total amount of poplar (kg DM) consumed could be calculated, for each treatment, per break. Diet selected samples were also pruned daily from the poplar fodder on offer at a diameter that was consistent with the diameter consumed by the ewes (5 to 7 mm). The daily samples were pooled for each break and stored at -20°C for later laboratory analysis. The diameter of poplar eaten was determined for the high and low treatment groups, at the end of grazing each break, by collecting 75 stems/treatment group and measuring the diameter eaten with electronic callipers (Mitutoyo Corp., Japan).

2.3.5 Animal Measurements

Mean initial LW and BCS was similar between the three treatment groups with the control, low and high groups weighing 56.4 kg, 57.6 kg, and 57.5 kg (s.e. 0.68), respectively, with body condition scores of 2.8, 2.8, and 2.7 (s.e. 0.07), for the three treatment groups. Ewes were weighed fortnightly using electronic scales (Tru-test, Auckland, New Zealand) during the period of poplar supplementation and body condition, scored from 1 to 5 (Jefferies 1961), was assessed monthly. Following the supplementation period, ewes were weighed and body condition scored monthly before lambing. After lambing, ewes were weighed monthly until the lambs were weaned. Reproductive data was collected during the lambing period, including lamb birth date, birth weight, birth rank and sex. Lamb weaning weights were recorded. Scanning, lambing, docking, and weaning percentages were calculated.

Ewe fleeces were weighed at shearing to determine the greasy fleece weight, with samples of 200 to 300 g collected from both the left and right mid-side areas for staple length (mm) measurements.

2.3.6 Laboratory Analyses

Poplar and pasture samples of diet selected were stored at -20°C, freeze-dried and ground to pass 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* OMD was determined by the enzymatic method of Roughan and Holland (1977), using separate standard curves prepared from *in vivo* values for forages and from poplar fed to sheep. Water-soluble carbohydrate (WSC) and pectin concentrations were determined by the method of Bailey (1967) and neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin by the detergent procedures of Robertson and Van Soest (1981) and Van Soest *et al.* (1991), with alpha amylase (BDH, Poole, UK) being added during NDF extraction. Sodium sulphite was not added. Hemicellulose was calculated as NDF-ADF and cellulose as ADF-lignin. All samples were analysed for acetone/water-extractable, protein-bound and fibre-bound condensed tannin (CT) fractions, using the butanol-HCL colorimetric procedure (Terrill *et al.* 1992); total CT concentration was then calculated by summing the three fractions. All CT concentrations were determined using CT extracted from *Lotus pedunculatus* as a reference standard (Jackson *et al.*, 1996). Pasture and poplar diet selected samples were analysed for zearalenone by the ELISA method, which detects total zearalenone (zearalenone plus α- and β-zearalenol; Towers 1997). Poplar diet selected samples were analysed for salicin and the concentration of other phenolic glycosides, using the high-performance liquid chromatographic procedure of Meier *et al.* (1988); the method also allowed measurement of catechin and epicatechin, other flavenoid monomers and chlorogenic acid.

2.3.7 Calculations and Data Analysis

The concentrations of metabolisable energy (ME) in the diets selected by the ewes were calculated as 16.3 x digestible OM/100g DM (DOMD) (Drew & Fennessy 1980). DOMD was measured by the *in vitro* digestibility assay.

The LW and BCS of ewes at different times were analysed using the MIXED procedure of SAS (2001). The model included the fixed effects of treatment (control, low poplar supplementation and high poplar supplementation), time and their interaction and the random effect of animals within treatments (Littell *et al.* 1998). Using the Akaike's information criterion, a compound symmetry error structure was determined as the most appropriate residual covariance structure for repeated measures over time within animals. Least squares means and their standard errors were obtained for each treatment for days 0, 8, 21, 36, 50, 64, 71, 85, 113, 148, 174, 259, and 292.

Differences in pregnancy rate between treatments were tested using PROC CATMOD of SAS (2001). Least-squares means for reproductive rate at scanning, lambing, docking and weaning were obtained for each treatment using PROC MIXED of SAS (2001). Reproductive performance was expressed as number of lambs born as a proportion of the number of ewes mated. PROC GENMOD was used to run a categorical analysis to compare the proportion of ewes bearing singles and multiples, assuming a binomial distribution with a logit transformation.

Lamb birth and weaning weights were analysed, using PROC MIXED of SAS (2001), with a linear model that included the effects of treatment, sex, birth rank and their interactions and lambing day as a covariable.

Regression equations for the percentage DM and total DMI of poplar fodder offered, the concentrations of NDF and CT of poplar fodder consumed, and the diameter of poplar branches eaten over time were estimated for each of the treatments using the GLM procedure in SAS (2001). Means and standard errors for each of the different variables describing chemical composition of the pasture selected in each of the treatments were obtained using the GLM procedure in SAS (2001).

2.4 Results

2.4.1 Forages

Pre- and post-grazing herbage mass and pasture dead matter content were generally similar for all groups (Table 2.1), with mean values of 1040 kg DM/ha, 531 kg DM/ha and 84%, respectively. Chemical composition of the pasture diet selected was similar for the three groups (Table 2.2) and was high in fibre and low in N and OMD, which is consistent with very low quality pasture in a drought (Tables 2.2 and 2.3).

Table 2.1 Pre-grazing and post-grazing mass (kg DM/ha) and dead matter content of drought pasture grazed during the experiment (mean values with standard errors)[1]

	Control	Low Poplar Supplementation	High Poplar Supplementation
Pasture mass (kg DM/ha)			
Pre-grazing	1034 ± 94.3	1044 ± 93.7	1042 ± 101.7
Post-grazing	533 ± 52.4	547 ± 39.9	512 ± 49.3
Pasture Utilisation (%)	48	48	51
Dead Matter Content (%)	83.2 ± 3.37	84.0 ± 3.04	84.9 ± 3.87

[1] n = 8 measurements per treatment

Table 2.2 Chemical composition and nutritive value of the pasture and poplar diet selected (g/kg DM) by ewes grazing low quality drought pastures when supplemented with no, low and high rates of poplar trimmings (mean values with standard errors)[1]

	Pasture*			Poplar**
	Control	Low Poplar Supplementation	High Poplar Supplementation	
Total N[2]	17.0 ± 1.88	18.3 ± 1.48	18.0 ± 1.79	28.4 ± 1.50
Organic Matter	894.9 ± 5.60	892.1 ± 4.48	892.5 ± 3.54	918.4 ± 3.0
OMD[3]	0.52 ± 0.006	0.53 ± 0.014	0.52 ± 0.005	0.66 ± 0.008
DOMD[4]	0.46 ± 0.005	0.47 ± 0.012	0.47 ± 0.005	0.60 ± 0.006
ME (MJ/kg DM)[5]	7.54 ± 0.089	7.69 ± 0.197	7.55 ± 0.089	9.72 ± 0.095

*Estimated from hand plucked samples of diet selected
**Estimated from hand cut samples (stem diameter<7mm) of diet selected
[1] n = 8 samples per treatment; [2] N = Nitrogen; [3] Organic matter digestibility *in vitro*; [4] Digestible organic matter in the dry matter *in vitro*; [5] ME = Metabolisable energy

DM % of the poplar offered increased ($P<0.001$) over time with a mean of 34.3% (Figure 2.1a). The poplar diet selected was relatively higher quality than the pasture diet selected, with an N content of 28.4 g/kg, OMD of 65.7% and a higher ratio of readily fermentable CHO to structural CHO, 0.68 vs. 0.21 (Tables 2.2 and 2.3). The NDF content of poplar diet selected increased ($P<0.01$) over time (Figure 2.1b) with a mean of 389.9 g/kg (Table 2.3).

Table 2.3 Carbohydrate and secondary compound content of the pasture and poplar diet selected (g/kg DM) by ewes grazing low quality drought pastures when supplemented with poplar trimmings (mean values with standard errors)

	Pasture*	**Poplar****
Carbohydrates		
Water Soluble CHO	113.1 ± 7.72	156.2 ± 4.96
Pectin	7.0 ± 0.79	33.3 ± 4.43
NDF[1]	622.5 ± 7.09	389.9 ± 14.14
ADF[2]	306.7 ± 4.14	261.6 ± 8.13
Ratio Readily Fermentable to Structural CHO	0.21 ± 0.011	0.68 ± 0.15
Secondary Compounds		
Lignin	39.8 ± 1.03	109.6 ± 8.62
Condensed tannin[4]	1.5 ± 0.12	7.0 ± 1.14
Catechin + Epicatechin	ND	0.74 ± 0.048
Other flavenoid monomers	ND	8.1 ± 0.41
Salicin	ND	3.2 ± 0.22
Other phenolic glycosides	ND	18.7 ± 0.68
Chlorogenic acid	ND	1.22 ± 0.089
Zearalenone (mg/kg)[5]	0.58 ± 0.255	0.24 ± 0.025

*Estimated from hand plucked samples of diet selected (n = 8 samples)
**Estimated from hand cut samples (stem diameter<7mm) of diet selected (n = 9 samples)
[1] NDF = neutral detergent fibre; [2] ADF = acid detergent fibre; [3] Water-soluble CHO + pectin / cellulose + hemicellulose; [4] Extractable CT + bound CT; [5] Probably produced by contaminating *Fusarium* fungi; ND = Not determined

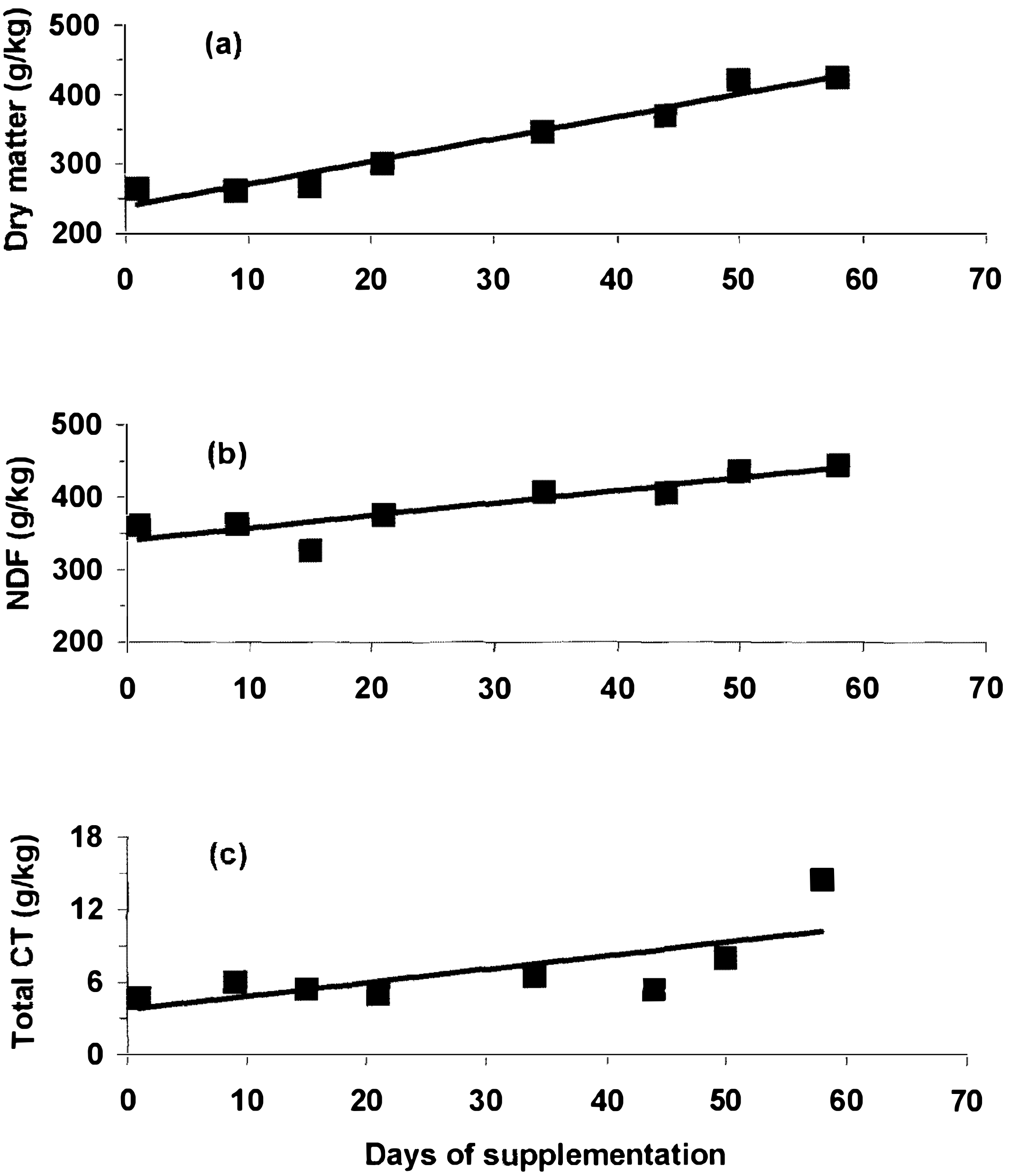

Figure 2.1 Change in the dry matter (DM; a) concentration of poplar offered and in the neutral detergent fibre (NDF; b) and condensed tannin (CT; c) concentrations of poplar diet selected during the experiment.

DM = 237.95 + 3.2427t
SE 10.219 0.2934
P *** ***

NDF = 339.61 + 1.7338t
SE 12.340 0.3543
P *** **

$$CT = 3.71 + 0.1118t$$
SE 1.553 0.0446
P 0.054 *

The poplar diet selected contained considerably higher concentrations of secondary compounds than the pasture diet selected, including that of lignin. The CT content of poplar was higher at 7 g/kg compared with 1.5 g/kg in pasture (Table 2.3) and increased ($P<0.05$) over time (Figure 2.1c). Laboratory analysis also showed substantial concentrations of salicin and other phenolic glycosides in the poplar diet (Table 2.3). Zearalenone concentrations were relatively lower in the poplar diet than the pasture diet, 0.24 vs. 0.58 mg/kg (Table 2.3).

Diameter (D, mm) of the poplar stem eaten increased ($P<0.01$) over the experimental period (t, days) for the low and high supplemented groups (Figure 2.2a), with the difference between regression intercepts being significant ($P<0.05$). Diameter means were 7.5 mm for the low and 7.4 mm for the high treatment groups. The DMI (kg) of poplar consumed/ewe/day also increased over the experimental period ($P<0.01$; Figure 2.2b; t, days) for both the low and high levels of supplementation, with mean values of 0.17 kg and 0.33 kg DM/ewe/day. The difference between the low and high regression slopes and intercepts were significant (Figure 2.2b; $P<0.05$). Poplar utilisation was 60% and 64% for the high and low treatments, respectively.

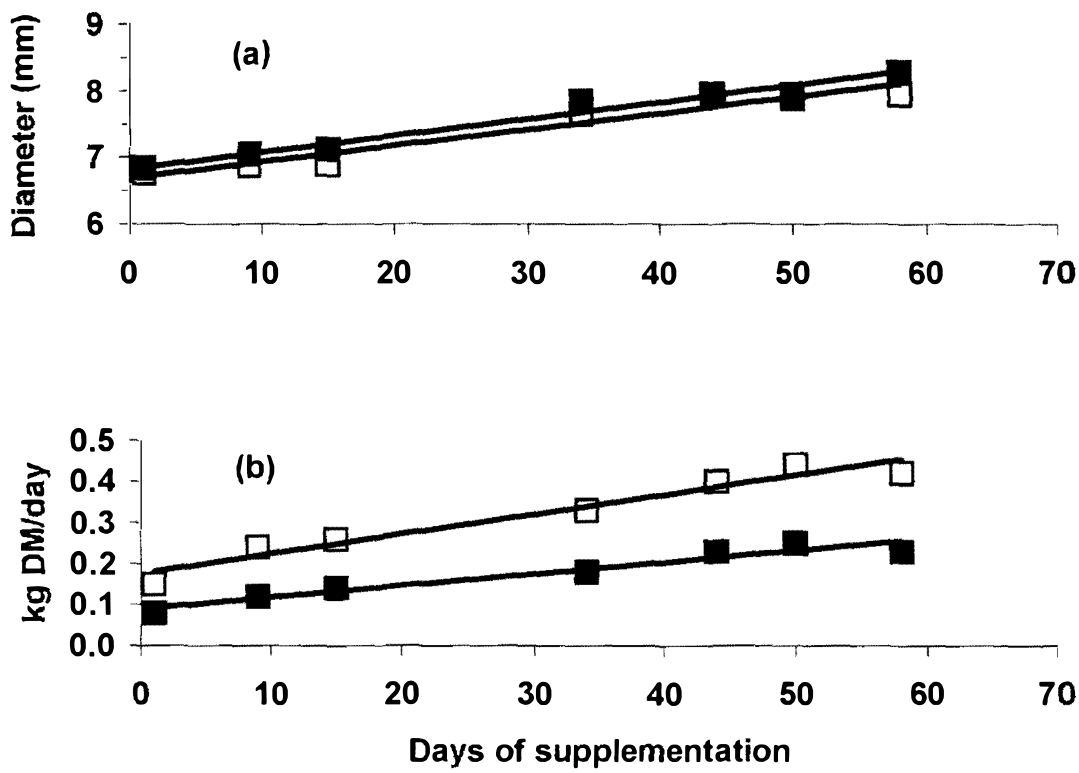

Figure 2.2 Change in the diameter consumed (D; a) and dry matter intake (DMI; b) of poplar tree fodder in ewes offered low and high amounts of poplar as a supplement to drought pasture. □ High; ■ Low

Low	D = 6.82 + 0.0252t		
	SE	0.083	0.0023
	P	***	***
High	D = 6.69 + 0.0243t		
	SE	0.083	0.0023
	P	***	***
Low	DMI = 0.09 + 0.0028t		
	SE	0.015	0.0004
	P	***	***
High	DMI = 0.18 + 0.0048t		
	SE	0.015	0.0006
	P	***	***

2.4.2 Animals

All groups of ewes lost LW and BCS during the 71-day supplementation period (Table 2.4), with the high level of poplar supplementation decreasing LW loss and loss in BCS by a small, but significant amount ($P<0.05$). Both LW and BCS increased after the groups were joined together at the end of the 71-day supplementation period (Figures 2.3a and 2.3b) and by the start of the lambing period there were no differences between the groups.

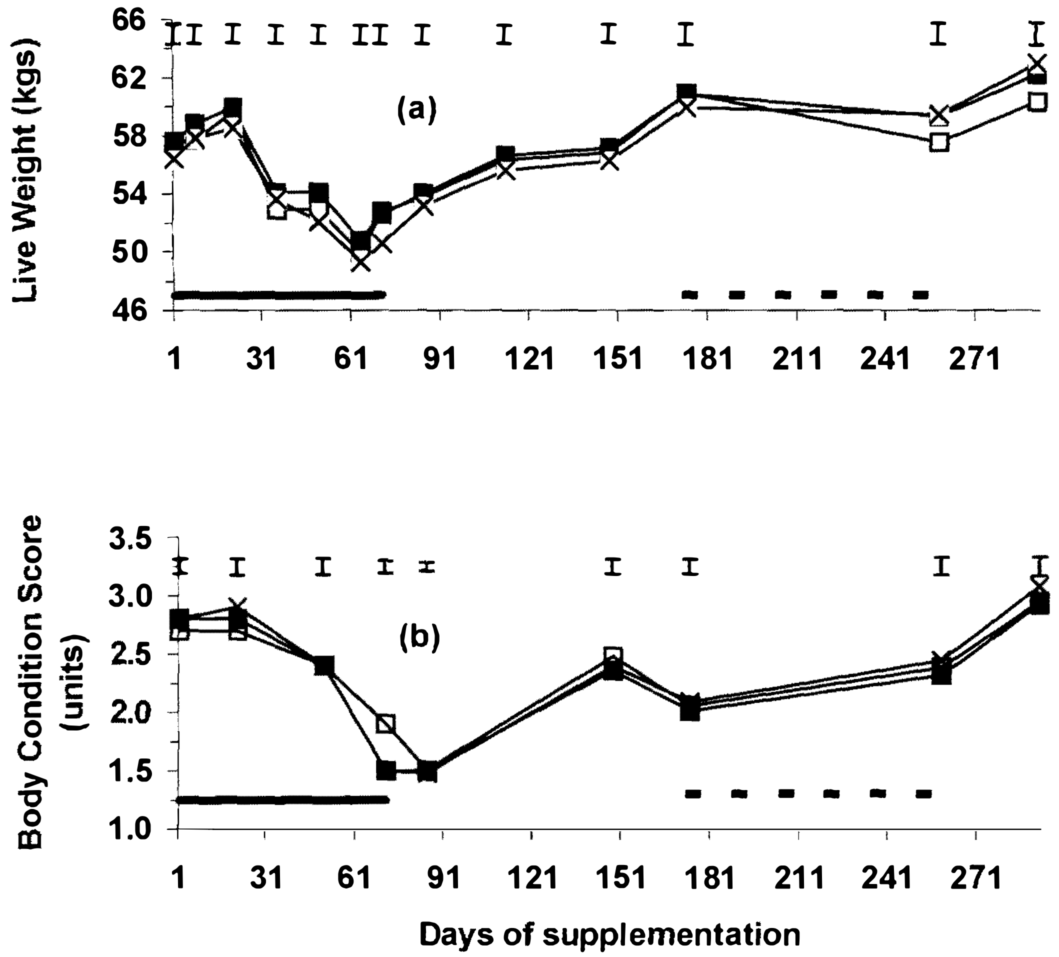

Figure 2.3 Change in mean ewe live weight (a) and body condition score (b) in ewes supplemented with no, low and high rates of poplar when grazing drought pasture. The solid line indicates the 71-day period of poplar supplementation. The broken line indicates period of lambing. □High; ■Low; × Control; I, Pooled SEM.

Ewe reproductive rate increased with both the high and low rates of poplar supplementation compared with the control. Scanning and actual lambing percentage was increased ($P<0.001$) in the high treatment group, with the increases being 41 and 34% units, respectively, relative to the control ewes (Table 2.4). The low poplar treatment increased ($P<0.01$) scanning percentage by 25% units and actual lambing percentage ($P< 0.05$) by 20% units, relative to the control. These treatment effects persisted to docking and weaning.

Table 2.4 Ewe live weight change (g/day) and body condition score change (units), during the 71-day period of poplar supplementation, and reproductive rate expressed as a percentage of the total number of ewes exposed to the ram (mean values with standard errors)[1]

	Control	Low Poplar Supplementation	High Poplar Supplementation
Change in Live weight (g/day)	$-82^{a} \pm 5.3$	$-71^{ab} \pm 5.3$	$-67^{b} \pm 5.2$
Change in BCS (units)	$-1.31^{a} \pm 0.046$	$-1.27^{a} \pm 0.046$	$-0.78^{b} \pm 0.046$
Reproductive rate			
Scanning	$122^{a} \pm 5.7$	$147^{b} \pm 5.8$	$163^{b} \pm 5.7$
Lambing	$121^{a} \pm 5.8$	$141^{b} \pm 5.9$	$155^{b} \pm 5.8$
Docking	$97^{a} \pm 6.4$	$113^{ab} \pm 6.5$	$127^{b} \pm 6.4$
Weaning	$96^{a} \pm 6.4$	$113^{ab} \pm 6.5$	$125^{b} \pm 6.4$

a,b. Means within rows with different superscripts differ significantly ($P<0.05$).
[1] n = 100 ewes per treatment

Table 2.5 shows that poplar supplementation increased reproductive rate through increasing both conception rate (ewes pregnant/100 ewes mated) and fecundity (lambs born/100 ewes lambing). Conception rate was higher for the high treatment group, compared with the control ($P<0.01$); 100% vs. 92.9% (Table 2.5). The proportion of ewes giving birth to multiple lambs was higher for both the high and low treatment groups, compared with the control ($P<0.05$; Table 2.5). Poplar treatment had a significant effect on mean lambing date ($P<0.05$), with ewes in the high treatment lambing four days earlier than control ewes ($P<0.01$; Table 2.5).

Table 2.5 The effect of supplementation with poplar trimmings for 71 days during the late summer/autumn, including mating, in ewes grazing drought pastures on conception rate, fecundity, mean lambing date and total lamb mortality from birth to weaning (mean values with standard errors). Lamb mortality data are presented as a percentage of the total number of lambs born for each treatment (proportions with standard errors)

	Control	Low Poplar Supplementation	High Poplar Supplementation
Conception rate*	$92.9^{b} \pm 1.89$	$95.8^{ab} \pm 1.92$	$100^{a} \pm 1.89$
Fecundity**			
Singles	69.2 ± 5.23^{a}	53.2 ± 5.61^{b}	47.2 ± 5.23^{b}
Multiples	30.8 ± 5.23^{a}	46.8 ± 5.61^{b}	$52.8 \pm 5.23b^{b}$
Mean lambing date	23 Aug$^{a} \pm 0.9$ d	21 Aug$^{ab} \pm 0.9$ d	19 Aug$^{b} \pm 0.9$ d
Total lamb mortality (%)	20.9 ± 3.79	19.7 ± 3.53	19.4 ± 3.30

a,b. Means within rows with different superscripts differ significantly ($P<0.05$)
*Expressed as ewes pregnant per 100 ewes mated.
**Expressed as lambs born per 100 ewes lambing.

There were only small treatment effects on birth weight ($P<0.01$) and weaning weight ($P=0.054$) of lambs (Table 2.6). In both cases, there were no effects on single-born lambs, although there were small effects on twinborn lambs. Twinborn ewe lambs tended ($P<0.05$) to be heavier at birth in the low supplemented group, compared with the control. The mean weaning weight of male twin lambs born to ewes supplemented with the low rate of poplar trimmings was lower ($P<0.05$) than those born to ewes in the control group, but there were no other effects on weaning weight.

Table 2.6 The effect of supplementation with poplar trimmings for 71 days during the late summer/autumn, including mating, in ewes grazing drought pastures on lamb birth and weaning weights, corrected for the small difference in the mean date of lambing (kilograms; mean values with standard errors)

			Control	Low Poplar Supplementation	High Poplar Supplementation
Birth Weight					
	Single				
		Male	6.0 ± 0.14	6.2 ± 0.15	6.1 ± 0.17
		Female	5.5 ± 0.14	5.7 ± 0.17	5.6 ± 0.16
	Twin				
		Male	5.2 ± 0.14^{a}	4.8 ± 0.11^{b}	4.8 ± 0.11^{b}
		Female	4.1 ± 0.15^{b}	4.6 ± 0.13^{a}	4.2 ± 0.11^{b}
Weaning Weight					
	Single				
		Male	34.5 ± 0.99	35.9 ± 1.06	34.0 ± 1.11
		Female	32.3 ± 0.99	32.2 ± 1.17	30.6 ± 1.14
	Twin				
		Male	31.6 ± 1.05^{a}	28.6 ± 0.86^{b}	29.6 ± 0.82
		Female	27.9 ± 1.17	26.7 ± 0.94	25.2 ± 0.78

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

2.4.3 Wool

Greasy fleece weight and staple length were generally similar for all groups and there were no effects due to poplar supplementation (Table 2.7).

Table 2.7 The effect of supplementation with poplar trimmings for 71 days during the late summer/autumn, including mating, in ewes grazing drought pastures on whole-year wool production and staple length (mean values with standard errors)

	Control	Low Poplar Supplementation	High Poplar Supplementation
Greasy Fleece Weight (kg)			
Single bearing ewes	3.0 ± 0.06	3.0 ± 0.08	3.1 ± 0.07
Twin bearing ewes	2.9 ± 0.09	3.1 ± 0.08	3.0 ± 0.06
Average for all ewes	3.0 ± 0.05	3.0 ± 0.06	3.0 ± 0.05
Staple Length (mm)			
Single bearing ewes	130 ± 2.3	133 ± 2.3	130 ± 2.8
Twin bearing ewes	129 ± 3.4	137 ± 2.5	133 ± 2.7
Average for all ewes	130 ± 2.1	135 ± 1.7	132 ± 2.0

2.5 Discussion

The increase in reproductive rate in ewes supplemented with poplar trimmings was due to increases in both conception rate and fecundity, with a higher proportion of pregnant ewes and a higher proportion of multiple pregnancies in supplemented groups. One mechanism to explain the increase in reproductive rate and reduction in LW loss in ewes supplemented with poplar trimmings is a simple increase in DM and ME consumed, with the control, low and high groups consuming 0.67, 0.87 and 1.03 kg total DM/ewe/day and 5.1, 7.0 and 8.5 MJ total ME/ewe/day, respectively (Table 2.8). It is generally accepted that increases in levels of nutrient intake for 6 weeks in the pre-mating period increase ewe LW and ovulation rate, which is reflected in increases in lambing percentage (Rattray *et al.* 1981; Smith *et al.* 1983; Smith 1985; Smith & Knight 1998). Smith (1985) found that as digestible energy intake increases, the percentage of ewes with multiple ovulations increases at about 1.5% for each additional MJ of digestible energy consumed. However, increases in reproductive rate found in the present experiment were much higher relative to the increases in DM and ME intake of the groups supplemented with poplar trimmings.

The increase in reproductive rate from poplar supplementation was also much greater than the difference in LW change between groups. Similar findings by Smith *et al.* (1983) showed level of feeding effects on ewe ovulation rate over and above those associated with LW change. These researchers concluded that ovulation rate was a more sensitive indicator of nutritional changes than LW because response times for LW changes are too slow to correlate with the very rapid changes that occur in the reproductive mechanisms controlling ovulation rate (Smith *et al.* 1983). The greater increase in reproductive rate, relative to LW change and DM and ME intakes, in the current study suggest that the higher energy intake with poplar supplementation did not account for all of the increase in reproductive rate.

Table 2.8 The effect of supplementation with poplar trimmings for 71 days during the late summer/autumn, including mating, in ewes grazing drought pastures on calculated dry matter intake (kg DM/ewe/day), calculated metabolisable energy (ME) intake (MJ ME/ewe/day), calculated crude protein (CP) intake (g/ewe/day) and calculated zearalenone intake (mg/day; mean values with standard errors)

	Control	Low Poplar Supplementation	High Poplar Supplementation
DM Intake			
Pasture[1]	0.67 ± 0.138	0.69 ± 0.147	0.70 ± 0.148
Poplar	0	0.18 ± 0.021	0.33 ± 0.036
Total	0.67 ± 0.138	0.87 ± 0.135	1.03 ± 0.128
ME Intake[2]			
Pasture	5.1 ± 1.05	5.2 ± 1.12	5.3 ± 1.12
Poplar	0	1.8 ± 0.21	3.2 ± 0.37
Total	5.1 ± 1.05	7.0 ± 1.00	8.5 ± 0.94
CP Intake[3]			
Pre-mating Period			
Pasture	80.5 ± 10.82	88.5 ± 7.38	89.1 ± 10.16
Poplar	0	23.2 ± 3.04	44.7 ± 5.88
Total	80.5 ± 10.82	111.7 ± 4.99	133.8 ± 4.92
Proportion intake from poplar	0	0.21	0.33
Mating Period			
Pasture	61.5 ± 10.58	70.0 ± 8.82	68.6 ± 10.69
Poplar	0	34.8 ± 2.03	61.9 ± 3.22
Total	61.5 ± 10.58	104.8 ± 6.93	130.5 ± 7.64
Proportion intake from poplar	0	0.33	0.47
g CP Intake / MJ ME Intake			
Pre-mating	15.8 ± 2.13	16.0 ± 0.72	15.7 ± 0.58
Mating	12.1 ± 2.08	15.1 ± 1.00	15.3 ± 0.90
Zearalenone Intake			
Pasture	0.39	0.40	0.41
Poplar	0	0.04 ± 0.008	0.08 ± 0.015
Total	0.39	0.44	0.49

[1] Estimated from pasture mass measurements before and after grazing; [2] DM intake * mean ME concentration in MJ/kg DM; [3] DM intake * CP concentration in g/kg DM

It is likely that poplar supplementation increased the amount of protein absorbed by the ewes, due to increased rumen outflow of both undegraded dietary protein and microbial protein. The higher total N and CT content of poplar tree fodder, relative to pasture, could have increased the supply of rumen undegradable dietary protein, since previous studies have shown that lower levels of ruminal N degradation may be a factor in the increases in ovulation rate and fecundity found in ewes fed lupin grain as a supplement during the pre-mating and mating periods (Knight *et al.* 1975). The findings by Knight *et al.* were consistent with Thompson *et al.* (1973) who showed that increased intakes of dietary N in the form of urea failed to increase ovulation rates. CT increases protein absorption and utilisation by binding strongly to proteins to form a pH-dependent complex, which is not degradable at rumen pH (6.0 to 7.0), but disassociates at abomasal pH (2.5 to 3.5) and so can be absorbed from the small intestine (Barry & McNabb 1999). The increased total N content of poplar, including rumen degradable N, plus the higher source of available energy as WSC, is likely to have increased microbial protein production. Barry & McNabb (1999) stated that only about 75% of N intake from temperate forages, such as perennial ryegrass and white clover, leaves the rumen as protein-N, with the balance absorbed as NH_3. Therefore it is likely that the ewes supplemented with poplar trimmings would utilise a much greater percentage of the limited amount of N consumed, and have a greater rumen outflow of undegraded and microbial proteins per unit of N consumed, due to increased dietary concentration of total N, CT and WSC, than ewes grazing drought pasture alone.

Protein is a critical component of the reproductive response of ewes to supplementary feeding. Studies have found responses to increased protein intake of feeds that contain low and moderate energy levels (Smith 1985). Smith (1985) reported a threshold intake level of 125 g protein/ewe/day necessary to achieve an increase in ovulation rate, with marked increases at levels above 125 g protein/ewe/day. In the present work, the calculated CP intake during the flushing and mating periods, of the control ewes were well below this figure, while calculated CP intakes of the poplar supplemented ewes approached or exceeded this figure (Table 2.8). However, it is notable that these figures are calculated CP intakes and that the amount of protein actually absorbed by the small intestine is likely to be proportionally greater for the treatment groups, vs. the control group, because of the likely increased flow of undegraded dietary and microbial protein to the small intestine per unit of CP consumed. Table 2.8 shows that during the flushing period, CP intake (g) relative to ME intake (MJ) was similar for the three groups. However, during the mating period, ewes supplemented with poplar trimmings had a much higher proportional increase in CP intake than in ME intake due to the increase in the amount of poplar consumed with time. The increase in ME and CP intakes, during the flushing and mating periods, and the increase in CP intake relative to ME intake, during the mating period, could all be involved in explaining the increased reproductive performance of poplar-supplemented ewes. Studies by Min *et al.* (1999 & 2001), with ewes grazing CT-containing *Lotus corniculatus* vs. ewes grazing perennial ryegrass/white clover pasture, during the pre-mating and mating periods, found increases in reproductive rate of 20 to 30% due to the protein binding action of CT.

Poplar trees are known to contain significant concentrations of the secondary compound salicin, and other phenolic glycosides, which may be a factor in the increase in reproductive rate in ewes supplemented with poplar tree trimmings. The chemical structure of phenolic glycosides includes one molecule of glucose and it can be calculated that 100g of phenolic glycoside will release 63g of glucose upon hydrolysis. The salicin and other phenolic glycoside content of the poplar consumed by ewes in this trial therefore contributed 13.8 g/kg, or 9 % of the total water-soluble CHO content of the poplar diet.

Zearalenone is a mycotoxin produced by *Fusarium* species, commonly found in New Zealand pasture, which reduces ovulation rate in sheep if daily intakes exceed 1mg/kg DM (Towers 1997). Fungal growth is highest during the ewe-mating period in February, March and April, and can reduce ovulation rate and subsequent lambing percentages by 10 to 25%. Total calculated zearalenone intakes of all three groups in this study were 0.4 to 0.5 mg/day (Table 2.8), making it unlikely that pasture zearalenone concentration affected ewe reproduction.

Pasture consumed in this experiment was typical of East Coast pastures affected by a summer/autumn drought. Initial and post-grazing pasture masses were very low and the pasture contained a large percentage of dead matter (>50%). Therefore, pasture diet selected was low in total N and OMD and very high in fibre. The poplar diet selected was superior in nutritive value to pasture diet selected, being higher in N and ME, with 14% more digestible OMD. Nutritive values for the poplar diet selected in this experiment were very similar to those obtained by Kemp *et al.* (2001) and Smith (1992) for Veronese poplar trimmings (i.e., leaves and stems less than 5 mm).

The poplar diet selected from the poplar fodder offered was mostly leaves and soft stem less than 7 mm in diameter. The poplar trimmings were consumed at the rate of 0.33 kg DM/day for the high and 0.17 kg DM/day for the low treatments, although an initial period was required for the ewes to adjust to the feed. This led to a gradual increase in intake of the high treatment from 0.15 kg DM/ewe/day in February to 0.42 kg DM/ewe/day in April. Increases in both the diameter of the poplar consumed and the DM% of the poplar trimmings with time contributed to the trend of increased poplar DM consumed/day with time. The gradual increase in consumption of tree fodder with time is consistent with Moore *et al.* (2003) in a similar experiment where willow trimmings were fed to beef cattle as a supplement to drought pasture. Moore *et al.* (2003) also found that cattle consumed an increasing stem diameter of willow, similar to the findings in the present experiment. The feeding levels of the two groups may explain the low treatment group ewes eating the stem to a slightly greater diameter than the high treatment.

2.6 Conclusion

The objective of this study was to determine whole-year production and reproduction responses to the supplementation of ewes with poplar trimmings, during mating, when grazing low quality drought pasture under dry East Coast conditions. Supplementation with poplar trimmings produced a large increase in reproductive performance, a small and transient reduction in rate of LW loss and no effect on wool production. Since there were only very small supplementation effects on the weight of single- or twin-born lambs at birth and weaning, the sole economic benefit of supplementation was due to an increase in the number of lambs born per ewe. This is reflected in the high and low supplemented ewes weaning 22% and 14% more lamb LW/ewe, respectively, compared with the unsupplemented ewes.

Results show that poplar trimmings are a beneficial feed supplement right up to the time of leaf senescence, to ewes grazing drought pasture during mating, and it is clear that there may be more than one mechanism for explaining the increase in reproductive rate. However, further research is needed to establish the mechanisms involved in the large increase in reproductive rate as a result of a relatively small quantity of poplar tree fodder consumed. Research on the production and reproduction effects of poplar vs. willow supplementation in livestock is also needed. The minimum length of feeding necessary to achieve the high productive and reproductive performance in the present investigation is also an area for further investigation.

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CHAPTER 3

2002 GRAZING EXPERIMENT

Effects of willow (*Salix spp.*) versus poplar (*Populus spp.*) supplementation on the reproductive performance of ewes grazing low quality drought pasture during mating

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3.1 Abstract

An 87-day grazing experiment, in the late summer/autumn of 2002 near Masterton (New Zealand), compared the effects of willow (*Salix*) versus poplar (*Populus*) supplementation (1.3 kg fresh/ewe/day), during mating, on reproductive performance and wool production in ewes grazing low quality drought pasture. A rotational grazing system with 285 mixed age Romney ewes (55.2 kg ± 0.54 kg) was used, with 95 ewes per treatment (control, willow supplemented and poplar supplemented). All ewes were offered an allowance of low quality pasture sufficient to provide a potential desired intake of 0.70 kg dry matter (DM)/d. Pasture offered contained 62% dead matter, with pre- and post-grazing masses of 941 kg and 456 kg DM/ha. Pasture consumed was typical of drought pasture; 571 g neutral detergent fibre (NDF)/kg DM, 0.540 organic matter digestibility (OMD). Both the willow and poplar diets selected were higher in OMD and metabolisable energy (ME) and had a higher ratio of readily fermentable carbohydrate (CHO) to structural CHO, than the pasture diet selected. Willow contained significantly higher concentrations of condensed tannin (CT; 52 g/kg vs. 19 g/kg; P<0.001) and total phenolic glycosides (34 g/kg vs. 17 g/kg; P<0.001) than poplar. The concentration of total phenolic glycosides increased curvilinearly over time with peak values between 51 and 61 days, corresponding to the mating period. Reproductive rate was low in the control ewes (133 lambs born / 100 ewes mated), with willow supplementation reducing live weight loss (-86 g/day vs. –103 g/day) and increasing ewe reproductive rate by 15%, 17%, 21% and 20% units at ultrasound scanning, lambing, docking and weaning, respectively, through an increase in the proportion of multiple pregnancies (fecundity). Poplar supplementation had no significant affect on reproductive rate, probably due to contamination with poplar leaf rust (*Melampsora larici-populina*), which may produce an unknown oestrogenic substance. There were no treatment effects on wool production and only small treatment effects on the LW of single- and twin-born lambs at birth and weaning. Willow tree trimmings are a beneficial supplement for increasing the reproductive rate of ewes grazing drought pasture during the pre-mating and mating periods and they may be superior to poplar tree trimmings, due to higher concentrations of both CT and phenolic glycosides. Willow supplementation increased the intakes of DM and ME, but this did not explain all of the increase in reproductive rate. The increased

concentration of total N, CT, phenolic glycosides and water-soluble CHO in the diet of supplemented ewes would be likely to increase amino acid absorption and this may explain the remainder of the increase in ewe reproductive rate from willow supplementation.

Keywords: Drought feeding; Poplar (*Populus* sp.) supplementation; Reproduction; Condensed tannin; Phenolic glycoside; Willow (*Salix* sp.) supplementation

3.2 Introduction

In New Zealand, the East Coast regions of Gisborne, Hawke's Bay, Wairarapa, Marlborough, Canterbury, and North Otago experience intensely hot, dry conditions during the summer and early autumn, with severe droughts occurring every 7-10 years. The loss in livestock productivity on pastoral farms, due to drought, lead to large losses in farm revenue; Ward (1999) estimated that the farm gate cost of the 1997 and 1998 droughts totalled $NZ 800 million.

Drought in the summer/autumn severely affects sheep production systems due to low pasture growth and quality, thus limiting the feed available for grazing ewes during the pre-mating and mating periods. Feeding ewes at a level below maintenance results in loss of live weight (LW) and body condition score (BCS) and, during mating, severely reduces ovulation rate and subsequent lambing percentage (Rattray *et al.* 1980, 1981, 1983; Smith & Knight 1998).

A recent study has shown that poplar tree trimmings are a beneficial supplement to sheep grazing drought pastures during the pre-mating and mating periods (McWilliam *et al.* 2004). The authors found that feeding poplar trimmings to ewes at the rate of 1.50 kg/ewe/day for 71 days, including mating, increased reproductive rate by approximately 30% and significantly reduced LW loss. Studies by Kemp *et al.* (2001), Douglas *et al.* (1996), Oppong *et al.* (1996) and McCabe & Barry (1988) have reported the nutritive value of willow trees (spp. *Salix*) and Moore *et al.* (2003) evaluated production responses to willow supplementation in cattle grazing drought pasture.

However, there are no reports on the potential benefits of supplementing ewes with willow tree trimmings and no direct comparisons of the feeding benefits of willow versus poplar supplementation.

The objective of this study was to compare the effects of willow versus poplar supplementation, during mating, on reproductive performance and wool production in ewes grazing low quality drought pasture.

3.3 Materials and Methods

3.3.1 Experimental Design

A grazing trial involving 285 mixed age Romney ewes was conducted at Massey University's Riverside Farm, near Masterton, New Zealand, on the North Island East Coast. Willow and poplar supplementation occurred over 87 days from 21 January 2002 (late summer) to 17 April (autumn) 2002. The experiment involved ewes grazing simulated drought pasture, of low quality and mass/ha, with poplar and willow limbs and leaves offered daily as supplementary feed. The ewes were randomly allocated to 3 groups, each of 95; willow supplementation, poplar supplementation and control. The willow and poplar treatment groups were offered 1.3 kg/ewe/day (fresh) of willow or poplar as a supplement to the low quality pasture. The control group was offered no tree trimmings. All ewes were offered a pasture allowance sufficient to provide a potential desired intake of 0.70 kg dry matter (DM)/d. The supplementation period included two 3-week cycles of mating.

3.3.2 Animals

On 17 January 2002, Romney ewes of similar age, size and LW were randomly assigned to the three treatment groups and individually tagged, scored for body condition (Jefferies 1961) and weighed to ensure that the initial average LW of each group was consistent. All ewes were vaccinated with, Salvexin™ +B (Schering-Plough Animal Health Ltd., Upper Hutt, Wellington, New Zealand), before the experiment to prevent salmonella infection and Ewegaurd™ (Fort Dodge New Zealand Ltd., Auckland, New Zealand), a combination 6-in-1 vaccine and anthelmintic drench, prior to lambing. From 8 March to 19 April, two Suffolk rams were run with each group of 95 ewes, the rams being randomly reassigned to the groups every two weeks to ensure that a ram failure did not affect reproductive results. Following supplementation and mating, the three groups were managed as one group until the conclusion of the trial on 19 December 2002. Pasture grazed by the experimental ewes after the supplementation period gradually increased in quantity and quality to reflect pasture availability after a summer/autumn drought; during winter and spring, pasture covers under set stocking were approximately 1000 and 1500 kg DM/ha, respectively, with an estimated organic matter digestibility (OMD) of approximately 0.8. Ewes were scanned for pregnancy using ultrasound on 2 July and non-pregnant ewes were culled. Ewes lambed between 5 August and 13 September and reproductive data was recorded at lambing. Lamb tails were removed with a searing iron (tail docking) on 26 September and weaned on 21 November. Ewes were shorn and wool production data was collected on 12 December.

3.3.3 Forages

3.3.3.1 Pasture Management

Perennial ryegrass/white clover pasture, grown on very shallow, stony soil, was prepared to simulate drought conditions. This was achieved by allowing the ryegrass to mature and develop seed heads, thus decreasing the quality of the sward, and then grazing the experimental area with cows and non-experimental ewes to reduce pasture mass. This resulted in pasture that was low in nutritive value, high in dead matter and low in pasture mass, as is typical of drought feeding conditions.

Pasture was rotationally grazed in ten breaks, each lasting 7 to 14 days, using electric fencing. All treatment groups were moved to a new break on the same day. Total grazing days (TGD) was calculated for each break, as:

$$TGD = ((HM-500) * PA) / (n * PI)$$

where: HM is initial pasture mass (kg DM/ha), PA is grazing area (ha), n is the number of animals, and PI is potential desired intake/ewe/day (0.70 kg DM/ewe/day). In the above equation, 500 is the expected post-grazing residue; the initial pasture mass must be subtracted by the expected post-grazing residue to determine the amount of edible forage available. This management system was intended to provide similar intake levels for each treatment group, approximately 0.70 kg DM/ewe/day. Further details of the method used can be found in Chapter 2.

A moveable water trough was available for each treatment group, with all ewes consuming water *ad libitum*.

3.3.3.2 Poplar and Willow Supply

Willow and poplar trimmings were delivered daily from Greater Wellington Regional Council's Akura Nursery, near Masterton. The small stems (basal diameter < 15 mm) of willow and poplar were cut every 3 days from coppiced stools, with the different fodders bundled separately, and stored at 4° C to reduce dehydration and weight loss. Each bundle of approximately 128 kg (fresh) willow and poplar tree fodder was weighed and fed daily to the willow and poplar treatment groups, respectively. Material from the poplar cultivars Veronese, Toa, Tasman, Weraiti, and Otahoua and material from the willow cultivars Tangoio and Moutere were each used on a 2-day rotation. Poplar and willow stems were spread out in a line, allowing access to the supplementary fodder by all ewes in each group.

Plate 3.1 Willow tree trimmings offered to grazing ewes.

Plate 3.2 Poplar tree trimmings offered to grazing ewes.

3.3.4 Forage Measurements

3.3.4.1 Pasture

Pre- and post-grazing herbage mass was determined immediately before and after grazing each break, by cutting eight random quadrats, per treatment group per break, to ground level, washing and then drying at 80° C for 18 to 24 hours. Six exclusion cages (approximately 1.4 x 0.9 m) were placed in each break before grazing. Diet selected samples were hand-plucked from the exclusion cages, after grazing, to simulate the pasture diet consumed by the ewes. These samples were stored at -20° C for later nutritive value analysis of diet selected. Samples for dead matter content of pasture offered were collected before grazing each break. Pasture dry matter (DM) intake was calculated using the method (Walters & Evans 1979) described in Chapter 2.

3.3.4.2 Poplar and Willow

The willow and poplar fodder offered was weighed daily and two samples per species per week were collected to determine the DM content of the feed offered. The willow and poplar residue was collected and weighed after each break and samples taken to determine DM content. Thus, the total amount of willow and poplar (kg DM) consumed could be calculated for each treatment for each break. Diet selected samples for each treatment were also pruned daily from the willow and poplar fodder on offer at a diameter that was consistent with the diameter consumed by the ewes; 3 to 5 mm for willow and 5 to 7 mm for poplar. The daily samples were pooled for each treatment for each break and stored at -20° C for later laboratory analysis. The diameter of willow and poplar eaten was determined for each treatment group, at the end of grazing each break, by collecting 75 stems/treatment group and measuring the diameter eaten with electronic callipers (Mitutoyo Corp., Japan).

3.3.5 Animal Measurements

Mean initial ewe LW and BCS was similar between the three groups with the control, poplar and willow groups weighing 55.2, 55.6 and 54.9 kgs (± 0.54) and BCS of 2.6, 2.6, and 2.7 units (± 0.06), respectively. Ewes were weighed fortnightly during the period of supplementation and body condition scored from 1 to 5 monthly (Jefferies 1961). Following the supplementation period ewes were weighed and body condition scored monthly, except during the lambing period, until shearing in December. Reproductive data was collected during the lambing period, including lamb birth date, birth weight, birth rank and sex. Lamb weaning weights were recorded.

Ewe fleeces were weighed at shearing to determine the greasy fleece weight, with samples of 200 to 300 g collected from both the left and right mid-side areas for staple length (mm) measurements.

3.3.6 Laboratory Analysis

Willow, poplar and pasture samples of diet selected were stored at -20°C, freeze-dried and ground to pass 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 from poplar/willow fed to sheep. Water-soluble carbohydrate (WSC) and pectin concentrations were determined by the method of Bailey (1967) and neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin by the detergent procedures of Robertson and Van Soest (1981) and Van Soest *et al.* (1991), with alpha amylase (BDH, Poole, UK) being added during NDF extraction (expressed with residual ash). Sodium sulphite was not added to the ND. Hemicellulose was calculated as NDF minus ADF and cellulose as ADF minus lignin. Willow and poplar samples were analysed for acetone/water-extractable, protein-bound and fibre-bound condensed tannin (CT) fractions, using the butanol-HCL colorimetric procedure (Terrill *et al.* 1992); total CT concentration was then calculated by summing the three fractions. All CT concentrations were determined using CT extracted from *Lotus pedunculatus* as a reference standard (Jackson *et al.*, 1996). Pasture, willow and poplar diet selected samples were analysed for zearalenone by enzyme linked immunosorbent assay (ELISA), which detects total zearalenone (zearalenone plus α- and β-zearalenol; Towers 1997). Willow and poplar diet selected samples were analysed for salicin and the concentration of other phenolic glycosides, using the high-performance liquid chromatographic procedure of Meier *et al.* (1988); the method also allowed measurement of catechin and epicatechin, other flavenoid monomers and chlorogenic acid.

3.3.7 Calculations and Data Analysis

The concentration of metabolisable energy (ME; MJ/kg DM) in the diets selected by the ewes were calculated as 16.3 x digestible OM / 100g DM (DOMD; Drew & Fennessy 1980). DOMD (g/100g DM) was measured by the *in vitro* digestibility assay.

LW and BCS of the ewes over the experimental period were analysed using the MIXED procedure of SAS (2001). The model included the fixed effects of treatment (control, willow supplementation and poplar supplementation), time and their interaction and the random effect of animals within treatments (Littell *et al.* 1998). Using the Akaike's information criterion, a compound symmetry error structure was determined as the most appropriate residual covariance structure for repeated measures over time within animals. Least squares means and their standard errors were obtained for each treatment for days 0, 9, 23, 37, 52, 65, 80, 108, 142, 176, 247, 296, and 324.

Differences in pregnancy rate between treatments were tested using PROC CATMOD of SAS (2001). Least-squares means for reproductive rate at scanning, lambing, docking and weaning were obtained for each treatment using PROC MIXED of SAS (2001). Reproductive performance was expressed as number of lambs born as a proportion of the number of ewes mated. PROC GENMOD was used to run a categorical analysis to compare the proportion of ewes bearing singles and multiples, assuming a binomial distribution with a logit transformation. Lamb birth and weaning weights were analysed using PROC MIXED of SAS (2001), with a linear model that included the effects of treatment, sex, and birth rank and their interactions as covariables; lambing day was not included as a covariable as lamb birth dates did not differ (P>0.05).

Means and standard errors for each of the different variables describing chemical composition of the pasture selected in each of the treatments were obtained, using the GLM procedure in SAS (2001), by fitting a linear model that considered the fixed effect of treatment. Regression equations for the DM content of willow and poplar fodder offered, the concentrations of N and total phenolic glycosides in willow and poplar fodder consumed, the concentrations of CT and lignin in willow consumed, and the diameter of willow and poplar branches eaten over time were estimated for each of the treatments, using the GLM procedure in SAS (2001), by fitting a linear model that considered the intercept and the linear effect of day. The estimates of parameters of the regression lines were tested to establish if they differed from zero. Contrasts between estimates of the regression lines for each of the treatments were performed to test if the slopes and intercepts for the willow and poplar regressions differed.

3.4 Results

3.4.1 Forages

Pre- and post-grazing herbage mass and pasture dead matter content were generally similar for all groups (Table 3.1), with mean values of 941 kg DM/ha, 456 kg DM/ha and 62%, respectively. Chemical composition of the pasture diet selected was similar for the three groups (Table 3.1). Therefore, treatment effects established in this paper are due to supplementation with tree fodder and are not confounded by differences in pasture mass or composition in the areas allocated to the three groups.

Table 3.1 Herbage mass and dead matter content of drought pasture grazed during the experiment and chemical composition and nutritive value of the pasture diet selected (mean values with standard errors)

	Control	Poplar Supplementation	Willow Supplementation
Pasture Mass (kg DM/ha)[1]			
Pre-grazing	909 ± 86.9	959 ± 72.2	954 ± 61.0
Post-grazing	420 ± 45.4	497 ± 47.6	450 ± 34.7
Pasture Utilisation (%)	54	48	53
Dead Matter Content (%)[1]	62.4 ± 2.34	61.2 ± 2.60	63.7 ± 3.52
Chemical Composition:[2]			
Total N[3] (g/kg DM)	24.5 ± 2.03	25.2 ± 1.78	25.1 ± 2.55
Organic Matter	872.3 ± 7.95	859.6 ± 17.60	876.0 ± 11.82
OMD[4]	0.53 ± 0.013	0.55 ± 0.012	0.54 ± 0.018
DOMD[5]	0.46 ± 0.009	0.48 ± 0.007	0.48 ± 0.013
ME (MJ/kg DM)[6]	7.5 ± 0.15	7.8 ± 0.12	7.8 ± 0.20

[1] n = 10 measurements per treatment; [2] Estimated from hand plucked samples of diet selected (n = 5 samples per treatment); [3] N = Nitrogen; [4] Organic matter digestibility *in vitro*; [5] Digestible organic matter in the dry matter *in vitro*; [6] ME = Metabolisable energy

DM content of the willow ($P<0.001$) and poplar ($P=0.064$) offered increased linearly over time with overall means of 387 g/kg DM and 348 g/kg DM, respectively (Figure 3.1), with all clones offered increasing in DM content over time. Slopes and intercepts of willow and poplar DM regressions differed ($P<0.05$). The total N content of willow ($P<0.001$) and poplar ($P=0.051$) diets selected decreased linearly over time with homogenous slopes and intercepts ($P<0.05$; Figure 3.2). N concentrations were similar for the willow and poplar diets selected with means of 26.3 g/kg DM for the willow diet and 27.4g/kg for the poplar diet (Table 3.2).

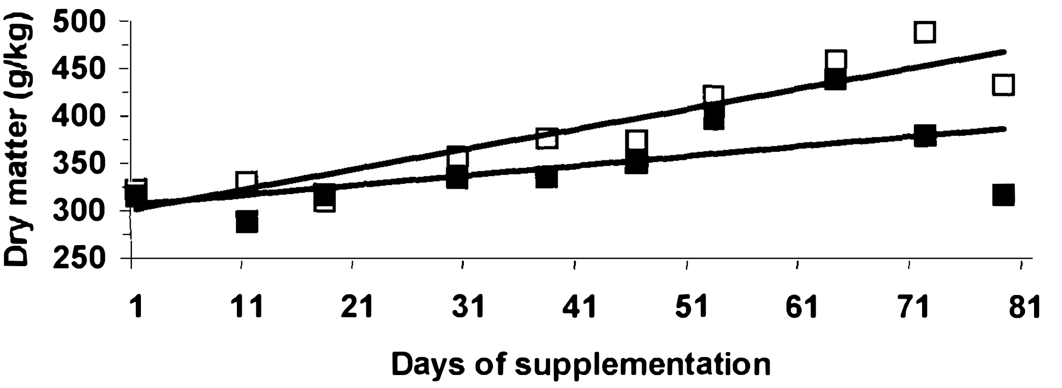

Figure 3.1 Change in the dry matter (DM) content, g/kg DM, of willow (WIL) and poplar (POP) offered during the experiment (t = days of supplementation). P indicates difference from zero. □Willow; ■Poplar

WIL	DM =	299.38 +	2.1339t
	SE	15.077	0.3128
	P	***	***
POP	DM =	304.81 +	1.0391t
	SE	23.336	0.4841
	P	***	0.064

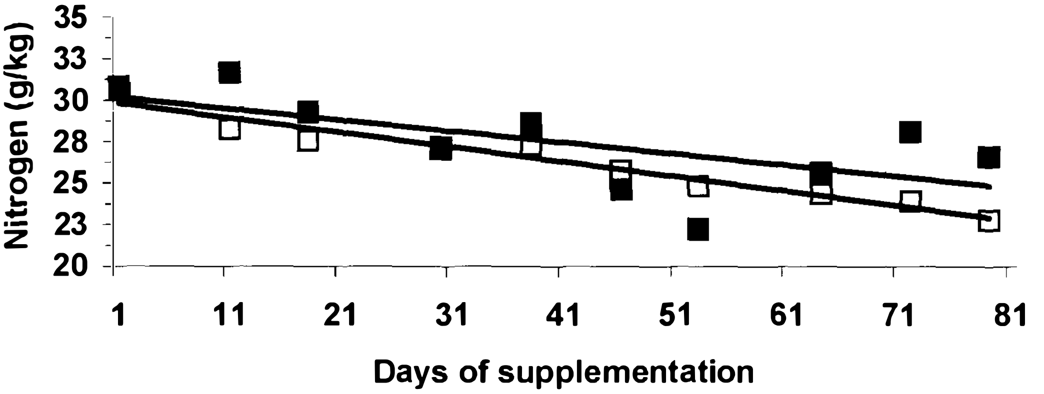

Figure 3.2 Change in the total Nitrogen (N) content, g/kg DM, of willow (WIL) and poplar (POP) consumed during the experiment (t = days of supplementation). P indicates difference from zero. □Willow; ■Poplar

WIL	N =	29.90 –	0.0881t
	SE	0.370	0.0077
	P	***	***
POP	N =	30.24 -	0.0681t
	SE	1.431	0.0297
	P	***	0.051

Table 3.2 Chemical composition and nutritive value of willow and poplar diet selected (g/kg DM) by ewes grazing low quality drought pastures (mean values with standard errors)[1]

	Poplar	Willow
Total N[2]	27.4 ± 0.89	26.3 ± 0.76
Organic Matter	906.9 ± 2.47	922.6 ± 0.93
OMD[3]	0.66 ± 0.007	0.68 ± 0.008
DOMD[4]	0.59 ± 0.007	0.62 ± 0.007
ME (MJ/kg DM)[5]	9.7 ± 0.11	10.1 ± 0.11

[1] Estimated from hand cut samples of diet selected (n = 10 samples per diet); [2] N = Nitrogen; [3] Organic matter digestibility *in vitro*; [4] Digestible organic matter in the dry matter *in vitro*; [5] ME = Metabolisable energy

The willow diet selected was higher in OM (923 vs. 907 g/kg DM; P<0.001) content and ME (10.1 vs. 9.7 MJ; P<0.05) and had a lower NDF content (381 vs. 404; P<0.05) than the poplar diet selected (Tables 3.2 and 3.3). OMD (P<0.001) and ME (P<0.001) content of the willow diet decreased over time, while total WSC concentrations of both the poplar (P<0.05) and willow diet (P<0.001) increased. The willow diet had a greater ratio of readily fermentable to structural CHO than the poplar diet selected, 0.65 vs.0.58 (P<0.05; Table 3.3). Both willow and poplar diets selected were of higher quality than the pasture diet selected, with a higher OM content, OMD, ME and a higher ratio of readily fermentable CHO to structural CHO (Tables 3.1, 3.2 and 3.3).

The willow and poplar diets selected contained significant concentrations of secondary compounds, including lignin, CT and salicin (Table 3.3). The tree fodder diets selected by the ewes had considerably higher concentrations of lignin, 133-134 g/kg DM, compared with the pasture diet, 36.5g/kg DM (Table 3.3). The CT content of the willow diet selected, 52.1g/kg, was considerably higher (P<0.001) than that of the poplar diet at 19.3g/kg (Table 3.3). In the willow diet selected, condensed tannin concentrations increased (P<0.05) over time, as lignin concentrations decreased (P<0.01), with differences (P<0.05) in the slopes and intercepts of the regression lines (Figure 3.3). The poplar diet selected contained higher (P<0.001) concentrations of salicin than the willow diet selected, 2.7 g/kg DM vs. 0.9g/kg DM (Table 3.3).

Conversely, the willow diet selected contained higher ($P<0.001$) concentrations of other phenolic glycosides, 32.7 g/kg DM vs. 14.4 g/kg DM (Table 3.3). The total phenolic glycoside content, including salicin and other phenolic glycosides, of the willow ($P<0.05$) and poplar ($P=0.095$) diets selected had curvilinear responses over time, with peak values between days 51 and 61 (Figure 3.4). Zearalenone concentrations were low in all diets (Table 3.3).

Table 3.3 Carbohydrate and secondary compound content of the pasture, poplar and willow diet selected (g/kg DM) by ewes grazing low quality drought pastures when supplemented with poplar or willow trimmings (mean values with standard errors)[1]

	Pasture*	Poplar**	Willow**
Carbohydrates			
Water Soluble CHO	90.8 ± 2.18	114.0 ± 7.74	122.9 ± 4.92
Pectin	11.3 ± 0.67	42.9 ± 2.11	35.9 ± 0.76
NDF[2]	570.6 ± 9.74	404.4 ± 8.60	381.3 ± 6.01
ADF[3]	296.3 ± 5.31	267.5 ± 6.42	264.1 ± 5.81
Ratio of Readily Fermentable: Structural CHO[4]	0.19 ± 0.006	0.58 ± 0.025	0.65 ± 0.016
Secondary Compounds			
Lignin	36.5 ± 1.18	133.3 ± 6.65	134.3 ± 6.35
Condensed Tannin[5]	ND	19.3 ± 2.25	52.1 ± 1.66
Catechin + Epicatechin	0.3 ± 0.05	0.8 ± 0.13	1.4 ± 0.14
Other Flavenoid Monomers	1.8 ± 0.22	7.6 ± 0.59	8.4 ± 0.41
Salicin	trace	2.7 ± 0.38	0.9 ± 0.06
Other Phenolic Glycosides	1.9 ± 0.17	14.4 ± 1.28	32.7 ± 3.61
Chlorogenic Acid	0.1 ± 0.01	1.3 ± 0.20	1.2 ± 0.12
Zearalenone (mg/kg)[6]	0.16 ± 0.032	0.26 ± 0.019	0.15 ± 0.034

* Estimated from hand plucked samples of diet selected
** Estimated from hand cut samples (stem diameter<7mm & <5mm, respectively) of diet selected
[1] n = 15 pasture, 10 poplar and 10 willow samples per treatment; [2] NDF = neutral detergent fibre; [3] ADF = acid detergent fibre; [4] Water soluble CHO + pectin / cellulose + hemicellulose; [5] Extractable CT + bound CT; [6] Probably produced by contaminating *Fusarium* fungi; ND=Not determined

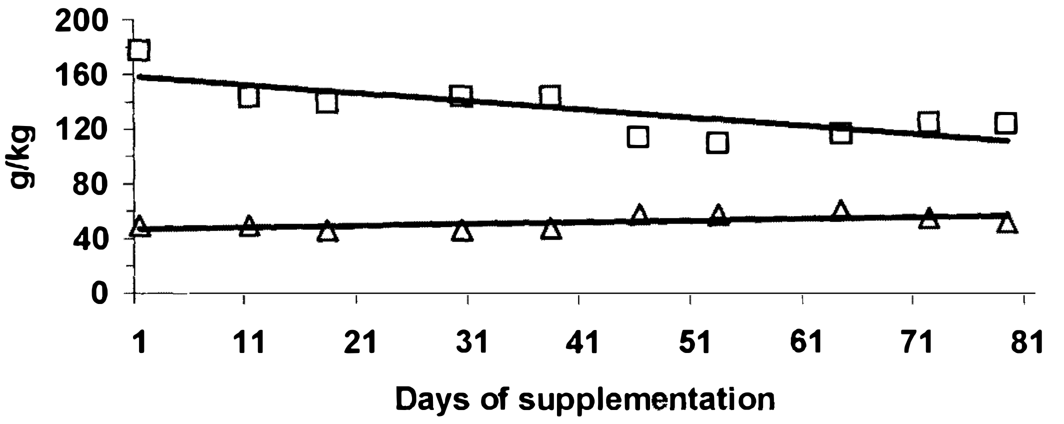

Figure 3.3 Change in the lignin (LIG) and condensed tannin (CT) concentration, g/kg DM, of willow consumed during the experiment (t = days of supplementation). P indicates difference from zero. □ Lignin; △ CT

LIG =	158.71	- 0.5935t
SE	8.151	0.1691
P	***	**

CT =	46.93	+ 0.1267t
SE	2.616	0.0543
P	***	*

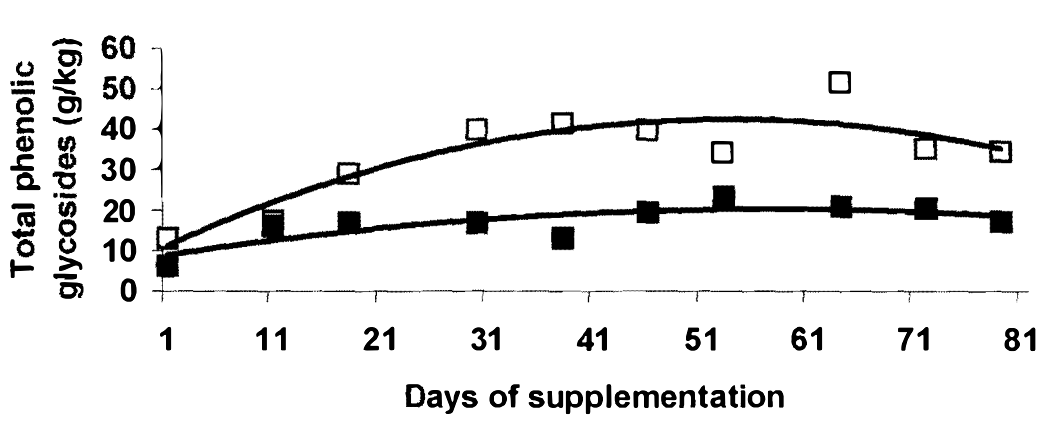

Figure 3.4 Change in total phenolic glycoside (PG) concentration, g/kg DM, of willow (WIL) and poplar (POP) consumed during the experiment (t = days of supplementation). P indicates difference from zero. □ Willow; ■ Poplar

WIL	PG =	100.85	+ 12.096t	$- 0.1130t^2$
	SE	48.553	2.7780	0.0331
	P	0.076	**	*
POP	PG =	85.65	+ 4.081t	$- 0.0355t^2$
	SE	26.950	1.5419	0.0184
	P	*	*	0.095

Diameter of the stem eaten increased (P<0.05) over the experimental period for the poplar supplemented group and decreased (P<0.05) for the willow-supplemented group (Figure 5), with differences (P<0.05) between regression slopes and intercepts. Diameter means were 6.5 mm for the poplar and 3.7 mm for the willow supplemented groups. Mean DM intakes of willow and poplar were 0.25 and 0.27 kg DM/ewe/day, with no significant trend over time. Poplar and willow utilisation was 58% and 48%, respectively.

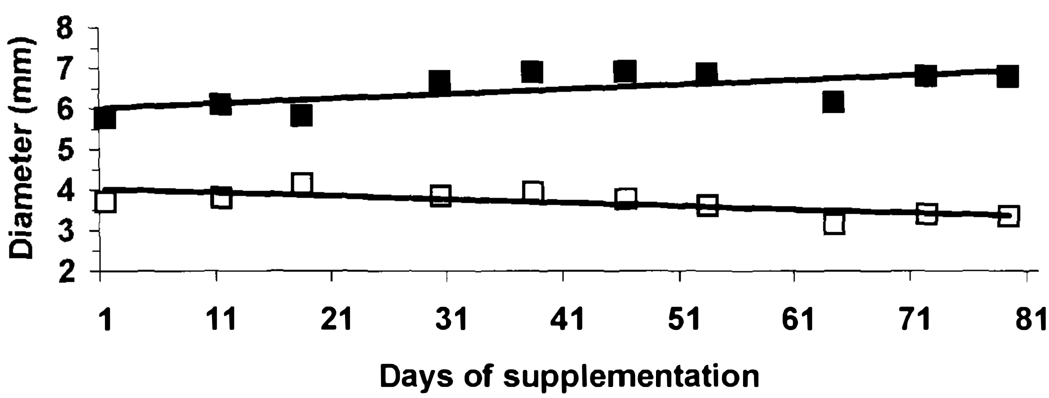

Figure 3.5 Change in diameter (D), mm, of willow (WIL) and poplar (POP) consumed during the experiment (t = days of supplementation). P indicates difference from zero. □ Willow; ■ Poplar

WIL	D = 4.02 – 0.0083t		
	SE	0.132	0.0027
	P	***	*
POP	D = 6.01 + 0.0116t		
	SE	0.224	0.0046
	P	***	*

3.4.2 Animals

All groups of ewes lost LW and BCS during the 87-day supplementation period, with willow supplementation decreasing ($P<0.01$) LW loss (Table 3.4). Both LW and BCS increased after the groups were joined together at the end of the 87-day supplementation period (Figures 3.6a & b) and, by the beginning of the lambing period, there were no differences between the three groups.

Table 3.4 Ewe live weight change and body condition score change, during the 87-day period of willow or poplar supplementation, and reproductive rate expressed as a percentage of the total number of ewes exposed to the ram (mean values with standard errors)[1]

	Control	Poplar Supplementation	Willow Supplementation	SEM
Live Weight Change (g/day)	-103^{a}	-95^{ab}	-86^{b}	4.0
BCS Change (units)	-0.69	-0.59	-0.60	0.051
Reproductive Rate				
Scanning	132^{ab}	127^{b}	148^{a}	6.8
Lambing	131^{ab}	122^{b}	148^{a}	6.9
Docking	107^{b}	97^{b}	128^{a}	7.4
Weaning	106^{ab}	97^{b}	126^{a}	7.4

a,b. Means within rows with different superscripts differ significantly ($P<0.05$)
[1] n = 95 animals per treatment

Willow supplementation increased scanning ($P=0.097$), lambing ($P=0.087$), docking ($P<0.05$) and weaning ($P=0.058$) percentages by 16, 17, 21 and 20% units, respectively, compared to the control group (Table 3.4). Poplar supplementation had no effect on reproductive rate.

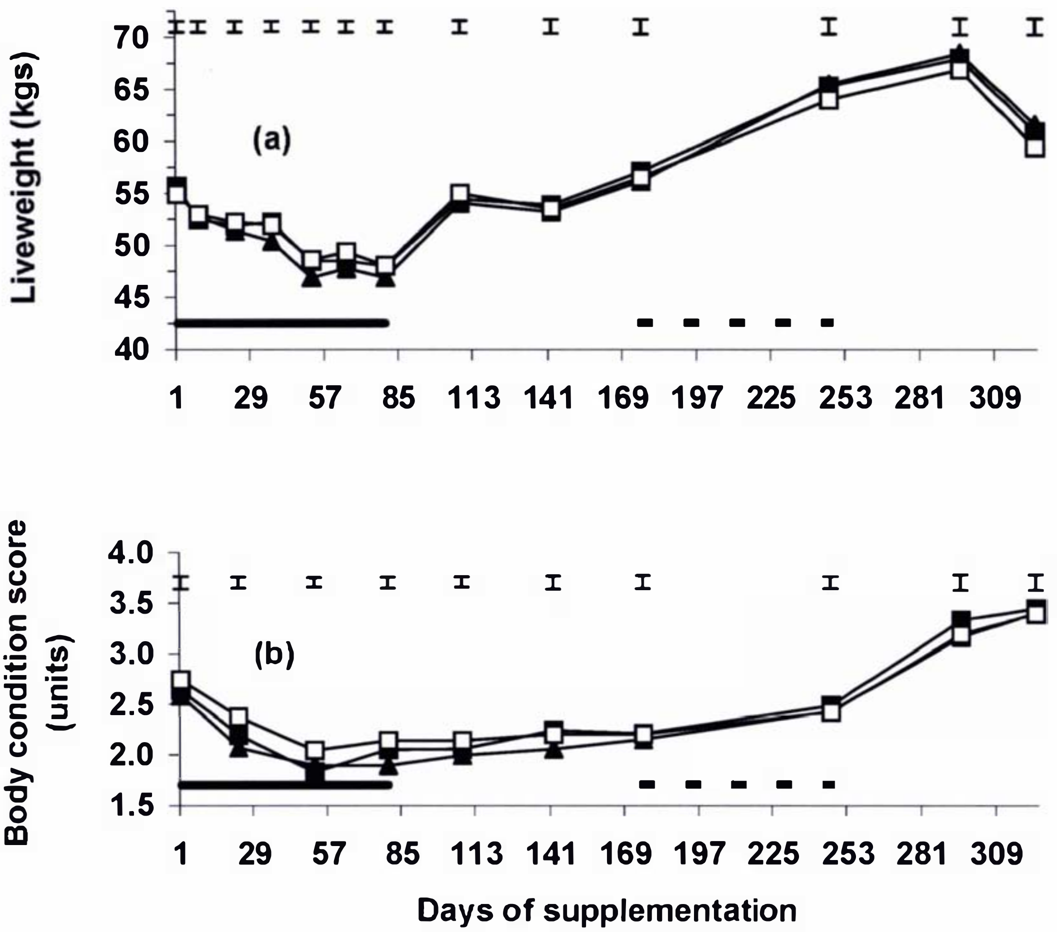

Figure 3.6 Change in mean ewe live weight (a) and body condition score (b) in ewes supplemented with willow or poplar trimmings when grazing drought pasture. The solid line indicates the 87-day period of willow or poplar supplementation. The broken line indicates period of lambing. The error bars indicate pooled SEM. □ Willow; ■ Poplar; ▲ Control

Willow supplementation increased reproductive rate through increases in fecundity (lambs born/100 ewes lambing), with more ewes bearing multiple lambs and fewer bearing singles, compared to both the poplar supplemented and the control groups ($P<0.05$; Table 3.5). There were no treatment effects on conception rate, mean lambing date and total lamb mortality (Table 3.5). Lamb mortality at birth was lower ($P<0.05$) in the willow-supplemented group compared to the poplar-supplemented group (Table 3.5).

Table 3.5 The effect of supplementation with willow or poplar trimmings for 87 days during the late summer/autumn, including mating, in ewes grazing drought pastures on conception rate, fecundity, mean lambing date and total lamb mortality from birth to weaning (mean values with standard errors). Lamb mortality data are presented as a percentage of the total number of lambs born for each treatment (proportions with standard errors)

	Control	Poplar Supplementation	Willow Supplementation	SEM
Conception Rate[1]	91.4	87.0	91.4	3.11
Fecundity[2]				
Singles	56.1^{a}	59.0^{a}	37.8^{b}	5.46
Twins	43.9^{b}	41.0^{b}	62.2^{a}	5.46
Mean Lambing Date	23 Aug	24 Aug	23 Aug	0.7
Lamb Mortality[3]				
Birth	3.4^{ab}	8.2^{a}	0.8^{b}	1.62
Total	19.5	20.9	15.0	3.52

a,b. Means within rows with different superscripts differ significantly ($P<0.05$)
[1] Expressed as ewes pregnant per 100 ewes mated; [2] Expressed as lambs born per 100 ewes lambing; [3] Expressed as lamb deaths per 100 lambs born

There were only numerically small treatment effects on birth weight (P<0.001) and weaning weight (P<0.01) of lambs (Table 3.6).

Table 3.6 The effect of supplementation with willow or poplar trimmings for 87 days during the late summer/autumn, including mating, in ewes grazing drought pastures on lamb birth and weaning weights (kilograms; mean values with standard errors)

			Control	Poplar Supplementation	Willow Supplementation	SEM
Birth Weight						
	Single					
		Male	6.1^{a}	6.2^{a}	5.5^{b}	0.17
		Female	5.6	5.6	5.2	0.16
	Twin					
		Male	4.7^{b}	5.1^{a}	4.6^{b}	0.12
		Female	4.5	4.7	4.5	0.12
Weaning Weight						
	Single					
		Male	39.7	37.4	35.7	1.29
		Female	33.2	33.8	31.1	1.07
	Twin					
		Male	31.7^{a}	32.7^{a}	28.8^{b}	0.86
		Female	27.8	27.8	27.2	0.87

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

3.4.3 Wool

Greasy fleece weight and staple length were generally similar for all groups and there were no treatment effects (Table 7).

Table 3.7 The effect of supplementation with willow or poplar trimmings for 87 days during the late summer/autumn, including mating, in ewes grazing drought pastures on whole-year wool production and staple length (mean values with standard errors)

	Control	Poplar Supplementation	Willow Supplementation	SEM
Greasy Fleece Weight (kg)				
Single bearing ewes	3.1	3.0	3.2	0.09
Twin bearing ewes	2.9	3.1	3.1	0.09
Average for all ewes	3.0	3.1	3.2	0.07
Staple Length (mm)				
Single bearing ewes	135	135	138	2.5
Twin bearing ewes	138	142	139	2.5
Average for all ewes	137	138	139	1.8

3.5 Discussion

The increase in reproductive rate in ewes supplemented with willow tree trimmings was due to an increase in fecundity, with a higher proportion of multiple pregnancies in the willow-supplemented group. The increase in reproductive rate and reduction in LW loss in the ewes supplemented with willow tree trimmings may have been due to a simple increase in DM and ME consumed (i.e. flushing effect); the control, poplar and willow groups were estimated to consume an average of 0.59, 0.83 and 0.86 kg total DM/ewe/day and 4.6, 6.8 and 7.2 MJ total ME/ewe/day, respectively (Table 3.8). It is generally accepted that increases in levels of nutrient intake for 6 week in the pre-mating period increases ewe LW and ovulation rate, and this is reflected in increases in lambing percentage (Rattray *et al.* 1981; Smith *et al.* 1983; Smith 1985; Smith & Knight 1998). The percentage of ewes with multiple ovulations increases at about

1.5% per additional MJ of ME consumed (Smith 1985). When applied to the present data, the additional ME intake from willow supplementation would have increased multiple birth by 3.9% units. This is considerably less than the 18.3% unit increase in fecundity observed (Table 3.5) and strongly suggests that there must be other mechanisms involved in the increase in reproductive rate found in the present experiment.

Table 3.8 The effect of supplementation with willow or poplar trimmings for 87 d during the late summer/autumn, including mating, in ewes grazing drought pastures on calculated dry matter (DM) intake (kg DM/ewe/day), calculated metabolisable energy (ME) intake (MJ ME/ewe/day), calculated crude protein (CP) intake (g/ewe/day) and calculated zearalenone intake (mg/ewe/day; mean values with standard errors)

	Control	Poplar Supplementation	Willow Supplementation	SEM
DM Intake				
Pasture[1]	0.59	0.56	0.61	0.061
Willow/Poplar	0	0.27	0.25	0.015
Total	0.59	0.83	0.86	0.065
ME Intake[2]				
Pasture	4.6	4.3	4.7	0.47
Willow/Poplar	0	2.6	2.5	0.15
Total	4.6	7.0	7.2	0.50
CP Intake[3]				
Pasture	90.5	88.1	95.7	7.82
Willow/Poplar	0	45.8	41.0	2.41
Total	90.5	133.9	136.7	5.58
g Tree Fodder CP / g Total CP	0	0.34	0.30	
g CP Intake / MJ ME Intake	19.7	19.1	19.0	0.79
Zearalenone Intake				
Pasture	0.07	0.07	0.14	0.028
Willow/Poplar	0	0.07	0.04	0.009
Total	0.07	0.14	0.18	0.026

[1] Estimated from pasture mass measurements before and after grazing; [2] DM intake * mean ME concentration in MJ/kg DM; [3] DM intake * CP concentration

Smith (1985) found a threshold intake level of 125 g protein/ewe/day necessary to achieve an increase in ovulation rate, with marked increases at levels above 125 g/ewe/day. In the present study, crude protein (CP) intake during the flushing and mating periods of the control ewes was well below this value, while the calculated CP intakes of the willow and poplar supplemented ewes exceeded it (Table 3.8). Cruickshank *et al.* (1988) reported that abomasal infusions of lactalbumin and soy protein isolate for 10 days, prior to and including ovulation, substantially increased ovulation rate by 16% and 14% units and the proportion of multiple ovulations by 17% and 19% units, respectively, demonstrating the importance of increased protein absorption in sheep fed forage diets.

Pasture consumed in this experiment was typical of New Zealand East Coast pastures affected by a summer/autumn drought. Pre-grazing and post-grazing pasture masses were very low and the pasture contained a large percentage of dead matter (>50%). The willow and poplar tree fodder diets selected were superior in nutritive value to the pasture diet selected, as they were higher in OM concentration, OMD and ME, with a higher ratio of readily fermentable to structural CHO. Nutritive values for the poplar and willow diets selected in this experiment were similar to values obtained in previous experiments (McWilliam *et al.* 2004; Moore *et al.* 2003; Kemp *et al.* 2001; Oppong *et al.* 2001, 1996; Matheson 2000; Smith 1992; McCabe & Barry 1988). The willow diet selected contained 16 g/kg DM more OM and 0.7 MJ more ME per kg DM, than the poplar diet selected.

The willow and poplar diets selected in this experiment contained substantial concentrations of the secondary compounds CT, salicin and other phenolic glycosides. The willow diet selected contained much higher concentrations of CT, 52g/kg versus 19g/kg, and total phenolic glycosides, 34 g/kg versus 17g/kg, than the poplar diet selected. McWilliam *et al.* (2004) concluded that the CT and phenolic glycoside content of poplar tree fodder most likely plays a significant role in the increase in reproductive rate due to poplar supplementation. Forage diets containing low concentrations of CT (20 to 40 g/kg DM) are known to increase the amount of protein actually absorbed by the ewes, through increasing the rumen outflow of undegraded dietary protein (UDP; Barry & McNabb 1999) and similar effects may occur with forage trees. Previous studies have shown that higher levels of rumen UDP increase ewe ovulation rate and fecundity and that increased intakes of dietary N, in the form of urea (i.e. rumen degradable nitrogen; RDN), do not increase ovulation rates (Knight *et al.* 1975; Thompson *et al.* 1973). CT increases protein absorption and utilisation by binding strongly to proteins to form a pH-dependent complex, which is not degradable at normal rumen pH (6.0 to 7.0), but disassociates at normal abomasal pH (2.5-3.5) with the protein absorbed from the small intestine (Barry & McNabb 1999). Phenolic glycosides could be an important source of glucose, to increase the synthesis of rumen microbial protein. The concentrations of total phenolic glycosides (salicin + other phenolic glycosides) responded curvilinearly to time, with concentrations peaking between 51 and 61 d, corresponding to the mating period.

Typical drought pasture is high in fibre and low in N and OMD. For efficient rumen digestion of such low quality forages, ruminants need to be supplemented with sources of rumen degradable N and soluble CHO to stimulate microbial protein synthesis and also UDP to meet protein requirements (Preston & Leng 1987). Forage trees, such as willow and poplar, should be a good supplement to low quality drought pasture in principle as they fulfil these requirements. We hypothesize that groups supplemented with willow and poplar tree trimmings have a higher rumen outflow of both undegraded dietary and microbial proteins, due to the higher concentrations of protein, WSC, CT and phenolic glycosides in fodder tree diet selected than in drought pasture.

There was no trend to increased DM intake of fodder trees over time, which contrasts to Moore *et al.* (2003) and McWilliam *et al.* (2004). In the present experiment, the diameter of stem consumed increased significantly over time for the poplar-supplemented ewes, which is consistent with McWilliam *et al.* (2004). However, the diameter of willow stem consumed decreased over time. In a similar experiment, in which willow tree trimmings were fed to beef cattle as a supplement to drought pasture, Moore *et al.* (2003) found that the diameter of willow stems consumed increased over time. The reason for the decrease in stem diameter consumed by ewes in the willow-supplemented group, in the present experiment, is unknown.

Zearalenone is an oestrogenic mycotoxin produced by *Fusarium* species, commonly found in New Zealand pasture under hot, dry conditions, which will reduce ovulation rate in sheep if daily intakes exceed 1 mg/day (Towers 1997). Fungal growth is highest during the ewe-mating period, in February, March and April, and can reduce ovulation rate and subsequent lambing percentages by 10 to 25%. Total calculated zearalenone intakes of all three groups were less than 0.2 mg/day in the present study (Table 9), and so it is unlikely that pasture zearalenone concentration affected ewe reproduction. It is possible that the poplar leaf rust (*Melampsora larici-populina*), which severely contaminated the poplar tree trimmings offered in this experiment, produces an unknown oestrogenic substance, similar to zearalenone. This could provide an explanation for the lack of reproductive response in ewes supplemented with the fungus-contaminated poplar tree trimmings, despite the higher DM intake and reduced LW loss. However, there is no evidence currently available concerning secondary compounds produced by leaf rust.

Plate 3.3 Mild leaf rust contamination (*Melampsora larici-populina*) of poplar fodder offered in the early stages of the experiment, which grew progressively worse over the experimental period.

3.6 Conclusion

The objective of this study was to compare whole-year ewe production and reproduction responses to the supplementation of ewes with willow versus poplar tree trimmings, during mating, when grazing low quality drought pasture under dry New Zealand East Coast conditions. Supplementation with willow tree trimmings for 87 days produced an increase in reproductive rate at lambing of 17% units, a transient reduction in the rate of LW loss and no effect on wool production. There was no increase in reproductive performance in poplar-supplemented ewes, possibly due to the severity of leaf rust contamination in the poplar fodder offered to the ewes. The mechanism for this lack of response is unknown. However, it is clear that unlike the rust-free poplar trimmings used by McWilliam *et al.* (2004), rust-infected poplar is not an effective supplement for increasing the reproductive rate of ewes grazing drought pasture. Research is needed to establish the precise mechanisms involved in the reproductive response to supplementation with willow and poplar tree fodder and to define the minimum length of feeding tree fodder necessary to increase ewe production and reproduction.

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CHAPTER 4

2003 GRAZING EXPERIMENT

Effects of willow (*Salix spp.*) supplementation for 31 and 63 days on the reproductive performance of ewes grazing low quality drought pasture during mating

This chapter is submitted to Animal Feed Science and Technology

4.1 Abstract

A grazing experiment, conducted for 63 days from 12 February 2003, in the late summer/autumn of 2003, at Massey University's Riverside Farm, near Masterton (New Zealand), evaluated the period of feeding necessary (0, 31, 63 days) to achieve reproduction responses from supplementation with willow tree trimmings in ewes grazing dry summer pastures of low nutritive value during mating. A rotational grazing system with 300 mixed age Romney ewes (54.3 kg ± 0.56 kg) were used, with 100 ewes per treatment (control, short supplementation and long supplementation). All ewes were offered an allowance of low quality pasture sufficient to provide a potential desired intake of 0.70 kg dry matter (DM)/d. Pasture offered contained 78% dead matter, with pre- and post-grazing pasture masses of 1261 kg DM/ha and 821 kg DM/ha, respectively. The effect of short (10 days before mating + 21 days during mating = 31 days) and long (21 days before mating + 42 days during mating = 63 days) willow supplementation (1.4 kg fresh/ewe/day) on live weight (LW) and body condition score (BCS) change, reproductive rate at pregnancy scanning, lambing, docking and weaning, and wool production was measured. Pasture consumed was typical of drought pasture; high in neutral detergent fibre (NDF; 603 g/kg) and low in organic matter digestibility (0.49; OMD). The willow diet selected was superior to the drought pasture diet selected; it had a higher N content, OMD and ME and was lower in fibre. The willow diets selected contained substantial concentrations of the secondary compounds condensed tannin (CT), salicin and other phenolic glycosides. The pasture diet selected also contained substantial concentrations of the anti-nutritional fungal metabolites zearalenone (Z) and trichothecenes, with Z increasing linearly over time to over 2 mg/kg DM ($P<0.01$). Z has been shown to reduce reproductive performance in ewes, and trichothecene mycotoxins may be a cause of autumn ill thrift in grazing livestock. Willow supplementation for 63 days (long treatment) reduced ewe LW loss (-96 g/d vs. -147 g/d; $P<0.05$) and loss in BCS (-0.79 vs. -1.09; $P<0.05$), compared with unsupplemented ewes, but these differences disappeared in the post-treatment period. There were no treatment effects on reproductive rate at scanning and lambing, probably due to the toxic concentrations of Z in the pasture consumed by ewes during mating (1.5 mg/kg DM). However, the long treatment weaned 13% units more lambs than

control ewes (P=0.12). This was due to a 9% unit reduction in post-natal lamb mortality from 17.1% to 8.4% (P<0.05). There were no treatment effects on wool production and staple length, only a small treatment effect on the LW of male lambs at birth and no effect on lamb weaning weight. Results from three years of experimentation have shown that supplementing ewes grazing drought pasture during mating with poplar and willow tree fodder consistently reduced LW loss and loss in BCS and substantially increased reproductive rate, given that the pasture or tree material was not contaminated with fungi that produce oestrogenic mycotoxins. Supplementation with tree fodder during mating also reduced post-natal lamb mortality; experiments with larger numbers of ewes/groups are needed to confirm this effect.

Keywords: Drought feeding; Willow (*Salix* sp.) supplementation; Reproduction; Condensed tannins; Phenolic glycosides; Trichothecenes; Zearalenone

4.2 Introduction

In New Zealand, livestock production is based on year round grazing systems of perennial ryegrass/white clover dominant pastures. This system has the advantage of low production costs and is generally animal welfare friendly, although climatic extremes can severely affect both pasture and animal growth. The East Coast regions of Gisborne, Hawke's Bay, Wairarapa, Marlborough, Canterbury, and North Otago, generally experience hot, dry conditions during the summer and early autumn, with frequent severe droughts. Low soil moisture levels reduce pasture growth and quality, thus limiting feed available for grazing livestock. These conditions can lead to large losses in livestock productivity, and subsequent profitability, unless remedial action is taken. In New Zealand, this usually involves supplementary feeding in the form of hay, silage or grains and pulses, transfer of stock to temporary grazing in non-drought areas, or sale of animals.

An alternative supplementary feed option that has been successfully used by farmers in East Coast regions is poplar and willow tree trimmings (Charlton *et al.* 2003). Previous studies (McWilliam *et al.* 2004a,b), showed that supplementing ewes with tree fodder for 71 to 87 days, including during mating, increased reproductive rate by 20 to 30% units and reduced live weight (LW) loss. Tree fodder was an ideal supplement for ewes grazing low quality drought pasture during mating; it provided sources of rumen degradable nitrogen (N) and soluble carbohydrate (CHO) to stimulate microbial protein synthesis as well as undegradable dietary crude protein (CP) to support metabolisable protein requirements (Preston & Leng 1987; McWilliam *et al.* 2004a,b). The authors concluded that the increase in CP intake, due to tree fodder supplementation, was a significant factor in the substantial increase in reproductive rate of supplemented ewes.

To date there has been no research defining production and reproduction responses to differing lengths of willow and poplar supplementation. This is an important aspect of supplementation, because many farms do not have enough trees to supplement a substantial group of ewes for the period of 10 to 12 weeks that was used in previous experimental research. Work with ewes grazing *Lotus corniculatus*, a dry-land forage crop with similar characteristics to tree fodder, showed that ovulation rate increased as the period of supplementation prior to mating increased. Other reports document increased ovulation rate when high CP supplements, such as lupins, were fed for just six days before ovulation, and increased ovulation rate (16 and 14 % units) and fecundity (17 and 19 % units) with abomasal infusions of lactalbumin and soy protein isolate, for ten days, prior to and including ovulation (Stewart & Oldham 1986; Cruickshank *et al.* 1988). Smith (1991) reported that the period that a supplement must be fed to achieve an increase in ovulation rate appears to be dependent on the characteristics of the supplement. Thus it is necessary to define the optimum length of supplementation, specifically for tree fodder, to most efficiently utilise the available resource.

The objective was to evaluate the length of feeding necessary to achieve reproduction responses from supplementation with willow tree trimmings in ewes grazing dry summer pastures of low nutritive value in the Wairarapa.

4.3 Materials and Methods

4.3.1 Experimental Design

A grazing trial involving 300 mixed age Romney ewes was conducted at Massey University's Riverside Farm, near Masterton, New Zealand, on the North Island East Coast. Ewes grazed simulated drought pasture of low quality and mass/ha for 63 days, from 12 February to 15 April 2003, and were offered willow tree trimmings daily as a supplementary feed. Ewes were randomly allocated to 3 groups, each of 100 being: long supplementation (63 days), short supplementation (31 days) and control (0 days). All ewes were offered a pasture allowance sufficient to provide a potential desired intake of 0.70 kg dry matter (DM)/d. The treatment groups were offered 1.4 kg/ewe/day (fresh) willow as a supplement to drought pasture; the long treatment, for 63 days, including 2 mating cycles (42 days), and the short treatment, for 31 days, including 1 mating cycle (21 days). In the long treatment, supplementation commenced on 12 February and was offered over the entire grazing period (21 days before mating + 42 days during mating = 63 days). In the short treatment supplementation commenced on 23 February and concluded on 25 March (10 days before mating + 21 days during mating = 31 days). All groups of ewes were mated during the same period (5 March to 15 April).

4.3.2 Animals

On 10 February 2003, Romney ewes of similar age, size and LW were randomly assigned to the three treatment groups and individually ear-tagged, scored for body condition and weighed to ensure that the initial average LW of each group was similar. All ewes were vaccinated with, Salvexin™ +B (Schering-Plough Animal Health Ltd., Upper Hutt, Wellington, New Zealand), before the experiment to prevent salmonella poisoning and Ewegaurd™ (Fort Dodge New Zealand Ltd., Auckland, New Zealand), a combination of 6-in-1 vaccine and anthelmintic drench, prior to lambing. During the mating period, two Suffolk rams were run with each group of 100 ewes, and rams were randomly reassigned to the groups every two weeks. This was to ensure that a ram failure did not affect reproductive results. Following supplementation and mating, the three groups were joined together on 16 April and managed as one group until the conclusion of the study on 15 January 2004. Pasture grazed by experimental ewes after the supplementation period gradually increased in quantity and quality to reflect pasture availability after a summer/autumn drought; during winter and spring, pasture covers under set stocking were approximately 1000 and 1500 kg DM/ha, respectively, with an estimated organic matter (OM) digestibility (OMD) of approximately 0.75 to 0.80. Ewes were ultrasound scanned for pregnancy and the number of embryos present recorded on 10 June. Non-pregnant ewes were sent to the abattoir. Ewes lambed between 4 August and 12 September and reproductive data was recorded at lambing. Lamb tails were removed with a searing iron (tail docking) on 15 October and lambs were weaned on 24 November. Ewes were shorn and wool production data was collected on 9 January 2004.

4.3.3 Forages

4.3.3.1 Pasture Management

Perennial ryegrass/white clover pasture, grown on very shallow stony soil, was prepared to simulate drought conditions. This was achieved by allowing the ryegrass to mature and develop seed heads, thus decreasing the quality of the sward, and then grazing the experimental area with cows and non-experimental ewes to reduce pasture mass. This resulted in pasture that was low in nutritive value, high in dead matter content and low in pasture mass, typical of drought conditions.

Pasture was rotationally grazed in ten breaks, each lasting 7 to 14 days, using electric fencing. All treatment groups were moved to a new break on the same day. Total grazing days (TGD) was calculated for each break as:

$$TGD = ((HM-500) * PA)) / (n * PI)$$

where: HM is initial pasture mass (kg DM/ha), 500 is the expected post-grazing residue, PA is grazing area (ha), n is the number of ewes per treatment group, and PI is potential desired intake/ewe/day (0.70 kg DM/ewe/d). This management system was intended to provide similar levels of intake for each treatment group. A potential dry matter intake of 0.70 kg DM/ewe/day is below maintenance energy level for ewes grazing low quality perennial ryegrass/white clover pasture, as would typically occur in a drought. Further details of the method used can be found in Chapter 2.

A moveable water trough was available for each treatment group, with all ewes allowed water *ad libitum*.

4.3.3.2 Willow Supply

Willow trimmings (*Salix matsudana* x *alba*, cultivar Tangoio) were delivered daily from the Greater Wellington Regional Council's Akura Nursery, near Masterton. The small stems (basal diameter < 15 mm) of willow were cut every three days from coppiced stools and stored in a room at 4° C to reduce dehydration and weight loss. 140 kg (fresh) willow tree fodder, was weighed and fed daily for 31 days in the short treatment and for 63 days in the long treatment. Willow stems were spread out in a line, allowing access to the supplementary fodder by all ewes in each group.

Plate 4.1 Willow tree trimmings consumed by grazing ewes.

4.3.4 Forage Measurements

4.3.4.1 Pasture

Pre- and post-grazing herbage mass was determined immediately before and after grazing each break, by cutting eight random quadrats (590 mm x 295 mm), per treatment group per break, to ground level, washing and then drying at 80° C for 18 to 24 hours. Six exclusion cages (approximately 1.4 x 0.9 m) were placed in each break before grazing. Diet selected samples were hand-plucked from the exclusion cages, after grazing, to simulate the pasture diet consumed by the ewes. These samples were stored at -20° C for later nutritive value analysis of the diet selected. Samples for dead matter content of pasture offered were collected before grazing each break. Pasture dry matter intake (DMI) was calculated using the method (Walters & Evans 1979) described in Chapter 2.

4.3.4.2 Willow

Willow fodder offered was weighed daily and samples were collected twice weekly, from fodder offered to each treatment group, then cut into 2 cm lengths and used to determine the DM content of the feed offered. The willow residue was collected and weighed after each break and samples collected to determine DM content. Thus, the total amount of willow (kg DM) consumed could be calculated for each treatment for each break. Diet selected samples for each treatment were also pruned daily from the willow fodder on offer at a diameter that was consistent with the diameter consumed by the ewes, 3 to 5 mm, and cut into 2 cm lengths. The daily samples were pooled for each treatment for each break and stored at -20° C for later laboratory analysis. The diameter of willow stem eaten was determined for each treatment group, at the end of grazing each break, by collecting 75 stems/treatment group and measuring the diameter eaten with electronic callipers (Mitutoyo Corp., Japan).

4.3.5 Animal Measurements

Mean initial ewe LW and body condition score (BCS) was similar between the three groups with the control, short willow supplementation and long willow supplementation groups weighing 54.3, 54.5 and 54.1 kgs (± 0.56), respectively, and a mean BCS of 2.8 ± 0.06 units. Ewes were weighed fortnightly using electronic scales (Tru-test, Auckland, New Zealand) during the period of supplementation and body condition scored from 1 to 5 (Jefferies 1961) monthly. Following the supplementation period, ewes were weighed and body condition scored monthly until shearing in December. Ewes were not weighed or body condition scored during the lambing period. Reproductive data was collected during the lambing period, including lamb birth date, birth weight, birth rank and sex. Lamb weaning weights were recorded and scanning, lambing, docking, and weaning percentages calculated.

Ewe fleeces were weighed at shearing (9 January 2004) to determine the greasy fleece weight, with samples of 200 to 300 g collected from both the left and right mid-side areas for staple length (mm) measurements.

4.3.6 Laboratory Analysis

Willow and pasture samples of diet selected were stored at -20°C, freeze-dried and ground to pass a 1 mm diameter sieve. Total N concentration was determined using the Dumas method (Leco Corporation, Michigan, USA 1994) and OM by ashing samples for 16 hours at 550°C. *In vitro* OMD was determined by the enzymatic method of Roughan and Holland (1977), using separate standard curves prepared from *in vivo* values for forages and from tree fodder fed to sheep. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and AD lignin were determined by the detergent procedures of Robertson and Van Soest (1981) and Van Soest *et al.* (1991), with alpha amylase (BDH, Poole, UK) added during NDF extraction. Sodium sulphite was not added. The NDF and ADF values are expressed inclusive of residual ash. Hemicellulose was calculated as NDF minus ADF and cellulose as ADF minus lignin. Willow samples were analysed for acetone/water-extractable, protein-bound and fibre-bound condensed tannin (CT) fractions, using a butanol-HCL colorimetric procedure (Terrill *et al.* 1992);

total CT concentration was then calculated by summing the three fractions. All CT concentrations were determined using CT extracted from *Lotus pedunculatus* as a reference standard (Jackson *et al.*, 1996). Pasture and willow diet selected samples were analysed for zearalenone (Z) by enzyme linked immunosorbent assay (ELISA), which detects total Z (zearalenone plus α- and β-zearalenol; Towers 1997). Willow diet selected samples were analysed for salicin and the concentration of other phenolic glycosides, using the high-performance liquid chromatographic procedure of Meier *et al.* (1988); the method also allowed measurement of catechin + epicatechin, other flavonoid monomers and chlorogenic acid. Salicin and quercetin were used as the reference standards in calculating the concentration of other phenolic glycosides and other flavonoid monomers, respectively. Pasture samples were analysed for nivalenol (NIV) and deoxy-nivalenol (DON) by ELISA (Garthwaite *et al.* 1994a,b), with a modified extraction that detects the acetylated forms of the two toxins (J. Sprosen, AgResearch, Hamilton, New Zealand, personal communication).

4.3.7 Calculations and Data Analysis

The concentration of metabolisable energy (ME) in the diets selected by the ewes are calculated as 16.3 * digestible OM / 100g DM (DOMD; Drew & Fennessy 1980). DOMD was measured by the *in vitro* digestibility assay.

Means and standard errors for each of the variables describing chemical composition of the pasture and willow diet selected in each of the treatments were obtained using the GLM procedure of SAS (2001). Regression equations for concentrations of DM in the willow fodder offered and concentration of Z in the pasture diet selected, over time, were estimated using the GLM procedure of SAS (2001). Individual regression equations for the short and long treatments were estimated for NDF, N and ME concentrations, OMD of the willow diet selected, and diameter of willow stem eaten. Common regressions were then calculated, as there were no differences in slopes and intercepts for individual calculated regressions for the treatment groups.

LW and BCS of the ewes were analysed using the MIXED procedure of SAS (2001). The model included the fixed effects of treatment (control, short supplementation and long supplementation), time and their interaction and the random effect of ewes within treatments (Littell *et al.* 1998). Using the Akaike's information criterion, a compound symmetry error structure was determined as the most appropriate residual covariance structure for repeated measures over time within ewes. Least squares means and their standard errors were obtained for each treatment for days 1, 16, 33, 45, 66, 95, 120, 157, 248, 288 and 340.

Differences in pregnancy rate between treatments were tested using PROC CATMOD of SAS (2001). Least-squares means for reproductive rate at scanning, lambing, docking and weaning were obtained for each treatment, using PROC MIXED of SAS (2001), after fitting a linear model that considered the fixed effect of treatment and residual random errors with a diagonal structure. PROC GENMOD (SAS 2001) 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 using PROC MIXED (SAS 2001) with a linear model that included the effects of treatment, sex, birth rank and the treatment*sex interaction. Greasy fleece weight and staple length of ewes were also analysed using PROC MIXED (SAS 2001) and adjusted for the effects of ewe LW and the number of lambs born.

Lamb mortality data was combined over the three experiments in 2001, 2002 and 2003 and analysed using PROC GENMOD (SAS 2001) assuming a binomial distribution with a logit transformation. The linear model considered the effects of year, treatment, sex and birth rank. Power analyses were carried out to calculate the number of lambs necessary to detect reductions in lamb mortality, for each of the three experiments. This figure was then divided by the lambing rate of the control group for each of the individual experiments to provide the number of ewes needed in future experiments of this kind.

4.4 Results

4.4.1 Forages

Pre- and post-grazing herbage mass and pre-grazing pasture dead matter content were similar for all groups (Table 4.1), with mean values of 1261 kg DM/ha, 821 kg DM/ha and 78 %, respectively. Chemical composition of the pasture diet selected was similar for the three groups and was low in total N, OMD and ME (Table 4.1).

Table 4.1 Pasture and dead matter content of drought pasture offered during the experiment and chemical composition and nutritive value of the pasture diet selected by ewes grazing low quality drought pastures when supplemented with willow (mean values with standard errors)

	Control	Short Willow Supplementation	Long Willow Supplementation
Pasture Mass[1]			
Pre-grazing (kg DM/ha)	1220 ± 117.2	1258 ± 141.9	1304 ± 132.1
Post-grazing (kg DM/ha)	777 ± 95.6	846 ± 96.4	841 ± 144.3
Pasture Utilisation (%)	36	33	36
Dead Matter Content (%)[2]	79.5 ± 2.83	78.4 ± 3.75	76.7 ± 2.88
Chemical Composition and Nutritive Value of Pasture Diet Selected[1,3]			
Total N[4]	15.9 ± 1.26	15.1 ± 1.01	16.3 ± 0.84
Organic Matter	915 ± 3.8	906 ± 2.8	906 ± 4.9
OMD[5]	0.49 ± 0.004	0.50 ± 0.005	0.49 ± 0.006
DOMD[6]	0.44 ± 0.005	0.45 ± 0.005	0.44 ± 0.006
ME (MJ/kg DM)[7]	7.2 ± 0.08	7.3 ± 0.09	7.2 ± 0.12

[1] n = 6 samples per treatment; [2] Pre-grazing; [3] Estimated from hand plucked samples of diet selected; [4] N = Nitrogen; [5] Organic matter digestibility *in vitro*, expressed as a proportion; [6] Digestible organic matter in the dry matter *in vitro*, expressed as a proportion; [7] ME = Metabolisable energy

The willow diet selected was superior to the drought pasture diet selected, as it had a higher N content (24 vs. 16 g/kg DM), OMD (0.70 vs. 0.49, proportion) and ME content (10.4 vs. 7.2 MJ/kg DM) and was lower in fibre (355 vs. 603 g/kg DM; Tables 4.1, 4.2, & 4.3).

Table 4.2 Chemical composition and nutritive value of willow diet selected (g/kg DM) by ewes grazing low quality drought pastures and supplemented with willow for 0 days (control), 31 days (short supplementation) and 63 days (long supplementation) (mean values with standard errors)

	Short Willow Supplementation[1]	Long Willow Supplementation[1]
Total N[2]	23.8 ± 0.16	24.7 ± 0.11
Organic Matter	912 ± 4.3	913 ± 3.1
OMD[3]	0.70 ± 0.014	0.70 ± 0.010
DOMD[4]	0.64 ± 0.014	0.64 ± 0.010
ME (MJ/kg DM)[5]	10.4 ± 0.23	10.4 ± 0.17

[1] Estimated from hand cut samples of diet selected, n = 3 samples (short) and n = 6 samples (long); [2] N = Nitrogen; [3] Organic matter digestibility *in vitro*, expressed as a proportion; [4] Digestible organic matter in the dry matter *in vitro*, expressed as a proportion; [5] ME = Metabolisable energy

The DM (g/kg; $P<0.01$) content of the willow diet offered and the fibre (NDF; g/kg DM; $P<0.05$) content of the willow diet selected in both the long and short treatment groups increased linearly over time, while the total N (g/kg DM; $P<0.01$) content of the diet selected decreased (Fig. 4.1; t, days). This is reflected in the decreases in OMD (proportion; $P<0.05$) and ME (MJ/kg DM; $P<0.01$) over time (t, days; Fig. 4.2).

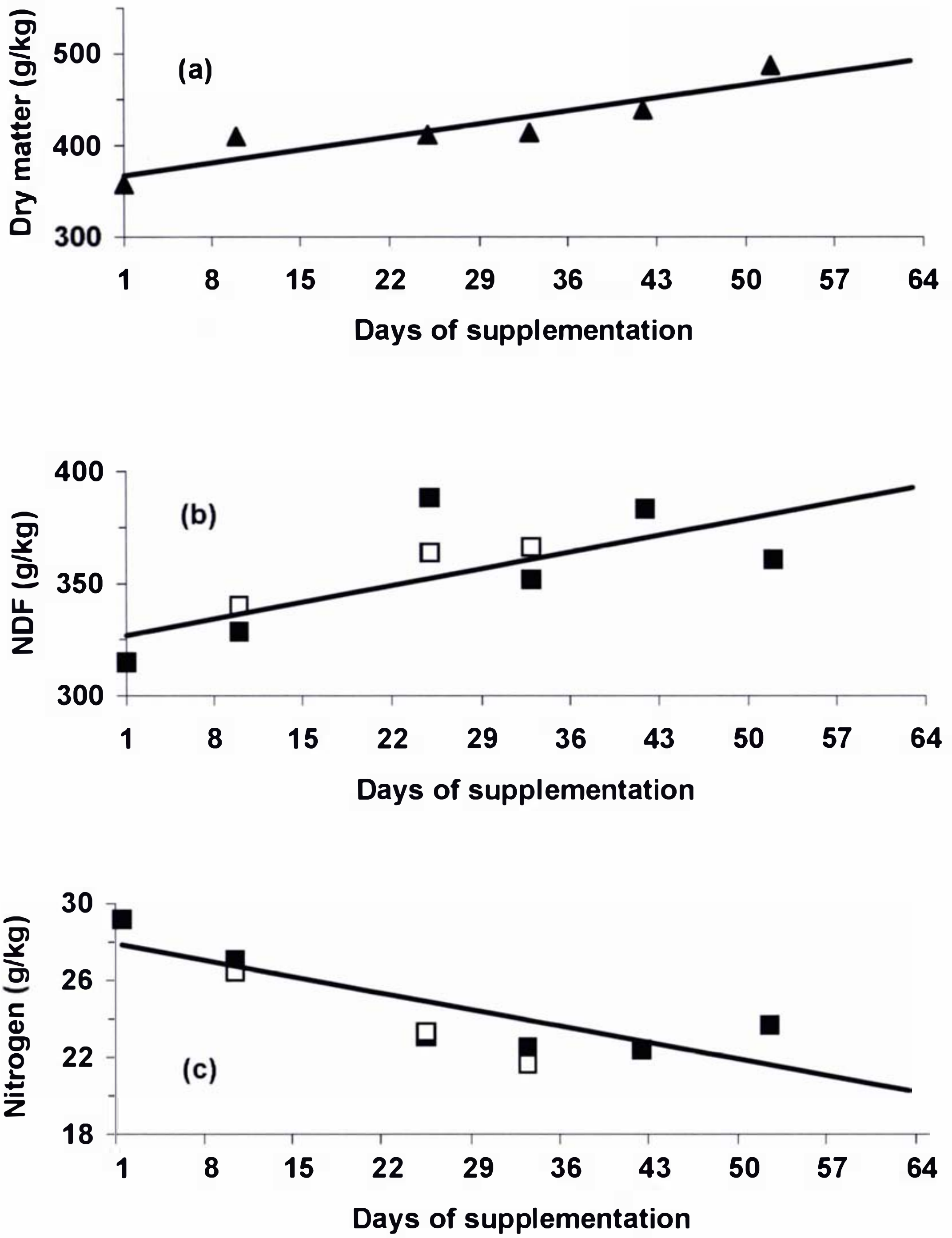

Figure 4.1 Change in the dry matter (DM; a), neutral detergent fibre (NDF; b) and nitrogen (N; c) content of Tangoio willow offered during the experiment, in g/kg DM. ▲ Pooled; ■ Long supplementation (63 days); □ Short supplementation (31 days)

DM =	365.0 +	2.0240t
SE	14.24	0.4401
P	***	**

$$NDF = 328.4 + 1.0489t$$

SE	11.62	0.3875
P	***	*

$$N = 27.67 - 0.1277t$$

SE	1.024	0.0341
P	***	**

Table 4.3 Carbohydrate and secondary compound content of the pasture and willow diet selected (g/kg DM) by ewes grazing low quality drought pastures and supplemented with willow trimmings (mean values with standard errors)

	Pasture[1]	Willow[2]
Fibre		
NDF[3]	603 ± 3.3	355 ± 8.0
ADF[4]	306 ± 2.2	250 ± 5.0
Secondary Compounds		
Lignin	39 ± 1.0	107 ± 1.7
Condensed Tannin[5]	ND	27 ± 0.7
Catechin + Epicatechin	0.1 ± 0.02	0.6 ± 0.15
Other Flavonoid Monomers	0.8 ± 0.11	8.5 ± 0.36
Salicin	NDT	2.0 ± 0.12
Other Phenolic Glycosides	1.0 ± 0.12	17.2 ± 0.97
Chlorogenic acid	0.02 ± 0.004	1.0 ± 0.12
Zearalenone (mg/kg)[6]	1.5 ± 0.29	0.1 ± 0.04
Trichothecenes (mg/kg)[6]		
Nivalenol	0.19 ± 0.045	ND[7]
Deoxy-nivalenol	0.26 ± 0.055	ND[7]

[1] Estimated from hand plucked samples of diet selected, n = 18 samples per treatment; [2] Estimated from hand cut samples (stem diameter<7mm) of diet selected, n = 9 samples per treatment; [3] NDF = neutral detergent fibre; [4] ADF = acid detergent fibre; [5] Extractable CT + bound CT; [6] Probably produced by contaminating *Fusarium* fungi; [7] Assumed to be zero; ND = not determined; NDT = not detectable

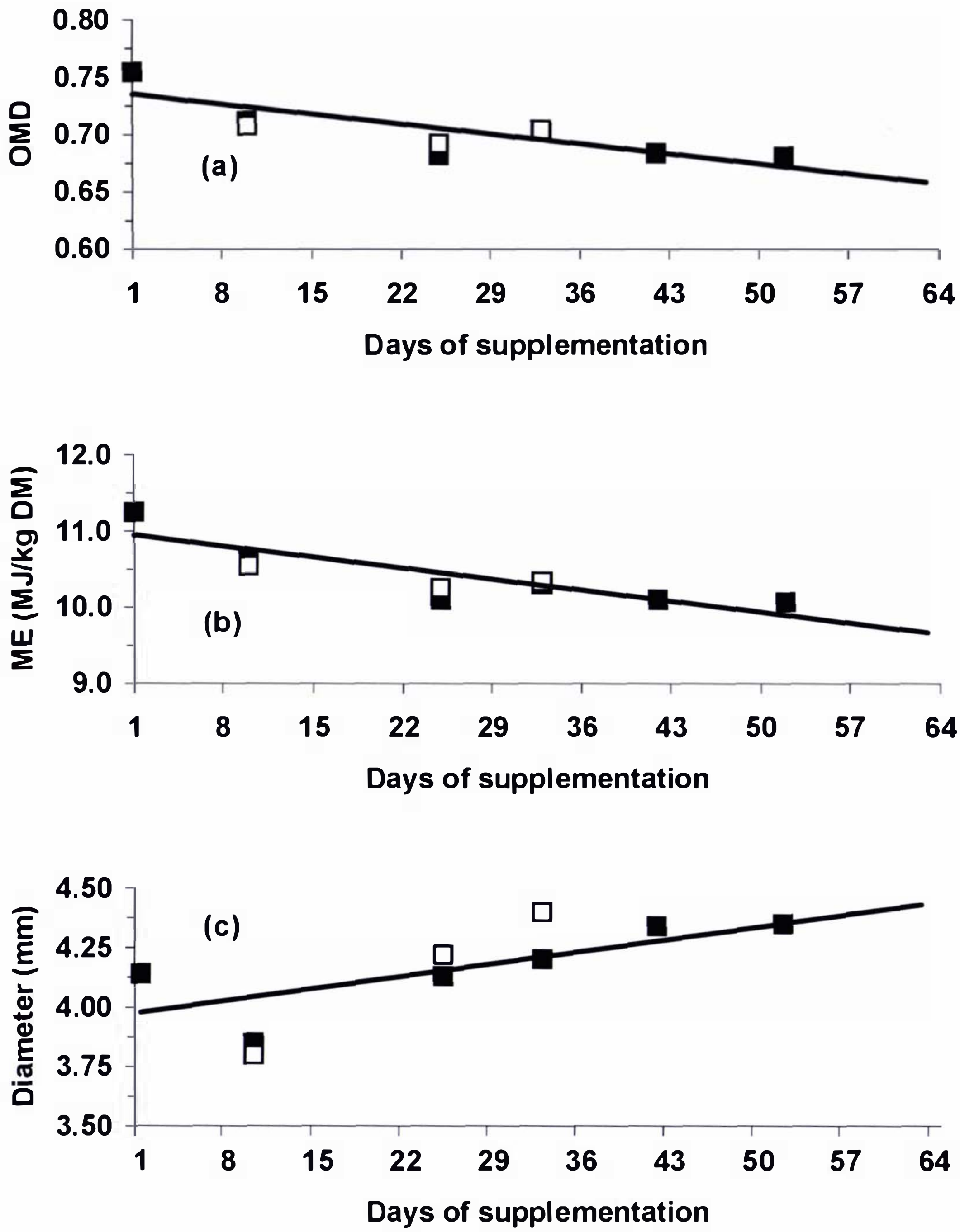

Figure 4.2 Change in the organic matter digestibility (OMD; a), metabolisable energy (ME; b) and stem diameter (D; c) of Tangoio willow consumed during the experiment. ■ Long supplementation (63 days); □ Short supplementation (31 days)

OMD =	0.73 –	0.0011t
SE	0.010	0.0003
P	***	*

$$ME = 10.88 - 0.0189t$$
SE 0.152 0.0051
P *** **

$$D = 3.91 + 0.0097t$$
SE 0.096 0.0032
P *** *

Diameter (D, mm) of stem eaten by the ewes increased significantly over time (t, days) for both the long and short supplementation treatments, with no difference in slopes and intercepts for individual calculated regressions. Thus a single common regression was calculated (Fig. 4.2c; $P<0.05$); mean diameter eaten was 4.2 mm. Mean DM intakes of willow for the long and short supplementation treatments were 0.26 kg DM/ewe/day and 0.27 kg DM/ewe/day, with no significant trend over time. Willow utilisation was 50% and 48% for the long and short treatments, respectively.

The willow diet selected by the ewes contained substantial concentrations of secondary compounds, including lignin, CT, salicin and other phenolic glycosides (Table 4.3). The willow diet selected contained considerably higher concentrations of lignin, 107 vs. 39 g/kg DM, and total phenolic glycosides, 19 vs. 1 g/kg DM than drought pasture (Table 4.3). Pasture consumed in this experiment contained no salicin, which is a common secondary compound found in willow species. A feature of this experiment was the presence of toxic concentrations of the fungal mycotoxin Z, 1.5 mg/kg DM and the presence of the fungal mycotoxins NIV, 0.19 mg/kg DM, and DON, 0.26 mg/kg DM, in the pasture diet during mating (Table 4.3). Z (mg/kg DM) concentration in the pasture increased from zero to over 2 mg/kg DM over the 63-day experimental period (t, days; $P<0.01$; Fig. 4.3).

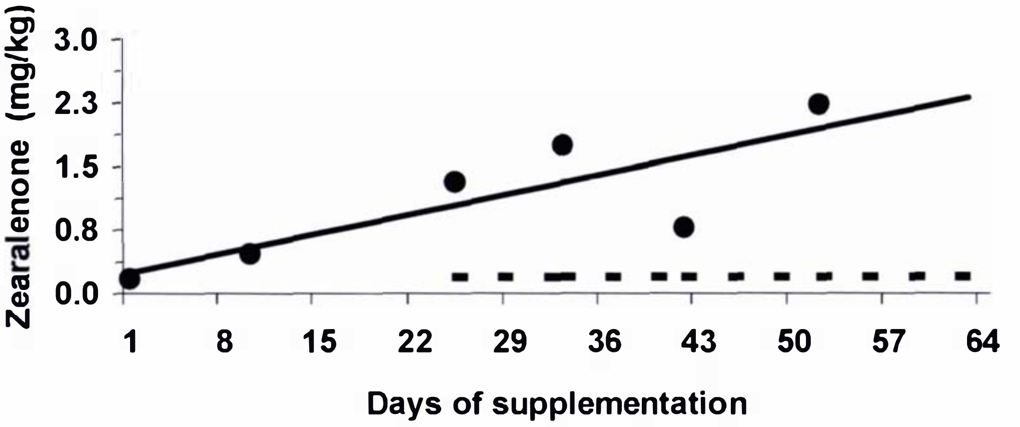

Figure 4.3 Change in the zearalenone (Z) concentration, in mg/kg DM, of drought pasture diet selected during the experiment. The broken line indicates the mating period.

$Z = 0.21 + 0.0333t$
SE 0.366 0.0113
P 0.58 **

4.4.2 Animals

All groups of ewes lost LW and BCS during the 63-day experimental period, with the long supplementation treatment significantly reducing LW loss and loss in BCS ($P<0.05$; Table 4.4). Both LW and BCS increased after the groups were joined together at the end of the experimental period (Fig. 4.4), with no differences between the three groups at the commencement of the lambing period.

There were no treatment effects on reproductive rate at scanning and lambing; therefore there were also no effects on conception rate and fecundity and no significant differences in lambing date. However the long treatment weaned 13 % units more lambs than control ewes ($P=0.12$; Table 4.4). This was due to a 9 % unit reduction in total post-natal lamb mortality ($P<0.05$; Table 4.4). Lamb mortality at birth did not differ between treatments ($P>0.05$).

Table 4.4 The effect of supplementation with willow trimmings for 0 days (control), 31 days (short supplementation) and 63 days (long supplementation) during the late summer/autumn, including mating, on live weight and body condition score change, reproductive rate, conception rate, fecundity, mean lambing date and total lamb mortality from birth to weaning (mean values with standard errors)

	Control	**Short Willow Supplementation**	**Long Willow Supplementation**	**SEM**
Change in Live Weight (g/day)	-147^{a}	-146^{a}	-96^{b}	4.5
Change in BCS (units)	-1.09^{a}	-1.05^{a}	-0.79^{b}	0.041
Reproductive rate[2]				
Scanning	128	128	128	5.6
Lambing	124	125	127	5.6
Docking	105	108	117	5.6
Weaning	103	107	116	5.8
Conception Rate[3]	93.9	94.0	97.0	2.16
Fecundity[4]				
Singles	67.0	66.7	69.2	4.94
Multiples	33.0	33.3	30.8	4.94
Mean Lambing Date	20 Aug	21 Aug	22 Aug	0.8 days
Total Lamb Mortality[5] (%)	17.1^{a}	14.2^{ab}	8.4^{b}	3.06

a,b. Means within rows with different superscripts differ significantly (P<0.05).
[1] n = 100 ewes per treatment; [2] Expressed as lambs per 100 ewes exposed to the ram; [3] Expressed as ewes pregnant per 100 ewes mated; [4] Expressed as lambs born per 100 ewes lambing; [5] Expressed as a percentage of the total number of lambs born for each treatment

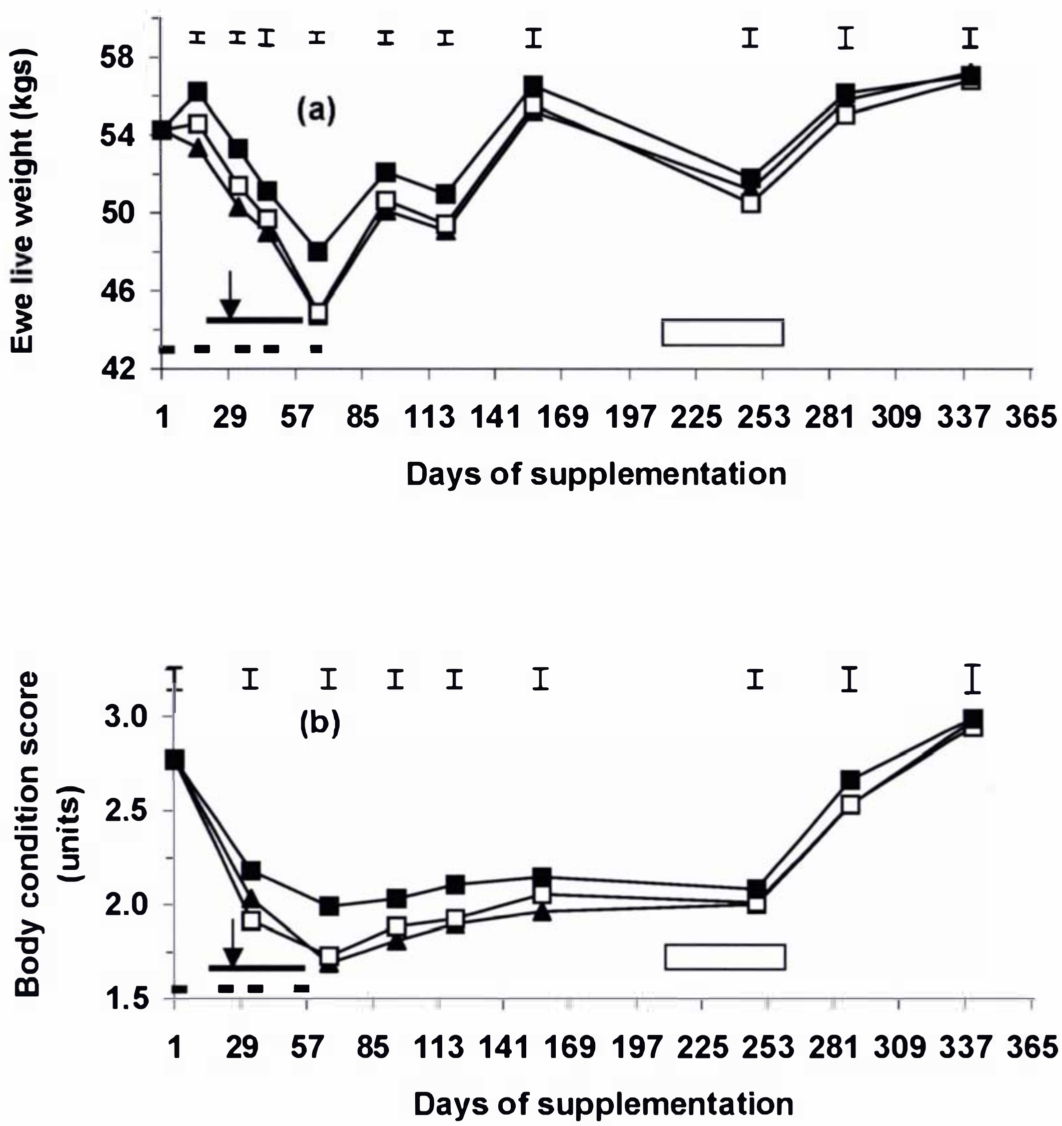

Figure 4.4 Change in mean ewe live weight (a) and body condition score (b) in ewes supplemented with willow trimmings for short, 31 days, and long, 63 days, periods when grazing drought pasture. The broken line indicates the long supplementation period and the solid line indicates the short supplementation period. The bar indicates the lambing period. ↓ Indicates the date rams were introduced. ■ Long supplementation; □ Short supplementation; ▲Control; I, Pooled SEM.

Willow supplementation had only small effects on birth weight ($P<0.01$) and no effect on weaning weight of lambs (Table 4.5). At birth, male lambs born to ewes supplemented with willow were slightly heavier than those born to control ewes ($P<0.01$).

Table 4.5 The effect of supplementation with willow trimmings for 0 days (control), 31 days (short supplementation) and 63 days (long supplementation) during the late summer/autumn, including mating, in ewes grazing drought pastures on lamb birth and weaning weights (kilograms; mean values with standard errors)

		Control	Short Willow Supplementation	Long Willow Supplementation	SEM
Birth Weight					
Single					
	Male	5.8^{b}	6.1^{a}	6.1^{a}	0.12
	Female	5.6	5.6	5.9	0.13
Twin					
	Male	4.5^{b}	5.2^{a}	4.7^{b}	0.13
	Female	4.5	4.4	4.6	0.14
Weaning Weight					
Single					
	Male	31.8	31.4	31.3	0.79
	Female	28.6^{b}	29.1^{ab}	31.2^{a}	0.82
Twin					
	Male	26.0	26.5	24.4	0.88
	Female	24.7	25.6	24.0	0.92

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

4.4.3 Wool

Greasy fleece weight and staple length were generally similar for all groups, 3.0 ± 0.06 kg and 140 ● 1.9 mm, respectively, and showed no significant treatment effects.

4.5 Discussion

The objective of the current experiment, the third in a series of experiments (McWilliam *et al.* 2004a,b) supplementing ewes grazing low quality drought pasture with tree fodder during mating, was to determine the length of feeding (days) necessary to achieve reproduction responses to supplementation with willow trimmings. The experiment confirmed significant reductions in LW loss and loss in BCS in ewes supplemented for 63 days compared with unsupplemented control ewes (McWilliam *et al.* 2004a,b). The work was unable to define the length of supplementation (days) necessary to achieve an increase in reproductive rate at ultrasound scanning and lambing, due to problems associated with the high Z concentration in drought pasture grazed by ewes. However, the experiment did show that supplementation for 63 days, including mating, reduced lamb mortality after birth.

One of the factors that may help explain different responses to fodder tree supplementation, between years, is the year-to-year variation in composition of drought pasture grazed during mating. Table 4.6 provides a summary of the pasture available to all ewes in each trial and the performance of unsupplemented ewes, for trials conducted in 2001 (McWilliam *et al.* 2004a), 2002 (McWilliam *et al.* 2004b) and the present experiment, 2003. Calculated DM intake (DMI) declined progressively from 2001 to 2003, while LW loss progressively increased, probably due to low herbage masses in 2002 and to very low pasture nutritive value in 2003. Pasture Z concentration was lowest in 2002, highest in 2003 and intermediate in 2001; pasture OMD and crude protein (CP) content followed a converse pattern. Thus, drought pastures that were high in Z concentration also tended to be low in OMD and CP, explaining the low DMI and large LW loss of ewes in 2003. Nevertheless, reproductive rate of control ewes was low and similar between years, typical of drought conditions.

Table 4.6 Variation in the control drought pasture between years and its effect on calculated dry matter intake (DMI) and on animal performance

Year	Pasture Mass			Composition of Diet Selected					DMI	LWC[5]	Reproductive Rate
	Pre-grazing kg DM/ha	Post-grazing kg DM/ha	% Dead Matter[1]	OMD[2] proportion	ME[3] MJ/kg DM	CP[4] g/kg DM	Zearalenone mg/kg DM	Trichothecene mg/kg DM	kg/d	g/d	lambs born / 100 ewes mated
2001[6]	1040	531	84	0.52	7.6	111	0.58	0.14	0.67	-82	121
2002[7]	941	456	62	0.54	7.7	156	0.16	0.11	0.59	-103	131
2003[8]	1261	821	78	0.49	7.2	99	1.5	0.45	0.47	-147	124

[1] Pre-grazing; [2] OMD = Organic matter digestibility; [3] ME = Metabolisable energy; [4] CP = Crude protein; [5] LWC = Live weight change; [6] From McWilliam *et al.* 2004a; [7] From McWilliam *et al.* 2004b; [8] Present experiment

Table 4.7 The effect of supplementing ewes (100/group) grazing low quality drought pasture with willow / poplar (1.4 kg fresh/ewe/d for approximately 70 days) during mating upon reproductive performance (lambs/100 ewes mated) and lamb mortality between birth and weaning

	Control	Supplemented Willow or Poplar	SEM
Experiment 1 - 2001 Poplar Supplementation[1]			
Live Weight Change (g/day)	-82[a]	-67[b]	5.2
Scanning	122[b]	163[a]	5.7
Lambing	121[b]	155[a]	5.8
Weaning	96[b]	125[a]	6.4
Post-natal Mortality (%)[4]	20.3	16.3	
(lower limit, upper limit)[5]	(13.8, 28.7)	(11.2, 23.2)	
Experiment 2 – 2002 Willow Supplementation[2]			
Live Weight Change (g/day)	-103[a]	-86[b]	4.3
Scanning	132	148	6.8
Lambing	131	148	6.9
Weaning	106	126	7.4
Post-natal Mortality (%)[4]	17.3	12.1	
(lower limit, upper limit)[5]	(11.5, 25.2)	(7.7, 18.5)	
Experiment 3 – 2003 Willow Supplementation[3]			
Live Weight Change (g/day)	-147[a]	-96[b]	4.5
Scanning	128	128	5.6
Lambing	124	127	5.6
Weaning	103	116	5.6
Post-Natal Mortality (%)[4]	16.0	8.0	
(lower limit, upper limit)[5]	(10.4, 23.8)	(4.3, 14.4)	
Overall Post-natal Mortality[4]	17.8[a]	11.7[b]	
(lower limit, upper limit)[5]	(14.1, 22.3)	(8.7, 15.5)	

a,b. Means within rows with different superscripts differ significantly ($P<0.05$)
[1] From McWilliam *et al.* 2004a; [2] From McWilliam *et al.* 2004b; [3] Present experiment; [4] Statistically adjusted for year, treatment, sex and birth rank effects; [5] Lower and upper statistical limits at 95% confidence interval

The production and reproduction responses to a constant rate of tree fodder supplementation (1.4 kg/day fresh for approximately 70 days), in each of three years, are summarised in Table 4.7. The table highlights the consistent response of ewes to tree fodder supplementation; reduced LW loss in all three years, with scanning and lambing rates increased by 15 to 40% units when ewes grazed drought pasture with non-toxic Z concentrations (2001 and 2002). However, in 2003 tree fodder supplementation did not increase scanning and lambing percentages, despite increasing calculated DMI from 0.47 to 0.75 kg DM/ewe/day and increasing calculated CP intake from 47 to 91 g/day, for unsupplemented and supplemented ewes respectively (Table 4.8).

Table 4.8 The effect of supplementation with willow or poplar trimmings for 0 days (control), 31 days (short supplementation) and 63 days (long supplementation) during the late summer/autumn, including mating, in ewes grazing drought pastures on calculated dry matter (DM) intake (kg DM/ewe/day), calculated metabolisable energy (ME) intake (MJ ME/ewe/day), calculated crude protein (CP) intake (g/ewe/day) and calculated zearalenone intake (mg/ewe/day; mean values with standard errors)

	Control	Short Willow Supplementation	Long Willow Supplementation	SEM
DM Intake				
Pasture[1]	0.47	0.44	0.49	0.056
Willow	0	0.27	0.27	0.032
Total	0.47	0.63	0.75	0.073
ME Intake[2]				
Pasture	3.4	3.2	3.5	0.41
Willow	0	2.8	2.8	0.34
Total	3.4	4.6	6.3	0.55
CP Intake[3]				
Pasture	46.9	42.0	49.7	6.19
Willow	0	19.8	40.8	6.32
Total	46.9	61.8	90.5	7.80
g CP Intake / MJ ME Intake	13.8	13.4	14.4	
Zearalenone Intake[4]				
Pasture	0.64	0.70	0.77	0.110
Willow	0	0.01	0.02	0.005
Total	0.64	0.71	0.79	0.112

[1] Estimated from pasture mass measurements before and after grazing; [2] DM intake * mean ME concentration in MJ/kg DM; [3] DM intake * CP concentration; [4] Estimated from mean zearalenone intake during the supplementation period

Z is a non-steroidal oestrogen produced by *Fusarium sp.* of fungi that are commonly found in New Zealand pasture under hot, dry conditions. Z has been found to reduce reproductive performance in sheep as concentrations in the pasture increase and is generally considered to be detrimental to reproduction when pasture concentrations approach 1mg/kg DM (di Menna *et al.* 1987; Towers 1997). This is supported by the dose-response curve of Smith *et al.* (1990, 1992), which shows that increasing doses of Z linearly depress multiple ovulations and that this first becomes noticeable at an intake of approximately 1 mg Z/day; lower doses still depress multiple ovulations but the effects are less apparent. Fungal growth is highest during the ewe-mating period, in late summer/autumn (February to April). The current experiment showed no effect of Z on conception rate, which is consistent with results from Smith *et al.* (1990) and confirms that concentrations of Z normally found in New Zealand pasture (0.4 mg to 4.0 mg/kg DM; di Menna *et al.* (1987) are not likely to affect the incidence of ovulation, fertilisation rate and appear not to cause embryonic wastage. It is likely that the relatively high concentration of Z during mating (> 2 mg/kg DM), combined with the very low CP and ME content of the pasture, in 2003, suppressed the potential increase in reproductive rate in tree fodder supplemented ewes, due to increased fecundity, that has been found with tree fodder supplementation in previous experiments (McWilliam *et al.* 2004a,b; Pitta *et al.* 2004). Ingestion of oestrogenic mycotoxins that may be produced by the fungal contaminate *Melampsora larici populina* (poplar leaf rust) or an associate fungus, which occurred in ewes offered poplar in 2002 (McWilliam *et al.* 2004b), may also reduce ovulation rate similar to the effects of Z in the present experiment.

Fusarium fungal sp. found in NZ pasture, often produce more than one mycotoxin at the same time, making co-contamination of affected pasture common (di Menna *et al.* 1987; Towers 1997; Lauren *et al.* 1988,1992; Fink-Gremmels 1999). Trichothecenes are a group of mycotoxins produced by *Fusarium* sp. that can cause a variety of human and animal toxicities (Ueno 1977; Fink-Gremmels 1999). Trichothecenes may partly be responsible for animal 'ill-thrift' disorders (failure to grow or produce), which often occurs in the autumn under New Zealand grazing conditions (Lauren *et al.* 1988, 1992; Towers 1997). NIV and DON are common trichothecene toxins produced by *Fusarium* sp. in New Zealand pasture (Lauren *et al.* 1988, 1992) and were found to total 0.45 mg/kg DM in drought pasture grazed in the 2003 experiment; a 3 and 4-fold increase from the previous two experiments. In dosing experiments, Odriozola (1996) reported that LW gain was inversely proportional to the quantity of NIV consumed (doses of 0 to 24 mg/day) in young sheep grazing pasture. Litherland *et al.* (2004) showed that pasture concentrations of NIV plus DON of greater than 0.8 mg/kg DM were consistently associated with ill-thrift in young sheep grazing dry autumn pastures and suggested that other unidentified mycotoxins, produced by *Fusarium* or other species, may also be involved. It is possible that trichothecene toxins in the pasture diet consumed by the ewes may have contributed to the large LW loss that occurred in all ewes in 2003.

The 2001 experiment showed that ewes consuming 330g DM/day of poplar increased reproductive rate at lambing by 34% units, while reducing the amount of poplar during mating consumed to 180g DM/d resulted in an increase in lambing rate of 20% units, compared with unsupplemented control ewes (McWilliam *et al.* 2004a). It was expected that willow supplementation, even if only for 4.5 weeks, should still have resulted in an increase in reproductive rate compared with control ewes, but this could not be shown in the present experiment, probably due to the effects of Z in the pasture diet consumed.

One of the unexpected results of the three grazing experiments was a reduction in post-natal lamb mortality from willow/poplar supplementation during mating. Increases in reproductive rate are usually associated with increases in lamb mortality, being typically 15 % and 25 % for single- and twin-born lambs, respectively (Meat and Wool Innovations 2003). Initial results showed that despite significant increases in fecundity in supplemented ewes in 2001 (McWilliam *et al.* 2004a) and 2002 (McWilliam *et al.* 2004b), post-natal lamb mortality was not increased. This, combined with the significant reduction in lamb mortality in ewes fed willow in 2003 ($P<0.05$; Table 4.4), suggested that tree fodder supplementation during mating may have reduced lamb mortality in all three experiments, but that the effect was masked by the increase in reproductive rate in the first two experiments. Thus, further statistical analysis was carried out to adjust all mortality data to equal birth rank and sex. This analysis showed that total post-natal lamb mortality for unsupplemented ewes and supplemented ewes over three experiments was 17.8% and 11.7%, respectively; a 34% reduction ($P<0.05$; Table 4.7), with no interaction between supplementation and years. Experiments involving mating ewes grazing CT-containing *Lotus corniculatus* for nine weeks have also shown substantial reductions in post-natal lamb mortality, despite increases in reproductive rate at scanning and lambing (Ramírez-Restrepo *et al.* 2004). The mechanism for this is unknown; however, it is believed to be due to increased absorption of essential amino acids, which is a characteristic of feeding CT-containing forages, at a critical point in early embryonic development (Barry *et al.* 2004).

The three experiments discussed in this paper were designed as reproduction experiments in which 100 ewes/group were adequate to determine significant responses in scanning and lambing percentages, but it appears that forage tree supplementation during mating may also reduce lamb mortality. An analysis of the data from the three experiments (Table 4.9) shows that much larger groups of ewes are needed to consistently detect significant reductions in lamb mortality. Hence, in future experiments of this type, much larger ewe numbers/group are needed, if the effects of supplementation during mating and early pregnancy on post-natal lamb mortality are to be detected at smaller magnitudes.

Table 4.9 Number of ewes needed to detect reductions in lamb mortality assuming probability of error type I, α=0.05, and probability of error type II, β=0.20

Reduction in Post-natal Lamb Mortality[1] (%)	**Ewes/Group**		
	Experiment 1 (2001)	**Experiment 2 (2002)**	**Experiment 3 (2003)**
20	1057	976	1031
30	465	430	454
40	245	227	240
50	146	135	143

[1] Assumed to be 17.8% mortality in lambs from control ewes

4.6 Conclusion

Results from three years of experimentation have shown that supplementing ewes with poplar and willow tree fodder during a summer/autumn drought will reduce live weight loss and loss in body condition and can substantially increase reproductive rate, as long as pasture or tree material is not contaminated with fungi that produce oestrogenic mycotoxins. Further research is needed to quantify the effects of different lengths of tree fodder supplementation prior to and during mating on reproductive rate. Fodder tree supplementation during mating also reduced post-natal lamb mortality; averaged over all three experiments, mortality was reduced from 17.8 to 11.7 %, with the effect being present in all years.

4.7 Acknowledgements

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CHAPTER 5

IN VIVO DIGESTIBILITY EXPERIMENTS

Organic matter digestibility of poplar (*Populus spp.*) and willow (*Salix spp.*) forage trees and its *in vitro* prediction

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5.1 Abstract

Trimmings from Poplar (*Populus*) and Willow (*Salix*) trees are used increasingly as supplementary feed for livestock in summer-dry and drought prone regions of New Zealand. The present experiment aimed to measure in *vivo* organic matter digestibility (OMD) and digestibility of organic matter in the dry matter (DOMD) in tree fodder and investigated if the *in vitro* system of Roughan and Holland (1977) can be used to predict *in vivo* OMD and DOMD in poplar and willow tree fodder, which contains high concentrations of secondary compounds, including condensed tannin (CT). *In vivo* work showed that the digestibility of poplar and willow tree fodder declined from late spring to autumn ($p<0.05$) and that this decline was much smaller than the decline in digestibility of grass-based pastures in New Zealand over the same time period. Mean metabolisable energy (ME) concentrations and digestibilities were generally higher for willow than for poplar. The *in vitro* enzymatic system of Roughan and Holland (1977) can be used to predict *in vivo* digestibility of tree fodder. A standard curve using *in vivo* values determined with animals fed tree fodder would be preferable, due to the very different chemical composition of pasture and tree fodder, particularly the greater concentration of secondary compounds in willow and poplar. However, the accuracy and the range of prediction need to be improved. Willow and poplar had similar ME concentrations to high quality lucerne hay; willow trimmings also had similar ME and CT concentrations to vegetative birdsfoot trefoil (*Lotus corniculatus*), a high quality forage legume.

Keywords: Drought feeding; Poplar (*Populus* sp.) supplementation; Condensed tannins; Phenolic glycosides; Willow (*Salix* sp.) supplementation

5.2 Introduction

Trimmings from Poplar (*Populus*) and Willow (*Salix*) trees are used increasingly as supplementary feed for livestock in summer-dry and drought prone regions of New Zealand (Charlton 2003; Olsen & Charlton 2003). Poplar and willow tree fodder contain substantial concentrations of secondary compounds, principally condensed tannins (CT; 7 to 52 g/kg DM) and phenolic glycosides (17 to 34 g/kg DM; McWilliam *et al.* 2004a,b). Secondary compounds may influence *in vivo* digestibility and the ability of *in vitro* methods to predict *in vivo* digestibility. Several grazing trials have been completed examining the effect of willow/poplar supplementation on the reproductive performance of ewes; however, there is a lack of information available on *in vivo* digestibility of tree fodder (McWilliam *et al.* 2004a,b). McCabe and Barry (1988) reported the only *in vivo* digestibility trial with willow forage trees; however, there has been no investigation into the validity of *in vitro* techniques for predicting *in vivo* digestibility of tree fodder.

In grazing experiments it is necessary to predict the organic matter digestibility (OMD) and digestible organic matter in the dry matter (DOMD) in the diet of animals. One technique for determining *in vitro* digestibility is that of Roughan and Holland (1977), and involves neutral detergent extraction of ground herbages, followed by an incubation period at 50°C with fungal cellulase (3.2.1.4; International Union of Biochemistry 1984) and hemicellulase enzymes. This technique was originally validated to predict the *in vivo* digestibility of dry matter (DMD) and OMD, in non CT-containing temperate and tropical grasses and temperate legumes, from *in vitro* values. It is clear from research done by Ramírez-Restrepo (2004) that a separate birdsfoot trefoil (*Lotus corniculatus*) standard curve is necessary for predicting the *in vivo* digestibility of CT-containing forages, such as birdsfoot trefoil, relative to non-CT containing forages such as perennial ryegrass (*Lolium perenne*; 0.80)/white clover (*Trifolium repens*; 0.20) pasture.

The objectives of the present research were to measure *in vivo* OMD and DOMD in poplar and willow tree fodder, as it changes from leaf formation in the spring to leaf fall in the autumn, and then to use diet samples from these *in vivo* studies as standards to investigate if the *in vitro* system of Roughan and Holland (1977) can be used to predict *in vivo* OMD and DOMD of poplar and willow tree fodder, which contain high concentrations of secondary compounds.

5.3 Materials and Methods

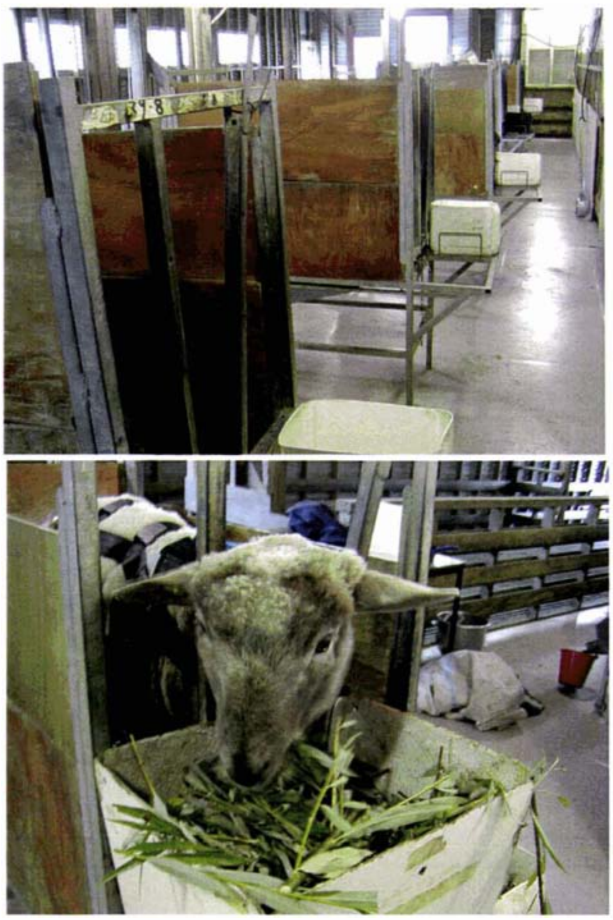
5.3.1 *In Vivo* Digestibility

5.3.1.1 Tree Fodder

Poplar (*Populus deltoides x nigra*, clone Veronese) and willow (*Salix matsudana* x *alba*, clone Moutere) tree trimmings were harvested, from Greater Wellington Regional Council's Akura Nursery near Masterton New Zealand. Three bundles of trimmings, approximately 35 kg per each, were harvested from approximately 15 stools with hand-shears twice each week. One bundle was delivered to the laboratory and fed to the trial lambs each day, with the two extra bundles stored in a room at 4°C to minimise dehydration of the fodder. Harvested material was approximately 1 to 2 m in length with a basal diameter of less than 20 mm. The poplar and willow fodder was chopped into 12 cm lengths and all leaf material plus stem less than 8 mm in diameter for poplar and less than 6 mm for willow, was offered to the lambs, which corresponded with the diameter selected by ewes supplemented with willow and poplar trimmings in grazing trials (McWilliam *et al.* 2004a,b).

5.3.1.2 Animals and Data Collection

Seven *in vivo* digestibility trials were conducted at the following times; early April 2001 (poplar), February, March and April 2002 (all poplar), and December, March and April 2003 (all willow). Each 14-day trial involved six male cryptorchid lambs, individually fed in metabolism cages. Lamb live weight was recorded at the start and the finish of each trial. The first 7 days of each trial was an adjustment period for the lambs to the cages and to the new feed. This also allowed feed intake of the lambs to stabilise. Data was collected over the final 7-day period. Throughout the 14-day trial period fresh tree fodder was offered twice daily, at 10.00 hour and 15.00 hour, to the lambs at an amount that allowed a residual of 10 to 15% of the total feed offered to be left by the lambs. Water was available *ad libitum*.



a

b

Plate 5.1 Metabolism crates used for digestibility trials (a) and lamb pictured consuming willow tree fodder under experimental conditions (b).

During the collection period, the feed offered and the residue left by each lamb was weighed daily, with sub-samples collected for DM determination (samples dried for 24 hours at 80°C) and for laboratory analysis (stored at -20°C). Faecal material from each lamb was weighed daily for 7 days, starting on the second day of the collection period, and stored at -20°C. At the end of each experiment the faecal material was thawed and the seven samples collected from each lamb were combined and thoroughly mixed. For each lamb, triplicate sub-samples were collected from the pooled faecal material for DM determination. Samples were dried for 48 hours at 80°C in a forced-air oven (Contherm, Thermotec 2000, New Zealand). Additional sub-samples from the pooled faecal material of each animal were stored at -20°C for laboratory analysis.


a
b

Plate 5.2 Willow fodder offered to lambs in digestibility trials (a) and willow fodder refused (b).

5.3.2 Grazing Trials

Grazing experiments were conducted at Massey University Riverside Farm, in the summer-dry region of Wairarapa, New Zealand, in the summer/autumn of 2001, 2002 and 2003. The purpose of the experiments was to determine the production and reproduction benefits of supplementing ewes grazing drought pasture, with poplar and/or willow tree trimmings for approximately 70 days, including mating; details from McWilliam *et al.* (2004a,b) and McWilliam unpublished. Samples of pasture and tree fodder were collected from each of these experiments to represent the diet consumed by the ewes and were stored at -20°C for laboratory analysis, including *in vitro* digestibility; sample collection methods are described in McWilliam *et al.* (2004a,b). Poplar samples were collected in 2001 and 2002 and willow samples were collected in 2002 and 2003.

A further trial was conducted, in the summer/autumn of 2004 on Fernglen Farm, in the Wairarapa, and involved ewes grazing a specialised fodder crop of densely planted (4000 trees/ha) willow trees coppiced to a height of 0.5 m. Ewe production and reproduction parameters were measured with samples of pasture and tree fodder collected to represent the diet consumed by the ewes and stored at -20°C for laboratory analysis, including *in vitro* digestibility.

5.3.3 *In Vitro* Digestibility

In vivo digestibility of poplar and willow diet consumed by ewes in the three grazing trials was predicted using an *in vitro* standard curve constructed using the digestibility coefficients from the seven *in vivo* digestibility trials. *In vivo* digestibility of pasture samples, from the same grazing trials, was predicted using an *in vitro* standard curve of perennial ryegrass (0.80) : white clover (0.20) pasture, the most commonly grazed forage in New Zealand. Thus, the tree fodder and pasture standard curves could be compared. To test repeatability, the two standard curves (fodder tree and pasture) were run in the same *in vitro* batch on three separate occasions, corresponding to the analyses of field samples taken during the three grazing experiments.

5.3.4 Laboratory Analysis

All samples of feed offered, feed residue and faeces and pasture, willow and poplar were freeze-dried, using a Cuddon 0610 freeze drier (W.G.G. Cuddon Ltd, Blenheim, New Zealand), and ground to pass through a 1mm diameter sieve (Wiley mill, USA) before laboratory analysis. Feed offered, feed residue and faeces samples were analysed for DM, organic matter (OM) and gross energy (GE; kJ/g DM). OM was determined by ashing samples for 16 hours at 550°C and GE was determined using an adiabatic bomb calorimeter (Gallenkamp, UK). Forage samples were also analysed for nitrogen (N), neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin. Total N concentration was determined using the Dumas method (Leco Corporation 1994). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined by the detergent procedures of Robertson and Van Soest (1981) and Van Soest *et al.* (1991), with alpha amylase (BDH, Poole, UK) being added during NDF extraction; sodium sulphite was not added.

CT fractions (acetone/water-extractable, protein-bound and fibre-bound) were determined using the butanol-HCL colorimetric procedure (Terrill *et al.* 1992); total CT concentration was then calculated by summing the three fractions. All CT concentrations were determined using CT extracted from *Lotus pedunculatus* as a reference standard (Jackson et al. 1996). Phenolic glycoside concentration was determined using the high-performance liquid chromatographic procedure of Meier *et al.* (1988); the method also allowed measurement of flavonoid monomers.

In vivo digestiblities of DM, OM, digestible organic matter in the dry matter (DOM) and energy and metabolisable energy (ME) concentration were calculated. ME/kg DM was calculated as DOMD (kg DOM/ kg DM) multiplied by 16.3 (Drew & Fennessy 1980).

In vitro digestibility of ground freeze-dried herbage was performed using the technique of Roughan and Holland (1977), which has an initial solubilization step with hot (90 to 96°C) neutral detergent solution, followed by centrifugation and triplicate residue washing. Residues are then incubated with standardised fungal (*Trichoderma reesei*) cellulase and hemicellulase enzymes at 50°C for 5 hours, separated by centrifugation and then incubated for a further 15 hours. The technique therefore measures the combined total of solubilization plus enzymatic cell wall degradation.

5.3.5 Statistical Analysis

For forage tree harvested in each year, analysis of variance using repeated measures for *in vivo* digestibility of DM, OMD, DOMD and energy and ME concentration were performed using the statistical package of SAS (2001). The linear model considered the fixed effects of diet, with dry matter intake as a covariate. The slopes and intercepts of *in vivo* versus *in vitro* standard curves were compared using PROC REG of SAS (2001).

5.4 Results

5.4.1 *In vivo* digestibility

The digestibility of poplar and willow tree fodder declined from late spring to autumn ($p<0.05$; Table 5.1); however, the decline in *in vivo* digestibility of GE, DM, OM and DOMD and ME concentration with the advancing growing season, was not large, with a relatively compact range of values. Mean ME concentration and digestibilities were generally higher for the willow than poplar, with no differences between the poplar diets fed in mid autumn, in 2001 and 2002.

Table 5.1 Chemical composition, daily intake, *in vivo* digestibility of gross energy (GE), dry matter (DM) and organic matter (OM), digestible organic matter in the dry matter (DOMD) and metabolisable energy concentration of poplar cultivar 'Veronese' and willow cultivar 'Moutere' at different growth stages, determined with cryptorchid weaned lambs (mean values ± SEM for 6 lambs/group). Statistical comparisons apply within each year only

	2001	2002			2003		
	Poplar	Poplar			Willow		
	mid autumn	late summer	early autumn	mid autumn	early summer	early autumn	mid autumn
	1 - 8 Apr	29 J – 4 Feb	10 – 16 Mar	14 – 20 Apr	11 – 17 Dec	5 – 11 Mar	7 – 13 Apr
Chemical composition (g/kg DM)							
Total N	22.4	30.0	21.9	21.4	27.3	22.7	18.8
NDF	404	397	431	374	356	425	457
ADF	257	260	266	223	250	295	307
Lignin	103	83	124	98	90	92	106
Lamb Live Weight (kg)							
	44.7 ± 1.05	36.2 ± 0.20	41.3 ± 0.36	43.7 ± 0.46	38.5 ± 0.51	40.4 ± 0.51	40.1 ± 0.60
Intake (kg DM/day)							
	1.12 ± 0.053	0.75 ± 0.032	1.04 ± 0.020	1.11 ± 0.026	1.01 ± 0.034	0.91± 0.029	0.93 ± 0.029
Digestibility							
DM[1]	0.611 ± 0.007	0.654 ± 0.009^{a}	0.595 ± 0.004^{c}	0.613 ± 0.006^{b}	0.675 ± 0.008^{a}	0.660 ± 0.008^{a}	0.622 ± 0.008^{b}
OM[2]	0.635 ± 0.009	0.674 ± 0.006^{a}	0.617 ± 0.001^{b}	0.648 ± 0.005^{a}	0.701 ± 0.005^{a}	0.677 ± 0.010^{b}	0.638 ± 0.01^{c}
DOMD[1]	0.576 ± 0.007	0.615 ± 0.009^{a}	0.555 ± 0.005^{c}	0.580 ± 0.006^{b}	0.630 ± 0.007^{a}	0.625 ± 0.007^{a}	0.589 ± 0.007^{b}
Energy	0.605 ± 0.009	0.661 ± 0.012^{a}	0.573 ± 0.006^{c}	0.607 ± 0.008^{b}	0.656 ± 0.009^{a}	0.651 ± 0.009^{a}	0.608 ± 0.009^{b}
Metabolisable Energy (MJ/kg DM)							
	9.39 ± 0.123	10.02 ± 0.146^{a}	9.04 ± 0.074^{c}	9.46 ● 0.101^{b}	10.27 ± 0.110^{a}	10.18 ± 0.115^{a}	9.59 ± 0.114^{b}

[1] Expressed as a proportion of DM
[2] Expressed as a proportion of OM
[a,b,c] Differences between means significant ($p<0.05$)

5.4.2 *In vitro* digestibility

In vivo digestibility of willow and poplar tree fodder could be predicted from its *in vitro* OMD (Table 5.2) and DOMD (Table 5.3), with the linear regressions accounting for 39 to 60 percent of the variability (r^2) and were similar for the four grazing experiments. The perennial ryegrass/white clover pasture standard curve accounted for a much higher level of the variability, 94 to 99 percent, due to the greater range of digestibility values that were available compared with tree fodder. In the four experiments, the slopes were not significantly different between the pasture and tree fodder standard curves for OMD and DOMD; however, in 2001 the intercept was significantly lower for the forage tree standard curve than the pasture standard curve for OMD ($p=0.07$; Fig 5.1a) and DOMD ($p<0.05$; Figs 5.2a). The intercepts were not significantly different in 2002 (Figs 5.1b and 5.2b), 2003 (Figs 5.1c and 5.2c) and 2004. The most appropriate measure of precision, the residual standard deviation (RSD), was similar for the perennial ryegrass/white clover and fodder tree standard curves (Tables 5.2 and 5.3); however, the forage tree standard curve is valid over a much shorter range than the pasture standard curve.

Table 5.2 Standard curves for the prediction of *in vivo* organic matter digestibility (OMD; y) from *in vitro* OMD (x) for perennial ryegrass/white clover (*Lolium perenne*/*Trifolium repens*) pasture or poplar and willow tree fodder

Experiment	Pasture Curve		n	r^2	RSD	Tree Fodder Curve		n	r^2	RSD
2001	y = 0.6539x + 23.0475		5	0.956	3.523	y = 0.7013x + 14.9896		4	0.524	3.286
SE	0.08080	5.30241				0.47259	33.12861			
2002	y = 0.7170x + 15.6582		5	0.975	2.653	y = 0.7084x + 16.8692		7	0.474	2.970
SE	0.06606	4.61083				0.30456	20.72876			
2003	y = 0.7377x + 17.5888		6	0.944	3.366	y = 0.7413x + 17.1627		7	0.538	2.778
SE	0.08976	5.84746				0.30709	20.08230			
2004	y = 0.6358x + 24.6430		6	0.948	3.242	y = 0.6810x + 21.0449		7	0.596	2.597
SE	0.07434	4.82266				0.25054	16.41393			

Table 5.3 Standard curves for the prediction of *in vivo* digestible organic matter in dry matter (DOMD; y) from *in vitro* DOMD (x) for perennial ryegrass/white clover (*Lolium perenne*/*Trifolium repens*) pasture or poplar and willow tree fodder

Experiment	Pasture Curve		n	r^2	RSD	Tree Fodder Curve		n	r^2	RSD
2001	y = 0.6508x + 20.9188		5	0.966	2.548	y = 0.6309x + 17.7553		4	0.544	2.732
SE	0.07087	4.17210				0.40865	26.09366			
2002	y = 0.7352x + 13.1279		5	0.986	1.633	y = 0.6524x + 18.5346		7	0.395	2.787
SE	0.05080	3.17006				0.36119	22.72271			
2003	y = 0.7387x + 15.4335		6	0.968	1.954	y = 0.7859x + 12.5669		7	0.543	2.421
SE	0.06709	3.86063				0.32219	19.27768			
2004	y = 0.6142x + 22.8149		6	0.967	1.979	y = 0.6781x + 18.7987		7	0.591	2.290
SE	0.05650	3.24935				0.25210	15.16891			

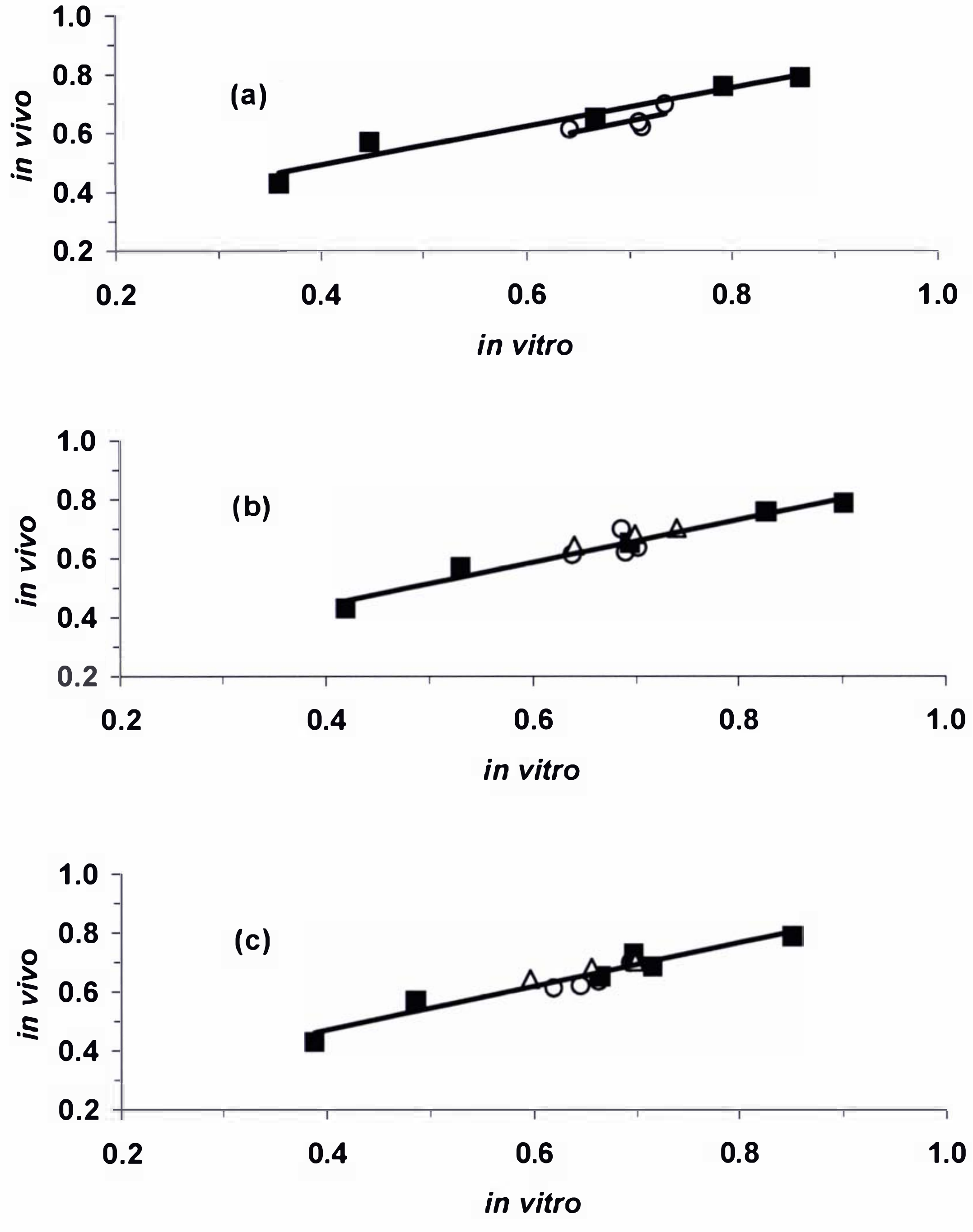


Figure 5.1 2001 (a), 2002 (b) and 2003 (c) pasture and tree fodder standard regressions for organic matter digestibility (proportion). ■ Pasture; ○ Poplar point; △ Willow point

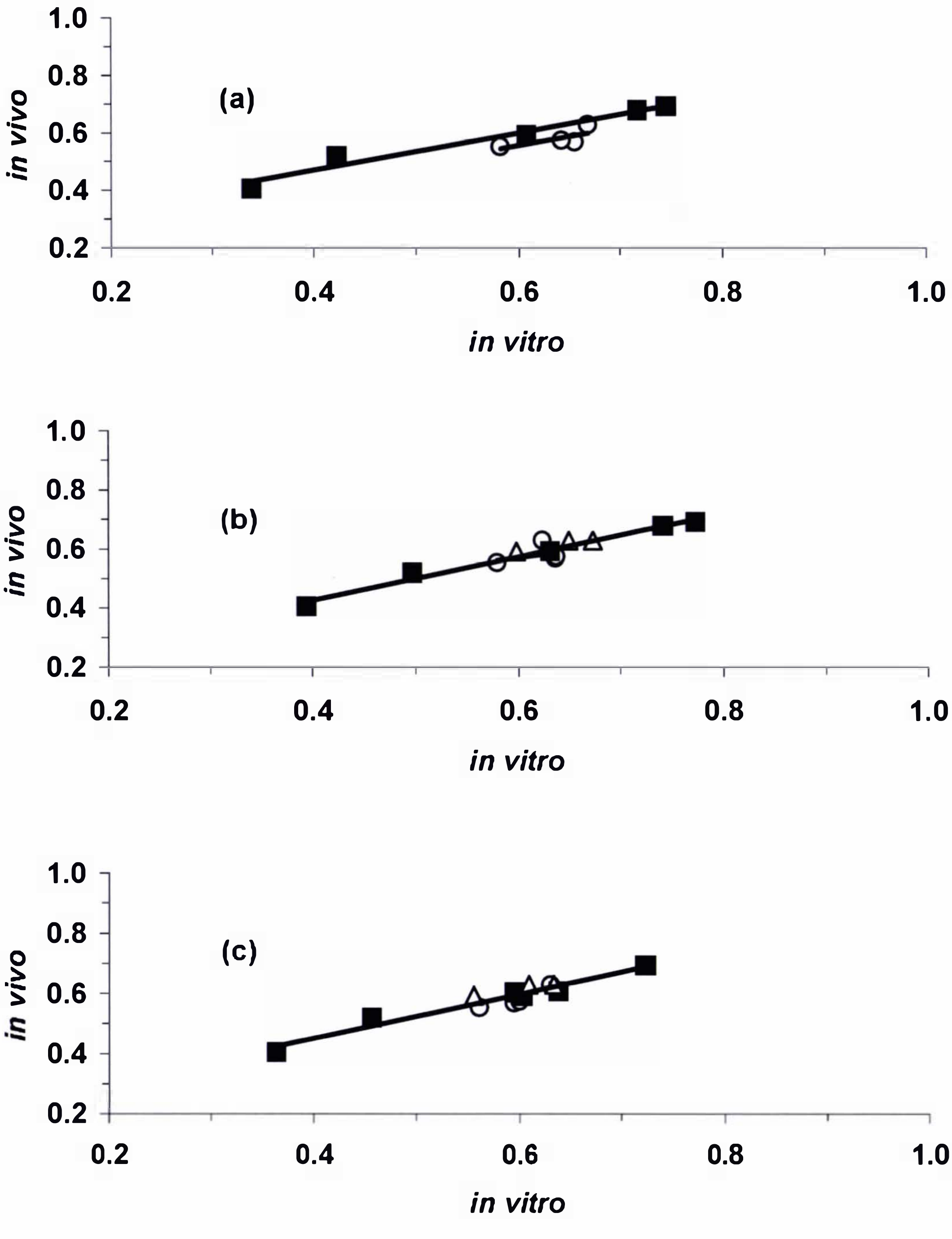


Figure 5.2 2001 (a), 2002 (b) and 2003 (c) pasture and tree fodder standard regressions for digestible organic matter in the dry matter (proportion).
■ Pasture; ○ Poplar point; △ Willow point

5.5 Discussion

The first objective of these experiments was to measure the change in *in vivo* OMD and DOMD of poplar and willow tree fodder, fed to sheep, from leaf formation in the spring to senescence and leaf fall in the autumn. The second objective was to determine if the enzymatic *in vitro* system of Roughan and Holland (1977) can be used to accurately predict *in vivo* OMD and DOMD of poplar and willow tree fodder. One of the most significant findings was that the decline in *in vivo* OMD and DOMD from spring to autumn is much smaller than the decline in digestibility of grass-based pastures in New Zealand over the same time period (Waghorn & Barry 1987). This resulted in relatively high OMD (0.62 to 0.70) and ME (9.0 to 10.3 MJ/kg DM) values for poplar and willow tree fodder, which changed little with advances in the growing season, and helps explain why willow and poplar are effective supplements to livestock grazing drought pasture (McWilliam *et al.* 2004a,b). Also, the enzymatic system of Roughan and Holland (1977) can be used to predict *in vivo* digestibility of tree fodder using an *in vitro* standard developed with digestibility coefficients from *in vivo* digestibility trials with animals fed poplar and/or willow tree fodder preferable.

Ramírez-Restrepo (2004) found that the slopes and intercepts of birdsfoot trefoil *in vivo* vs. *in vitro* standard curves were consistently and significantly different from the standard curves for perennial ryegrass-based pastures in each of six experiments. Using a standard curve involving *in vitro* data from perennial ryegrass/white clover pasture to predict *in vivo* digestibility of birdsfoot trefoil led to a bias in the prediction. The authors concluded that a more valid and precise prediction of *in vivo* digestibility could be made if birdsfoot trefoil standards were used when unknown birdsfoot trefoil samples were being evaluated and that separate standard curves may be needed for different CT-containing forages.

A separate standard curve may also be needed for CT-containing tree fodder; however, differences between standard curves for forage trees and those for pasture, which contain only trace amounts of secondary compounds, were very small in the present work. The 2001 grazing experiment showed that the standard curve prepared with perennial ryegrass/white clover pasture over-estimated the actual digestibility of poplar fodder by a small but significant amount. However, in the grazing experiments in

2002, 2003 and 2004 this over-estimation was not repeated. The reason for the over-estimation in 2001 is not known; however, the *in vitro* method of Roughan and Holland (1977) extracts soluble substances in the initial solubilization step and therefore assumes them completely digested when they may be digested less than this *in vivo*. One example is CT, which is not digested at all (Terrill *et al.* 1992).

When using *in vitro* methods to predict *in vivo* digestibility, it is necessary to use a standard that represents the chemical composition of the fodder being analysed. Thus, due to the very different chemical compositions of pasture and tree fodder, particularly the greater concentration of secondary compounds in willow and poplar, a tree fodder standard curve would be preferable when predicting *in vivo* digestibility, using *in vitro* methods. However, the accuracy and the range of prediction need to be improved. One reason for the reduced precision is the compact range of *in vivo* data points in the present study. Higher and lower data values need to be added in future studies.

Willow and poplar tree fodder is substantially lower in fibre and higher in ME concentration, compared with drought pasture, and is similar in digestibility and ME to good quality lucerne hay (*Medicago sativa*), a common legume feed supplement to livestock during drought (Table 5.4). Birdsfoot trefoil is considered a high quality forage legume for summer-dry regions and is known to be beneficial for increasing livestock production due to its excellent nutritional characteristics and to its beneficial CT concentration (Terrill *et al.* 1992; Min *et al.* 2003; Ramírez-Restrepo *et al.* 2004). Willow trimmings are similar to vegetative birdsfoot trefoil in both ME & CT concentration (Table 5.4). However, unlike lucerne hay and forage crops such as birdsfoot trefoil, tree fodder does not have to be specially sown and harvested or purchased for fodder. Some 1.44 million willow and poplar trees already exist on drought prone North Island East Coast pastoral land, in New Zealand, and 30 to 40 thousand more are planted every year to prevent soil erosion (Charlton 2003, Moore *et al.* 2003; Olsen & Charlton 2003). These trees can be trimmed at little or no cost in times of drought. Thus there is a supplementary resource that already exists on East Coast pastoral farms which is under utilised.

Table 5.4 Comparison of metabolisable energy (ME) concentration and chemical composition of poplar and willow tree fodder with that of other forages commonly fed to grazing livestock in New Zealand over the late summer/autumn period

	ME[1]	Total N	NDF	CT	Total Flavonoid Monomers[2]	Total Phenolic Glycosides[3]
	MJ/kg DM	g/kg DM				
Drought Pasture						
McWilliam *et al.*(2004a)	7.6	18	623	1.5	ND	ND
McWilliam *et al.*(2004b)	7.7	25	571	ND	2	2
Pitta *et al.* (2004)	7.7	23	588	2.6	2	2
McWilliam unpublished	7.2	16	603	ND	1	1
Non-Drought Summer Pasture[4]	9.6	26	463	1.6	6	11
Poplar						
McWilliam *et al.*(2004a)	9.7	28	390	7	9	22
McWilliam *et al.*(2004b)	9.7	27	404	19	8	17
Willow						
McWilliam *et al.*(2004b)	10.1	26	381	52	10	34
Pitta *et al.* (2004)	10.8	17	358	34	12	15
Pitta *et al.* (2004)	9.7	16	370	30	14	16
McWilliam unpublished	10.4	24	355	27	9	19
Birdsfoot Trefoil[4]	10.6	27	344	40	12	11
Lucerne Hay[5]						
pre-bloom	10.5	32	ND	0.5[6]	ND	ND
early bloom	9.8	29	ND	0.5[6]	ND	ND

[1] Calculated from *in vitro* DOMD values; [2] Catechin, epicatechin and other flavonoid monomers; 3 Salicin and other phenolic glycosides; [4] From Ramírez-Restrepo *et al.* (2004); [5] From Ulyatt *et al.* (1980); [6] CT concentrations from Jackson *et al.* (1996)

5.6 Conclusions

Willow and poplar tree fodder is a valuable feed supplement for livestock grazing summer-dry and drought pasture as it is a high quality (ME), highly digestible feed (OMD and DOMD) with beneficial concentrations of CT. Tree fodder is similar in digestibility and ME content to good quality lucerne hay and vegetative birdsfoot trefoil and does not decline greatly in OMD and DOMD over the growing season. The *in vivo* digestibility of willow and poplar tree fodder can be predicted using *in vitro* techniques, but more *in vivo* standards are needed to extend the range of prediction by including lower and higher values.

5.7 Acknowledgements

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CHAPTER 6

GENERAL DISCUSSION

6.1 Introduction

Periodic drought is an integral part of pastoral farming in East Coast regions of New Zealand, including Gisborne, Hawkes Bay, Wairarapa, Canterbury and North and Central Otago. Pastoral production represents a significant proportion of the New Zealand economy, with pastoral based exports contributing $14.1 B, or 45%, of total exports and sheep production alone accounting for almost half of this. Loss of livestock production caused by even moderate drought conditions can severely impact, not only farmers, but also the country as a whole. This highlights the importance of drought management strategies to reduce the impact of prolonged dry weather on livestock production systems.

Farm management strategies to counteract the effects of drought on pastoral production can be divided into two categories - reduce feed demand or increase feed supply. Traditional strategies include selling surplus livestock, grazing animals outside the drought affected areas and conserving high quality feed, such as hay, silage and grains, from seasons with good growing conditions, to supplement stock during drought. Summer/autumn droughts are particularly detrimental in hill country environments where there may be little or no flat land to grow supplementary feeds and feeding on steep hillsides can be difficult. In New Zealand, willow and poplar trees have been used, by a small group of farmers, as a source of emergency fodder for sheep and cattle during summer/autumn droughts (Treeby 1978; Charlton *et al.* 2003; Moore *et al.* 2003). However, only very recently has evidence emerged of more widespread and extremely successful integration of tree fodder into dry-land beef, sheep and deer farming (Charlton *et al.* 2003), in response to recent droughts and the predicted increase in future drought incidences in East Coast regions.

This thesis documents the production and reproduction responses of supplementing ewes, grazing typical drought pasture, with poplar and/or willow tree trimmings, and is the first report of such research carried out in New Zealand. Three grazing experiments were conducted in the summer/autumn of 2001, 2002 and 2003 at Massey University's Riverside Farm, in Wairarapa. The experiments were designed to simulate a hill country management system, in which poplar and willow trees, originally planted for soil conservation, are pruned or thinned to provide livestock fodder. Poplar and willow tree fodder is an abundant, low-cost supplementary feed option for farmers in drought-prone regions of New Zealand.

Results generated by the experiments encompassed in this thesis, in general, answered the questions posed in the hypothesis. Poplar and willow tree fodder was found to be a beneficial supplement to ewes grazing drought pasture during the pre-mating and mating period as supplementation consistently reduced reduce live weight loss and increased scanning and lambing percentages in two out of three experiments. Reproductive rate was not increased in the final experiment, probably due to zearalenone contamination of the pasture diet selected by grazing ewes. Supplementation of ewes grazing fungal-free drought pasture with poplar and willow tree fodder has thus proved to be a successful strategy for reducing the decline in reproductive rate that normally occurs under drought conditions.

6.2 Effect of Drought on Sheep Production

6.2.1 Livestock Production Loss

On an individual farm level, drought reduces livestock production through loss of live weight and body condition due to inadequate nutrient intakes. In East Coast regions of the North and South Islands of New Zealand, drought often occurs during the summer and autumn, which also coincides with the ewe-mating period. Live weight and body condition loss during mating can substantially reduce conception rate, ovulation rate and subsequent lambing percentages (Rattray *et al.* 1980, 1981, 1983; Smith & Knight 1998). To quantify this reduction, reproductive rate at ultrasound scanning of experimental control ewes grazing simulated drought pasture during mating, on Riverside Farm, was compared with that of non-experimental ewes grazing non-drought pasture managed on the same property at the same time under commercial farming conditions. This comparison showed a 22.4% reduction in reproductive rate, over three years, in ewes suffering drought conditions (Table 6.1).

Table 6.1 Comparison of reproductive rates at ultrasound scanning over the three field experiments for experimental control ewes grazing simulated drought pasture during mating versus commercially farmed ewes grazing non-drought pastures during mating at Massey University Riverside Farm in Wairarapa

	Reproductive Rate at Scanning*			
	Drought Pasture 'Control'	**Riverside Farm Commercial Management**	**Reduction Due to Drought**	**Percentage Reduction Due to Drought**
2001	122	176	54	30.7
2002	133	153	20	13.1
2003	128	167	39	23.4
Mean	**127.7%**	**165.3%**	**37.6**	**22.4%**

*Number of lambs/100 ewes mated

6.2.2 Farm Economic Loss

To determine the economic cost of this reduction in reproductive rate, a gross margin analysis was conducted using Riverside Farm as a model (J. Stantiall, Agricultural Consultant, Wilson & Keeling Ltd., Palmerston North). The model uses actual data for the drought pastures only, or control ewes from each of the three grazing trials and compares these with Riverside Farm commercial data. The analysis shows that a 22.4% reduction in scanning rate and a 20% reduction in wool production caused by drought would reduce sheep production income by $14.12/ewe or $35,300 per annum for Riverside Farm (Table 6.2).

Table 6.2 Estimated cost of a drought using Massey University Riverside Farm, Wairarapa, as a model (J. Stantiall, Agricultural Consultant, Wilson & Keeling Ltd.)

	Gross Margin Analysis	
	Drought	**Normal**
Number of Ewes	2,500	2,500
Scanning Rate	127.7 %	165.3 %
Pre- and Post-natal Lamb Mortality[1]	20 %	23 %
Weaning Rate	102.3 %	127.3 %
Number Lambs Sold	1,912	2,534
Lamb Live Weight at Sale	32.3 kg	30.0 kg
Total Wool Weight	10,000 kg	12,500 kg
Sheep Gross Income	$169,305	$204,930
Sheep Gross Expenditure	$31,714	$32,024
Sheep Gross Margin	$137,591	$172,906
Sheep Gross Margin / Ewe	$55.04	$69.16
Cost Of Drought / Ewe	**$14.12**	
Farm Gate Loss	**$35,300**	

[1] From scanning to weaning

6.3 Benefits of Tree Fodder Supplementation on Livestock Production and Reproduction

Field trials conducted in the summer/autumn of 2001, 2002 and 2003 at Massey University's Riverside Farm confirmed that poplar and willow tree trimmings are a good source of supplementary feed for livestock in drought conditions. Tree fodder supplementation consistently reduced live weight loss and increased reproductive efficiency through increases in conception rate and fecundity and decreases in lamb mortality. This resulted in a significant economic benefit at farm level when ewes were offered fungal free fodder.

6.3.1 Effect of Quantity of Tree Fodder Supplementation

The 2001 (Chapter 2) experiment was designed to determine how much tree fodder needed to be fed to increase ewe production and reproduction. Results showed that feeding poplar at a rate of 1.5 kg fresh/ewe/day ('high') significantly reduced live weight and body condition score loss and increased reproductive rate by 41 % units at scanning and 29 % units at weaning compared with ewes on drought pasture only ('control'; Table 6.3), with ewes offered 0.75 kg fresh/ewe/day ('low') achieving intermediate increases.

6.3.2 Poplar Versus Willow Supplementation

Matheson (2000) reported that poplar and willow differed in chemical composition, notably the much greater concentrations of condensed tannin (CT) in willow tree fodder, which could result in differences in livestock production in ewes offered the two feeds. The 2002 experiment (Chapter 3) was designed to determine if production and reproduction varied between ewes fed poplar versus willow at the same rate of supplementation, 1.4 kg fresh/ewe/day. Willow supplementation reduced live weight loss and increased reproductive rate by 16% units at scanning and 20% units at weaning compared with ewes on drought pasture only 'control' (Table 6.3). Unlike previous experiments, poplar supplementation showed no effect on reproductive rate, despite the increase in DM intake and apparent reduction in live weight loss (P=0.11). It is likely that the severe contamination of the poplar fodder with leaf rust, caused by the fungus *Melampsora larici-populina*, confounded the results.

6.3.3 Effect of Period (days) of Supplementation

Building on the results of the first two grazing trials, the next step was to determine the period of time (days) tree fodder must be offered to ewes prior to and during mating to achieve an increase in reproductive rate. The 2003 experiment (Chapter 4) was very similar in design to those conducted in 2001 and 2002; however, it involved ewes fed 1.3 kg fresh willow/ewe/day for a 'long' period, 63 days including 6 weeks of mating, and a 'short' period, 31 days including 3 weeks of mating. Willow supplementation for

63 days reduced live weight and body condition score loss, but did not increase reproductive rate at scanning and lambing. The lack of response was due to toxic concentrations of zearalenone, produced by *Fusarium* species of fungi in the pasture during mating, which confounded the results by negating any potential benefits due to increased nutrient intakes. Willow supplementation for 63 days did, however, increase reproductive rate at docking and weaning, due to a reduction in post-natal lamb mortality (Table 6.3).

Table 6.3 Live weight and body condition score change over the approximate 70 day experimental periods in the summer/autumn of 2001, 2002 and 2003 and reproductive rate in ewes grazing simulated drought pasture versus ewes supplemented with approximately 1.4 kg of fresh poplar and/or willow tree fodder per day

	Drought Pasture 'Control'	**Poplar/Willow Supplementation**	***Benefit Due to Poplar/Willow Supplementation**
2001 Poplar Experiment			
Live Weight Change (g/d)	-82	-67	15 g/d
Body Condition Score Change (units)	-1.31	-0.78	0.53 units
Scanning Rate**	122	163	41 % unit
Weaning Rate***	96	125	29 % units
Gross Margin / Ewe	$43.83	$50.24	$6.41
2002 Willow Experiment			
Live Weight Change	-103	-86	17 g/d
Body Condition Score Change (units)	-0.69	-0.60	0.09 units
Scanning Rate**	132	148	16 % units
Weaning Rate***	106	126	20 % units
Gross Margin / Ewe	$62.68	$68.08	$5.40
2003 Willow Experiment			
Live Weight Change	-147	-96	51 g/d
Body Condition Score Change (units)	-1.09	-0.79	0.30 units
Scanning Rate**	128	128	-
Weaning Rate***	103	116	13 % units

*Difference between supplemented and unsupplemented groups
** Number foetus/100 ewes mated
*** Number lambs/100 ewes mated

6.3.4 Economic Benefit of Tree Fodder Supplementation

Ewe production and reproduction data from the grazing experiments were then used to quantify the economic costs and benefits of tree fodder supplementation. A gross margin analysis was completed to compare the difference in farm income when supplementing ewes in a drought with approximately 1.4 kg fresh/ewe/day willow and poplar tree fodder versus no supplementation. 'Gross margin/ewe' represents the mean benefit of each ewe's annual production on farm profits and shows an approximate $6/ewe benefit to feeding tree fodder as opposed to offering no supplementation to ewes in drought conditions, when rust free tree fodder was offered (Table 6.3; S. Orsborn, Agriculture Consultant, Baker & Associates, Masterton). Tables 6.2 and 6.3 shows that the incidence of severe drought reduces gross margin/ewe by $14 and almost half of the cost ($6) can be recovered by tree fodder supplementation during mating.

The results from the Riverside Farm trial work were then used to model the costs and benefits of feeding tree fodder in a drought, on a whole farm basis (J. Stantiall, Agricultural Consultant, Wilson & Keeling Ltd., Palmerston North). Stockpol™ farm modelling software was used to model a typical Rangitikei (Central region hill country, summer wet) and Hawkes Bay/Wairarapa (East Coast region hill country, summer dry) farm, based on MAF monitor model farms (MAF Policy 2003). The analyses provided a comparison of gross margin between scenarios where livestock are offered fodder from space planted trees, originally planted for soil conservation, during drought versus livestock offered no supplementation (Table 6.4). The Hawkes Bay/Wairarapa model farm comprises 550 ha and assumes that 94.5 ha (17.2%) of the farm is planted with an average of 50 trees/ha that provide 10 kg edible DM/tree at a cost of 31 cents/kg DM (includes tree establishment costs, annual costs, tree repairs and maintenance and cost of feeding). Table 6.4 shows an economic benefit of $58/ha for supplementing livestock with tree fodder in drought, as opposed to offering no supplementation, on Hawkes Bay/Wairarapa hill country farms. This is a $31,900 benefit for the summer dry model farm. The Rangitikei (Central region) hill country model also showed a significant economic benefit at $127/ha. The economic benefit is larger in this model because the Rangitikei region usually has favourable rainfall for pasture growth during the summer and droughts occur infrequently. Because of this, farmers in typically summer-wet regions, such as Rangitikei, usually have higher livestock numbers (higher stocking rate/ha) and are less prepared for a drought (i.e., less preserved supplementary feed such as hay and silage). Therefore farms in this region incur greater losses in animal productivity due to the poor quality and inadequate pasture that is typical of drought conditions. Stantiall (personal communication) concluded that when the conditions are most likely to favour the advantages of the fodder trees, there is a significant financial benefit. These calculations show that although drought conditions, similar to those simulated in the present experiments, can result in a large economic loss, fodder tree supplementation can substantially reduce this loss. However, to eliminate financial loss entirely, other drought management strategies are also required. This highlights the importance of individual farm drought management plans that incorporate the management strategies that are practical within the resources available for the particular farm.

Table 6.4 Financial benefit from supplementing ewes with willow and poplar on typical Rangitikei (summer wet) and Hawkes Bay/Wairarapa (summer dry) hill country farms, during summer/autumn drought (J. Stantiall, Agricultural Consultant, Wilson & Keeling Ltd., Palmerston North)

	Rangitikei	**Hawkes Bay/ Wairarapa**
Gross margin		
Base Year (no drought)	$424/ha	$505/ha
Drought (no alternative feed)	$117/ha	$297/ha
Drought, Space-Planted Trees	$244/ha	$355/ha
Financial loss due to drought		
No Alternative Feed	$307/ha	$208/ha
Tree Supplementation	$180/ha	$150/ha
Benefit Due to Supplementation	$127/ha	$58/ha

6.4 Mechanism of Action of Tree Fodder on Ewe Production and Reproduction

6.4.1 Increased Nutrient Intake

The possible mechanisms for the increases in ewe production and reproduction found in these field experiments can be explained by the relatively higher nutritive value of tree fodder compared with the simulated drought pasture consumed by the ewes. The simulated drought pasture reflected poor quality pasture available in summer/autumn droughts in East Coast regions, as it was high in fibre (neutral detergent fibre; NDF), approximately 600g/kg DM, and low in metabolisable energy (ME), approximately 7.5 MJ/kg DM, and total nitrogen (N) content, approximately 20 g/kg DM (Table 6.5). Both poplar and willow fodder contained more beneficial concentrations of these nutrients with an NDF content of less than 400g/kg DM, an ME of approximately 10MJ/kg DM and a total N content of approximately 26 g/kg DM.

Table 6.5 Comparison of metabolisable energy (ME; MJ/kg DM) concentration and chemical composition (g/kg DM) of drought pasture and poplar and willow tree fodder fed to grazing livestock during the late summer/autumn period in the three field experiments

	ME	RFC[1]	NDF	Total N	CT	PG
	MJ/kg DM			g/kg DM		
Simulated Drought Pasture						
2001	7.6	120	623	18	1.5	ND
2002	7.7	102	571	25	ND	2
2003	7.2	ND	603	16	ND	1
Poplar						
2001	9.7	190	390	28	7	22
2002	9.7	157	404	27	19	17
Willow						
2002	10.1	159	381	26	52	34
2003	10.4	ND	355	24	27	19

[1] Readily fermentable carbohydrate = Water-soluble carbohydrate + pectin; [2] Neutral detergent fibre; [3] Total nitrogen; [4] Condensed tannin; [5] Phenolic glycosides; ND, not determined

Tree fodder supplementation increased calculated DM, ME and CP intakes of ewes grazing drought pasture (Table 6.6). The increase in ewe ovulation rate with increasing energy intakes is well documented (Rattray *et al.* 1981; Smith *et al.* 1983; Smith & Knight 1998), with Smith (1985) reporting an increase of 1.5% units for each additional mega joule of digestible energy consumed. Based on the figures in Table 6.6, this would result in an increase in ovulation rate of only 5 and 4% units in 2001 and 2002, respectively, due to fodder tree supplementation; however, the increases in scanning rate were substantially greater at 41 and 16% units (Table 6.3). Protein is also a critical component of the reproductive response of ewes to supplementary feeding. Studies have found responses to increased protein intake of feeds that contain low and moderate energy levels (Smith 1985). Smith (1985) reported a threshold intake level of 125 g protein/ewe/d necessary to achieve an increase in ovulation rate, with marked increases at levels above the threshold. CP intake of unsupplemented ewes was below this threshold in all years; supplementation with tree fodder substantially increased CPI intakes above 125 g/d in two of the three years. This highlights the likelihood that a small proportion of the increases in reproduction in ewes supplemented with tree fodder can be attributed to the increase in ME intake, while a large proportion is probably due to increased protein supply.

Table 6.6 Calculated[1] total dry matter (DM; kg), metabolisable energy (ME; MJ) and crude protein (CP; g) intakes of unsupplemented and supplemented ewes grazing simulated drought pasture and fed poplar or willow tree trimmings

	Drought Pasture 'Control'	**Poplar/Willow Supplementation**
2001		
Total DM Intake	0.67	1.03
Total ME Intake	5.1	8.5
Total CP Intake	71	132
2002		
Total DM Intake	0.59	0.86
Total ME Intake	4.6	7.2
Total CP Intake	91	137
2003		
Total DM Intake	0.47	0.75
Total ME Intake	3.4	6.3
Total CP Intake	47	91

[1] Calculated from pre- and post-grazing pasture DM mass and from weighing tree fodder offered and tree fodder residue; measurements were taken weekly

In this thesis, apparent DMI was calculated using the pasture sampling technique, in which pre- and post-grazing pasture mass was measured for each weekly break and intake/ewe/day calculated from these measurements. Thus, all calculated intakes reported can only be considered apparent values. This method was effective in estimating DMI for the purposes of the current experiments as grazing intervals were short (weekly), stocking densities were high (approximately 100 ewes/ha/grazing interval) and pasture growth was assumed to be insignificant due to dry summer conditions. Walters & Evans (1979) report that any bias introduced by the exclusion of pasture growth in intake measurements over short grazing periods is likely to be minimal and can be ignored for practical purposes. This method provides a level of accuracy and precision in reasonable agreement with those obtained by indirect animal techniques, as long as there is minimal sample loss during collection (Walters & Evans 1979). However, it is clear that the pasture sampling technique has a very limited applicability and a more critical assessment of intake could be made using animal-based techniques.

The primary advantage of animal-based methods over plant-based methods is that separate estimates of intakes for individuals within a group can be made (Mayes and Dove 2000). The most common method for estimating intake, especially in pasture-based systems, is from separate estimates of faecal output, usually using indigestible markers such as alkanes and chromium sesquioxide (Cr_2O_3), and diet digestibility (Mayes and Dove 2000). Animal-based methods are considered more reliable, however it is important to note that determinations of intake in grazing livestock is generally difficult to undertake, and that their errors are often large, mainly owing to the limitations of available measurement techniques (Mayes and Dove 2000). For example, direct faecal output measurements can be biased due to loss of faeces and restriction of animals' normal grazing behaviours and indirect faecal measurements can be biased through variation in faecal marker concentrations and incomplete faecal recovery. Mayes and Dove (2000) also note that it is difficult to obtain reliable estimates of digestibility in animal-based intake determination and that errors in the estimation of digestibility will always cause a larger error in the resultant intake estimate.

In the present studies it has been possible to calculate the mean daily intakes of ME, CP and Z in the drought pasture diet selected, through multiplying the concentrations of the nutrients by the apparent DMI. Similarly, mean daily intakes have been calculated for tree supplementation. DMIs for willow/poplar-supplemented ewes were calculated from direct fodder weights and are therefore likely to be estimated with a higher accuracy than for the drought pasture. This has allowed total nutrient intakes (i.e. pasture + trees) to be compared with published estimates. From this data, it has been possible to suggest which of the nutrients supplied from forage trees are most likely to have been responsible for the observed increases in reproductive rate. It has also been possible, from calculated zearalenone intakes, to detect years when pasture zearalenone intakes were likely to have restricted multiple ovulations.

Useful deductions have been made from calculated mean intakes in the present studies. A limitation of the pasture-based technique used to calculate DMIs in the present studies is that statistical comparisons in estimated intake could not be made between treatment groups, because individual animal intakes were not measured and thus there was no replication. It is acknowledged that this would be a limitation in some grazing studies, but in the present studies it has not prevented reasonable deduction of the compounds/nutrients that were most likely to have limited animal performance.

6.4.2 Increased Secondary Compound Intake

Tree fodder has an advantage over other drought supplements, such as silage, as it contains relatively high concentrations of CT and phenolic glycosides. CT binds strongly to proteins to form a pH-dependent complex that is not degradable at rumen pH (6.0–7.0), but disassociates at abomasal pH (2.5-3.5) with the protein absorbed from the small intestine (Barry & McNabb 1999). Several studies have shown that animal diets containing low to medium concentrations of CT, similar to those found in poplar and willow tree fodder, increase the efficiency of protein digestion by increasing the flow of protein-N to the intestine (undegraded dietary protein; UDP), relative to N intake, and by increasing the flow of essential amino acids (EAA) out of the abomasum (abomasal flow) by 50-53%. This increases net absorption of EAA from the small intestine by 59-63%, with no effect on apparent digestibility in the small intestine (Barry & McNabb 1999; Waghorn *et al.* 1999; Barry *et al.* 2001). This finding is consistent with other studies that have shown increases in ewe ovulation rate and fecundity in response to greater levels of rumen UDP, with no increase in ovulation rate due to intakes of dietary N, in the form of urea (i.e. rumen degradable nitrogen; RDN; Knight *et al.* 1975; Thompson *et al.* 1973).

Experiments conducted in New Zealand with ewes grazing birdsfoot trefoil (*L. corniculatus*) have shown increases in wool production (15%; Min *et al.* 1998), milk production (20-40%; Wang *et al.*, 1996; Woodward *et al.*, 1999) and ovulation rate (20–30%; Min *et al.*, 1999, 2001), relative to control sheep grazed on perennial ryegrass/white clover pasture, with generally at least 50% of these increases attributed to the action of CT. Increases in ovulation rate were associated with increases in plasma concentration of total EAA and branched chain amino acids (BCAA; Table 6.7), with PEG drenching studies showing that most of this could be attributed to CT. Correlations coefficients between ovulation rate and the plasma concentrations have been reported to be 0.95 and 0.61 for BCAA and EAA, respectively (Waghorn *et al.* 1990). Similarly, part of the increase in reproductive rate and reduction in live weight loss in ewes fed tree fodder is also likely to be due to increases in EAA and BCAA absorption, although PEG studies have not yet been undertaken with tree fodder diets.

Table 6.7 The effect of condensed tannins (CT) in birdsfoot trefoil (*Lotus corniculatus*) on plasma concentration of essential amino acids (EAA) and branched chain amino acids (BCAA; μm) in ewes grazing perennial ryegrass/white clover pasture and birdsfoot trefoil during mating. Adapted from Min *et al.* (1999)

	Pasture		**Trefoil**	
	PEG [1] Sheep	**CT acting Sheep**	**PEG [1] Sheep**	**CT acting Sheep**
Total EAA	786	742	894	1128
Total BCAA	267	241	312	379
Valine	138	126	161	199
Leucine	77	69	93	108
Iso-Leucine	52	45	58	72

[1] PEG = Polyethylene glycol, acts as a binding agent with CT in the rumen, thus inactivating dietary CT

Preston & Leng (1987) report that ruminants fed low quality forages, such as drought pasture, need to be supplemented with sources of rumen degradable N (RDN) and soluble CHO to stimulate microbial protein synthesis and also UDP to fully meet animal protein requirements. Tree fodder ideally suits these criteria as it supplies RDN in the form of increased dietary N, readily fermentable carbohydrate (RFC), with a proportion of the glucose contributed by phenolic glycosides, and UDP due to the protein binding action of CT. Thus it is likely that the increase in DM, ME and CP intakes, and the increase in microbial protein and UDP leaving the rumen were important factors contributing to the beneficial effects of supplementing ewes grazing drought pasture with tree fodder in these experiments.

6.5 Effect of Tree Fodder Supplementation on Lamb Mortality

One of the unexpected results of the three field trials was a reduction in post-natal lamb mortality due to willow/poplar supplementation of ewes during mating, when grazing drought pasture. Increases in reproductive rate are usually associated with increases in lamb mortality; however, initial results showed that despite significant increases in fecundity in supplemented ewes in 2001 and 2002, post-natal lamb mortality was not increased. This, combined with a statistically significant reduction in lamb mortality in ewes fed willow in 2003, in the absence of any differences in fecundity between the groups, suggested that tree fodder supplementation during mating may have reduced lamb mortality in all three experiments, but that the effect was masked by the increase in reproductive rate in the first two experiments. Therefore, data from the three field trials was combined and analysed by adjusting all mortality data to equal birth rank and sex (Chapter 4). This analysis showed that over three years of experimentation, supplementation with tree fodder reduced post-natal lamb mortality by an average of 34% (Table 6.8). Combining all of the reproduction and lamb mortality data resulted in greater ewe numbers to better detect statistically significant differences in lamb mortality. Calculations showed that approximately 450 ewes/group are necessary to detect a 30% reduction in lamb mortality in any one year, given a lambing rate of approximately 125% for control ewes (Chapter 4).

Table 6.8 Post-natal lamb mortality (%) of ewes grazing drought pasture only versus ewes supplemented with tree fodder, over three years of experimentation. Data are adjusted to equal birth rank and sex

	Post-Natal Lamb Mortality		
	Drought Pasture 'Control'	**Poplar/Willow Supplementation**	**Percentage Reduction Due to Supplementation**
2001	20.3	16.3	19.7
2002	17.3	12.1	30.1
2003	16.0	8.0	50.0
Overall Mean	**17.8**	**11.7**	**34.3***
Range	**14.1 – 22.3**	**8.7 – 15.5**	

* $P<0.05$

Similarly, ewes grazing CT-containing birdsfoot trefoil during mating have shown substantial reductions in post-natal lamb mortality, despite increases in reproductive rate at scanning and lambing (Table 6.9; Ramírez-Restrepo *et al.* 2004). Ramírez-Restrepo *et al.* (2004) reported a 51% reduction in post-natal lamb mortality compared with ewes grazing perennial ryegrass/white clover pasture (Table 6.9). The mechanism for this reduction is unknown; however, it is believed to be due to increased absorption of essential amino acids, which is a characteristic of feeding CT-containing forages, at a critical point in early embryonic development (Barry *et al.* 2004).

Table 6.9 The effect of mating ewes on perennial ryegrass/white clover pasture and on the legume birdsfoot trefoil (*Lotus corniculatus*) on reproductive performance and lamb mortality between birth and weaning. Adapted from Ramírez-Restrepo *et al.* (2004)

	Pasture	**Birdsfoot Trefoil**	**Difference Between Treatments**	**Levels of Significance**
Live weight change	-5 g/d	67 g/d	73 g/d	***
Reproductive rate				
Scanning[1]	170	179	9	*
Lambing[2]	159	175	16	*
Weaning[2]	123	155	32	*
Post-natal mortality	22.9 %	11.7 %	11.2% units	*

[1] foetus/100 ewes mated; [2] lambs/100 ewes lambing

6.6 Fungal Contamination of Pasture and Tree Fodder

Fungal contamination was a significant factor in the results obtained in the field experiments in 2002 and 2003. In all years, simulated drought pasture was found to contain metabolites of zearalenone and the trichothecenes nivalenol and deoxy-nivalenol, while in 2002 the poplar was severely contaminated with *Melampsora larici-populina* or poplar leaf rust.

6.6.1 Zearalenone in Pasture

Zearalenone is an oestrogenic toxin, produced by *Fusarium* sp. that reduces reproductive performance in sheep if pasture contains toxic concentrations (≥1mg/kg DM) (di Menna *et al.* 1987; Towers 1997). Fungal growth and toxin production is at its highest during late summer/autumn (February to April), and usually coincides with the ewe mating period. Fungal populations thrive in pastures with high dead matter content under very hot conditions that often occur in pastures that are poorly managed or moisture-stressed. Zearalenone concentrations were at their greatest in the 2003 Experiment (Table 6.10) and increased to over 2 mg/kg DM during the mating period. This helped to explain the lack of increase in reproductive rate expected in willow-supplemented ewes, which was a feature of previous experiments (McWilliam *et al.* 2004a,b; Pitta *et al.* 2004), but did not explain the much greater loss in ewe live weight in 2003 (Table 6.3). Pasture zearalenone concentrations are unlikely to have affected reproductive rate in 2001 and 2002.

Table 6.10 Concentrations of zearalenone and the trichothecenes, nivalenol and deoxy-nivalenol, in pasture consumed by ewes and calculated ewe intakes over three years of experimentation

	Zearalenone	Nivalenol	Deoxy-nivalenol	Total Trichothecenes
Pasture Concentrations (mg/kg DM)				
2001	0.58	0.05	0.10	0.15
2002	0.16	0.05	0.06	0.11
2003	1.51	0.19	0.26	0.45
Calculated Intakes (mg/ewe/day)				
2001				
Pasture Mean[1]	0.40	0.03	0.07	0.10
Total Intake (Pasture+Tree[2])	0.48	ND	ND	ND
2002				
Pasture Mean[1]	0.09	0.03	0.04	0.06
Total Intake (Pasture+Tree[3])	0.16	ND	ND	ND
2003				
Pasture Mean[1]	0.71	0.09	0.12	0.21
Total Intake (Pasture+Tree[4])	0.79	ND	ND	ND

[1] Mean pasture zearalenone intake for all treatments; [2] Poplar zearalenone intake for the high treatment; [3] Mean poplar/willow zearalenone intake; [4] Willow zearalenone intake for the long treatment; ND = Not determined, assumed to be zero

6.6.2 Trichothecenes in Pasture

Trichothecenes may be partly responsible for animal 'ill thrift' disorders (failure to grow or produce), which often occurs in the autumn under New Zealand grazing conditions (Towers 1997; Lauren *et al.* 1988, 1992). Nivalenol (NIV) and deoxy-nivalenol (DON) are common trichothecene toxins also produced by *Fusarium* spp. in New Zealand pasture (Lauren *et al.* 1988, 1992) and were found in pasture samples from all three years. However, the concentration in 2003 was three- to four-fold greater than in previous experiments (Table 6.8). In dosing experiments, Odriozola (1996) reported that live weight gain was inversely proportional to the quantity of NIV consumed (doses of 0 mg/d to 30 mg/d) in young ewe and wether lambs (approximately 30 kg initial live weight) grazing winter (Experiment 1, June) and spring (Experiment 2, October) pasture (Figure 6.1). Using the regressions equation derived from Figure 6.1, an increase in NIV intake of 1 mg/d would only reduce live weight gain by 2 to 5 g/day.

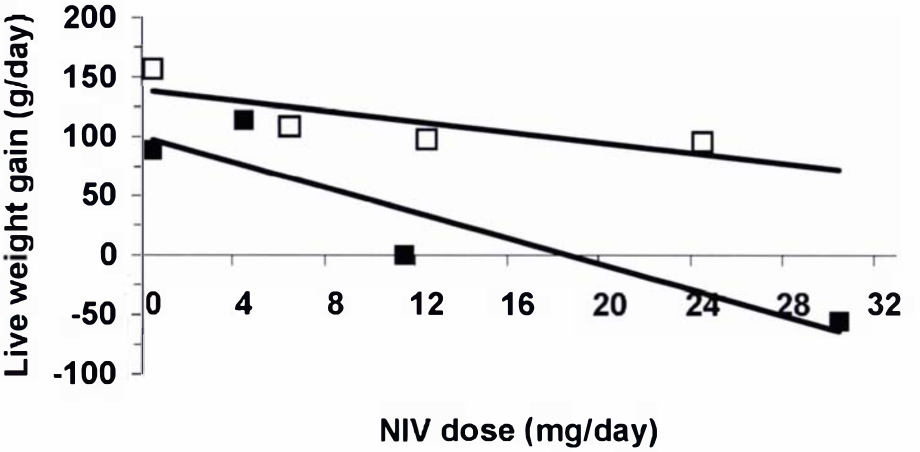

Figure 6.1 Comparison of mean live weight gain in sheep grazing pasture during two experiments, and dosed with nivalenol (NIV) for 30 and 42 days, respectively. Adapted from Odriozola (1996). ■ Experiment 1; □ Experiment 2

Regressions:
Expt 1 y = 97.6 – 5.39x $r^2 = 0.83$
Expt 2 y = 138.2 – 2.21x $r^2 = 0.63$

DON intake, up to 35 mg/day, did not affect live weight change in the experiments conducted by Odriozola (1996). However, a study with dairy cattle indicates that DON may have reduced live weight gain with increases in quantity of DON consumed (Ingalls 1996; Figure 6.2), with no effect on feed intake or milk production. A regression equation developed from the data reported by Ingalls (1996) indicates a reduction in live weight gain of 1 g/day for every 1 mg of DON ingested. Similarly problems were experienced with dairy herds fed contaminated silages averaging 0.7 mg DON/kg DM; however, the problems were not specified in the report (Ingalls 1996).

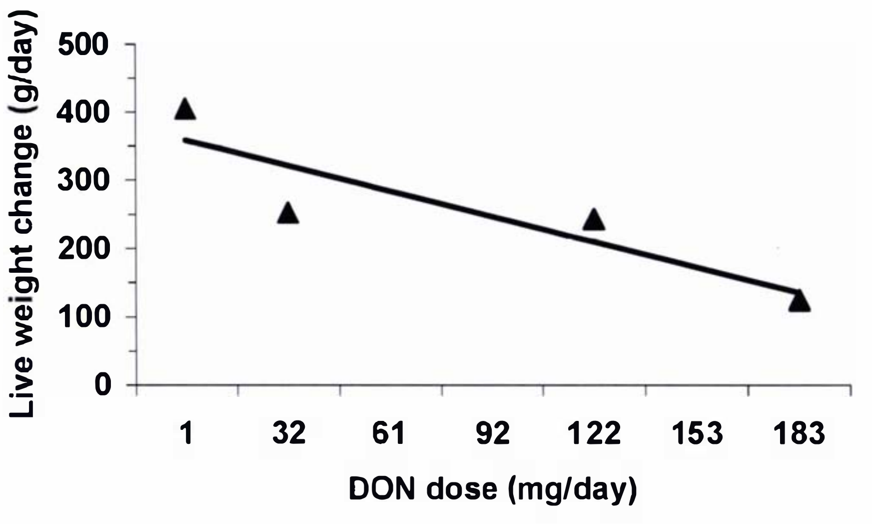

Figure 6.2 Comparison of mean live weight gain in dairy cows consuming feeds with increasing concentrations of deoxy-nivalenol (DON) for 21 days. Adapted from Ingalls (1996)

Regression:
$y = 370.2 - 1.17x$ $r^2 = 0.83$

Litherland *et al.* (2004) showed that pasture concentrations of NIV plus DON of greater than 0.8 mg/kg DM were consistently associated with ill thrift in young sheep grazing dry autumn pastures in New Zealand and suggested that other unidentified mycotoxins, produced by *Fusarium* or other species, may also be involved in the ill thrift seen in livestock in the autumn. From the equations developed from Odriozola (1996; Figure 6.1), it appears that the trichothecene content of the pasture in 2003 was too low to account for all the greater live weight loss observed in the 2003 Experiment and in the ill thrift studies reported by Litherland *et al.* (2004) and may be an indicator of the production of other more potent fungal toxins. Further research is necessary on the effects of trichothecenes, found in New Zealand pasture, on grazing animals and the amount of toxin necessary to impact on animal health and production.

6.6.3 Leaf Rust on Poplar Fodder

High rainfall and humidity in the nursery where the tree fodder was sourced caused the poplar trimmings offered to grazing ewes in 2002 to be severely contaminated with poplar leaf rust. It is possible that leaf rust produces toxins similar to those produced by *Fusarium* species that may have reduced ewe production and reproduction in the 2002 Experiment. This would provide an explanation for the lack of reproductive response in ewes supplemented with the fungus-contaminated poplar tree trimmings, despite the greater DM intake and apparent reduction in live weight loss. It is important to note that rust contamination occurred because of warm, humid conditions. In a normal dry summer or drought, rust would not usually occur.

6.7 Future Developments

6.7.1 Effect of Poplar versus Willow Supplementation on Ewe Production and Reproduction

Results on the effects of poplar versus willow supplementation on ewe production and reproduction were inconclusive in the 2002 experiment. Therefore further research is necessary to determine if willow and poplar supplementation affect ewe production and reproduction differently due to the differences in their chemical composition. The methodology used in the experiment described in Chapter 3 could be used again, as the experimental design was sound. However, care must be taken to avoid feeding fungal contaminated poplar or pasture to experimental animals.

6.7.2 Effect of Period (days) of Supplementation on Reproductive Rate

It was unclear from the results obtained in 2003 how different periods of supplementation prior to and during mating, 63 and 31 days versus 0 days, affected reproductive rate, due to the confounding effects of zearalenone in the pasture consumed by grazing ewes. It is likely that both periods of supplementation would result in an increase in reproductive rate, with ewes fed for 31 days being intermediate between those fed for 0 and 63 days. Ramírez-Restrepo *et al.* (2004) demonstrated the importance of determining the number of days CT-containing forages must be fed to achieve a production/reproduction response in experiments with ewes grazing birdsfoot trefoil. The authors found a linear increase in ovulation rate in ewes grazing Birdsfoot trefoil for 0, 10, 21 and 42 days before synchronised mating.

To better determine how the length of time tree fodder is offered to ewes grazing drought pasture affects reproductive rate, the experimental design described in Chapter 4 could be used with ewes grazing pastures with little or no fungal contamination, with regular monitoring of fungal toxins.

6.7.3 *In vivo* Digestibility of Willow and Poplar Tree Fodder

In vivo digestibility trials (Chapter 5) were conducted in summer/autumn of 2001 (1 poplar), 2002 (3 poplar) and 2003 (3 willow) and showed that the actual digestibility of tree fodder declined from spring to autumn and that the decline was not as great as for pasture during the same period. This is beneficial in that tree fodder maintains its quality relatively well over time. Ramírez-Restrepo (2004) found that typical forage standards could not accurately predict the *in vivo* digestibility of CT-containing birdsfoot trefoil and that a separate standard curve using *in vivo* coefficients from sheep fed birdsfoot trefoil was necessary. Thus, the seven *in vivo* coefficients for tree fodder were used to develop a standard curve for *in vitro* prediction of *in vivo* digestibility of poplar and willow in the present study. The 2001 tree fodder standard regression was significantly different compared with the pasture standard regression in the same year; however, the effects were not repeated in the following years. Thus, further experimentation is necessary to determine if a separate tree fodder standard curve is necessary when predicting the *in vivo* digestibility of tree fodder using *in vitro* techniques and if poplar and willow require separate standard curves due to differences in secondary compound content between the two fodders. The relatively compact values in the tree fodder standard curve compared with those in the pasture standard curve reduced the range of the prediction. Further digestibility experiments should be carried out, with sheep fed tree fodder as early as the leaf bud stage in the spring and as late as almost complete leaf fall in the autumn, to obtain a wider range of digestibility values to increase the range and accuracy of the predictive regression equation.

6.7.4 Effect of Tree Fodder Supplementation on Fibre Digestion, Absorption of Amino Acids and Digestion of Secondary Compounds

It is clear that willow and poplar are beneficial supplements to grazing livestock, particularly in times of drought. However, little is actually known about the mechanics of metabolism and digestion associated with tree fodder supplementation. Research is needed on the effect of tree fodder supplementation on fibre digestion, absorption of amino acids and digestion of secondary compounds. Much of this information can be obtained using *in vitro* incubation methods with rumen fluid from animals fed tree fodder. Abomasal cannulation is an effective method to allow measurement of digesta outflow, including microbial nitrogen and UDP, as used by Min *et al.* (2002). An indication of differences between treatments in amino acid absorption can be obtained by analysing blood serum for EAA and BCAA from animals supplemented with tree fodder.

6.7.5 Effect of Tree Fodder Supplementation on Post-Natal Lamb Mortality

Further research is needed on the reduction in post-natal lamb mortality due to consumption of CT-containing feeds, as found in the present series of experiments and by Ramírez-Restrepo *et al.* (2004). Grazing trials with 100 ewes per group are adequate to determine statistically significant differences in reproductive rate; however, they are not adequate to detect differences in lamb mortality. Similar grazing trials should be conducted with much larger groups of ewes (300 to 450/group) to allow changes in lamb mortality to be better detected. The mechanism for the reduction in lamb mortality is unknown; however, it may be due to the ability of the newborn lamb to better withstand cold stress or due to better placental development in ewes fed CT-containing fodder. One method to determine the physiological response of lambs, born to ewes fed CT and non-CT containing forages during mating, to cold stress is by comparing the amount of energy required for lamb survival using calorimetry (McCutcheon *et al.* 1983). An indication of placental development can be obtained through blood serum measurements of placental lactogen in ewes.

6.7.6 Potential of Willow and Poplar Supplementation for Reducing Parasite Burdens in Sheep

Poplar and willow tree fodder may reduce the impact of gastrointestinal parasites in growing sheep. Niezen *et al.* (1995; 1998b) reported that lambs with a naturally acquired gastrointestinal nematode burden, which grazed CT-containing sulla (*Hedysarum coronarium*), had lower faecal egg counts and gastrointestinal nematode burdens than those that grazed non CT-containing forages, such as lucerne (*Medicago sativa*). Sources also report a reduction in the establishment of gastrointestinal nematodes in lambs fed lotus (*Lotus pedunculatus*, now called *Lotus uliginosus*; Niezen *et al.* 1998a) and red deer (*Cervus elaphus*) fed sulla (Hoskin *et al.* 1999) compared with animals fed lucerne. A further study showed that lambs fed lotus achieved a high level of performance despite high worm burdens and faecal egg counts (Niezen *et al.* 1998b). The mechanisms are unclear; however, data indicate that CT in plants probably reduces internal parasite burdens by direct inhibition of larvae and indirectly by increasing protein absorption, supporting the immune system and helping the animals to cope with the demands of infection.

The potential use of CT-containing poplar and willow tree fodder to reduce internal parasitism in growing sheep such as lambs or hoggets may contribute to farm sustainability by reducing dependence on chemical control. Ewe hoggets are a priority group in the late spring and summer period for farms preparing to mate them at 18 months of age. Feeding studies could be conducted with ewe hoggets prior to mating to determine if ewes supplemented with tree fodder have reduced parasite burdens and/or increased live weight gain, in addition to the potential increase in reproductive rate, compared with ewes grazing perennial ryegrass/clover pasture only. Directly grazing hoggets on willow or poplar fodder blocks would be the most efficient method of feeding the ewes in a trial of this nature, as opposed to the cut and carry feeding method used in the present experiments.

6.7.7 Other Methods of Tree Fodder Supplementation

Another tree fodder supplementation option available to farmers is densely planted fodder blocks. Providing fodder blocks, where livestock can graze *in situ*, would reduce the labour required for pruning and pollarding trees for fodder. Wet, swampy areas are ideal for tree fodder blocks, as transpiration from the trees removes moisture from the soil, encouraging better quality grasses, legumes and herbs to grow instead of swamp grasses and weeds. Ewe production and reproduction effects of ewes grazing willow fodder blocks is currently being researched at Riverside Farm (Pitta *et al.* 2004) and preliminary results show beneficial effects on ewe live weight and reproductive rate similar to those found in the present series of experiments. However, further experimentation is required to determine best management practices of the fodder blocks and how to incorporate them into whole-farm management. It is necessary to determine optimum timing and frequency of grazing and experiment with grazing by various stock types to develop a management plan to effectively utilise the lush growth of trees, grasses, legumes and herbs where previously only weeds persisted. Recent experience managing the fodder blocks has highlighted the importance of developing a plan that focuses on the tree/pasture association; initial management focused on the trees alone and resulted in poor quality pasture.

6.7.8 Management of Tree/Pasture System

For any relatively new fodder crop to be readily adopted by farmers there are several important aspects to be considered, particularly herbage mass production, harvesting and/or grazing management to optimise edible forage production and longevity of the plants and cost are all important factors.

Recently, Kemp *et al.* (2001) reported that seven-year-old Tangoio willow (*S. matsudana x alba*) and Veronese poplar (*P. deltoides x nigra*) trees grown on Wairarapa hill country will produce 9.5 kg and 7.5 kg of edible dry matter, respectively. Kemp *et al.* (2003) found that the quantity of edible dry matter per tree in a previously un-harvested willow and poplar was related exponentially to the diameter of the tree trunk at a height of 1.4 m above the ground (DBH) and that the quantity in a tree branch increased linearly with increasing basal diameter of the branch. However, little is know about how much edible biomass can be harvested from a tree that has been previously harvested. Douglas *et al.* (2003) reported that average regrowth from six Tangoio willow trees (DBH = 29 cm), in the Hawke's Bay region, after one year was 0.8 kg dry matter per tree (0.4 kg edible dry matter per tree). However, there are no other data available on the production of regrowth from previously harvested trees under New Zealand hill country conditions. Studies should be conducted using trees of similar size and age and pollarded for the first time, on East Coast hill country farms with a proportion of trees harvested each subsequent year for a five-year period. Therefore, the quantity of edible biomass could be measured for regrowth after one, two, three, four and five years. The shading effect of the trees on the pasture and the effect on soil moisture and nutrient content could also be measured, to determine how much pasture production was lost as the harvesting interval increased. The effect of cutting height of the tree on biomass production may also be important. Thus half of the trees in each of the cutting year treatments could be harvested at two different heights to determine if there are differences associated with tree stump height. Continuation of this study over a 15 to 20 year period would also allow for data to be collected on the longevity of the trees under different management regimes and the causes of mortality, such as fungal infection, bacterial infestation and stress.

Recently, it has been pointed out that many trees planted on East Coast hill country farms for soil conservation are 20+ years old and are too big and dangerous to harvest as livestock fodder and pose a danger to farm staff and livestock because of the brittle nature of the branches as the trees age. This has led to the realisation that poplar and willow trees must be planted and managed like any other species, such as *Pinus radiata*, *P. macrocarpa*, acacia or eucalypts (Cameron 2003). Charlton *et al.* (2003) suggest the following management plan, based on farmer experience and advice.

Year 1	Plant pole and protect from stock by fencing or plastic sleeves
Year 2	Maintain protection and control weeds if necessary
Year 3	Light prune and initial feed use during late summer
Year 4	Keep trunk protected from stock
Year 5	Prune/pollard at 2.0 to 2.5 m above the ground
Subsequent years	Prune every two to three years (regardless of drought), to reduce pasture shading and for safer harvesting of tree fodder

This management plan provides a good basis for integration of poplar and willow trees into a whole-farm management plan and because trees are never left to grow to full size, old trees will not be a risk to people or livestock. However, as this plan is based on a compilation of anecdotal evidence, research as described previously is needed to further refine advice on the pollarding height and frequency for optimum herbage production and to most efficiently utilise the resource available.

6.7.9 Poplar and Willow Breeding Programs

It is clear that poplar and willow fodder is a beneficial supplement to grazing livestock, particularly to ewes suffering feed shortages during mating. However, the relatively early onset of leaf fall, particularly in very dry conditions, is one of the shortfalls of tree fodder supplementation. Recently, seed from willow and poplar trees were imported from the Western states of Oregon and California, USA; *Salix lucida*, variety lasiandra, and *Populus trichocarpa* (S. Hurst, Scientist, HortResearch, personal communication). These species retain their leaves longer into the autumn because they evolved in a mild maritime climate, similar to that of New Zealand. Most of the poplar and willow trees currently in New Zealand evolved in more Northern continental climates, and therefore they are adapted to cope with long cold winters. In 2003, *S. lucida* variety lasiandra was crossed with *S. matsudana*, *S. pentandra* and *S. matsudana x S. pentandra* at HortResearch, Hardwood Tree Breeding and Physiology, Environmental Group, Palmerston North (S. Hurst, personal communication), with the objectives primarily to improve willow tree form, genetic diversity and sawfly resistance. It is unlikely that trees will be bred specifically for nutritive value; however, resistance to sawfly infestation indicates that the foliage may contain beneficial concentrations of secondary compounds and it is likely that, due to the longer growing season and increased sawfly resistance, the new cultivars will be ideal fodder trees. New willow cultivars resulting from the breeding program with *S. lucida*, variety lasiandra, are expected to released from 2006 onwards.

6.7.10 Effect of Zearalenone on Reproductive Rate

Zearalenone and other toxins produced by pasture-dwelling fungi can have a devastating effect on farm productivity. Chapters 3 and 4 provide excellent examples of the negative effect *Fusarium* and other fungi can have on otherwise healthy livestock. The presence of toxic concentrations of Z in drought pasture at Riverside Farm in one experimental year out of three indicates that toxic concentrations probably occur with the same frequency on most East Coast hill country farms in New Zealand. Preventing the oestrogenic effects of zearalenone can be achieved by reducing the amount of toxin ingested by grazing ewes through periodic pasture monitoring for zearalenone levels in late summer and early autumn (February to May) and providing toxin-free forages when concentrations begin to approach 1mg/kg DM. Toxin-free fodder can be provided by growing summer/autumn forage crops for ewes prior to and during the mating period; legumes and brassicas are both excellent options. Conserved fodder such as silages can also be used; however, the supplement must provide most of the ewes' diet to reduce the quantity of pasture fungal toxins consumed.

Benzimidazole fungicides have been used successfully to reduce *Pithomyces chartarum* spore numbers to control facial eczema (Smith & Towers 2002). However, at economic rates of application, Benzimidazoles have not been effective in controlling *Fusarium* species in pasture, and have no effect on zearalenone production even at application rates 10-fold those used for controlling *Pithomyces*. Development of a fungicide that will effectively and economically reduce *Fusarium* contamination would improve animal health and production on farms regularly affected by fungal toxins.

Biocontrol of *P. chartarum* through introducing atoxigenic spores into the pasture in early summer, so that they become the dominant population, has successfully reduced toxin levels by 80 percent on treated pasture plots (Fitzgerald *et al.* 1998). However, difficulties have been experienced developing an inoculum that provides protection at a cost per hectare that is financially viable (Smith & Towers 2002). Long-term survival of atoxigenic strains may be a problem as they have a low survival and persistence, with Fitzgerald *et al.* (1998) reporting that 4 months after application the percentage of atoxigenic isolates was only 53 percent. Despite these hurdles, this is an excellent area for future research because effective biocontrol of *Fusarium* species using atoxigenic strains in New Zealand grazing conditions would be environmentally sustainable, which is essential in modern animal production systems.

6.7.11 The Effect of Trichothecenes on Animal Production

Recently, reports have suggested that trichothecenes, also produced by *Fusarium* species, may be partly responsible for the reduced performance of otherwise healthy livestock grazing autumn pasture, often referred to as 'ill thrift' (Towers 1997; Lauren *et al.* 1988, 1992). However, there is very little scientific evidence to support this theory. Dosing young sheep with relatively larger quantities of the fungal toxin NIV, compared with those typically found in New Zealand pasture, reduced live weight gain by 2 to 5 g/day for each mg of NIV consumed, while DON showed no effect on live weight. This suggests that NIV and DON only have a very small impact on livestock production at concentrations found in New Zealand pasture and that these toxins are likely to be indicators of other more potent fungal toxins, which are likely to be involved in ill thrift found in livestock grazing New Zealand pastures during the autumn.

Litherland *et al.* (2004) reported that *Fusarium* fungi contributed about 9% of the total ill thrift found in lambs on farms monitored from January to May 2002, in the South Island East Coast region of Canterbury, and in the North Island, contributed about 29%, which increased to 50% in 2003. In this study, computer modelling (Q-graze; Woodward *et al.* 2000) was used to determine expected weight gain in livestock based on pasture quantity and quality and animal energy requirements on twenty-two sheep and beef farms with chronic ill thrift problems. In the model, ill thrift was defined as lower than expected actual live weight gain in otherwise healthy animals. It is likely that fungal toxins contribute more to ill thrift in young stock grazing dry autumn pastures in East Coast regions than is currently acknowledged. The authors confirmed that NIV and DON are probably indicative of the presence of other more potent fungal toxins. Therefore, it is essential to identify the fungal toxin or toxins that cause loss of production in livestock and to develop methods that will effectively control or reduce the impact of these toxins on livestock health and productivity.

Metabonomics is a recently reported technique that may help identify unknown causes of ill thrift in livestock (L.R. Fletcher, Scientist, AgResearch, personal communication). Metabonomics is defined as the study of time-related multivariate metabolic response to pathophysiological stimuli or genetic modification in cells, tissues and whole organisms (Lindon *et al.* 2003; Lindon 2004) and relies on the principle that when animals ingest toxins or encounter stress, they produce a range of metabolites not seen in healthy or unstressed animals. Biological fluids, such as blood and urine, and tissue from healthy and unhealthy animals can be analysed using a range of techniques, including High Resolution Nuclear Magnetic Resonance (HNMR) Spectroscopy, Mass Spectrometry (MS), Infrared Spectroscopy and other analytical techniques that allow all metabolites present in a sample show up as various peaks in a single profile (Lindon 2004). Profiles from healthy and unhealthy animals can be compared using computer pattern recognition methods, with peaks present only in unhealthy animals identified to provide a pattern of "fingerprint" peaks likely to be associated with ill thrift (Lindon *et al.* 2003; Lindon 2004; L.R. Fletcher, personal communication). Peaks associated with ill-thrift can then be classified according to where they are positioned in the scan and the metabolite represented by that peak can be identified using NMR or MS to determine the molecular structure. Metabonomics is an exciting advance in the investigation of the causal agent/s of ill thrift and has the potential to provide the necessary information to improve animal health and reduce losses in productivity in livestock grazing dry autumn pastures in New Zealand.

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