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**GROWTH, MANAGEMENT AND NUTRITIVE VALUE OF
WILLOWS (*SALIX* SPP.) AND OTHER BROWSE SPECIES IN
MANAWATU, NEW ZEALAND.**

**A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF
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ABSTRACT

Pastoral farming in New Zealand depends mainly on the grazing of ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). These pastures yield less during dry summers and farmers are then faced with feed shortages. This study revealed the potential of deciduous willows, *Salix matsudana* x *alba* and *Salix kinuyanagi* as useful supplementary fodder during dry summers. The species can be managed under cut and carry or *in situ* browsing systems. The use of the *Salix* spp. as drought fodder is a viable option for pastoral farmers to assist them to overcome pasture feed shortages while maintaining their role in conserving soil.

Three experiments were conducted to determine (1) the effects of cutting height and frequency on browse yield and quality of deciduous *Salix* spp., compared with *Dorycnium rectum*, a small leguminous shrub and (2) the effects of planting stocks and fertiliser use on the yield and quality of the *Salix* species. Experiment 1, conducted at HortResearch, Aokautere (10 km from Palmerston North) demonstrated that edible dry matter (DM) yield of the *Salix* spp. and *D. rectum* was uninfluenced by stump height and frequency of harvest. *S. matsudana* x *alba* outyielded *S. kinuyanagi* and *D. rectum*. The *in vitro* organic matter digestibility (OMD) and nitrogen (N) concentration of the three species were: *S. matsudana* x *alba* (670 g kgDM⁻¹ and 21 g kgDM⁻¹), *S. kinuyanagi* (613 g kgDM⁻¹ and 18 g kgDM⁻¹) and *D. rectum* (665 g kgDM⁻¹ and 22 g kgDM⁻¹). Experiments 2 and 3 were conducted at AgResearch Grasslands, Ballantrae (25 km from Palmerston North). Experiment 2 showed that unrooted stem cuttings produced as much foliage as rooted stem cuttings, and the former are recommended due to their cheaper establishment. *S. matsudana* x *alba* consistently outyielded *S. kinuyanagi* even though DM yields were lower than at Aokautere. Experiment 3 revealed that DM yields of the *Salix* species were unaffected by fertiliser application. The low DM yield at Ballantrae may be due to the effects of strong winds and low temperatures. At both Aokautere and Ballantrae, *S. kinuyanagi* (255 vs. 289 g kgDM⁻¹) had higher total condensed tannin concentrations than *S. matsudana* x *alba* (60 vs. 154 g kgDM⁻¹).

Two experiments were conducted at AgResearch Grasslands, Palmerston North to determine (1) the leaf lifespan and effect of leaf maturation on leaf quality of the *Salix* spp. and the legume *Chamaecytisus palmensis*, (2) the appropriate time to cut the *Salix* spp. to optimise regrowth and browse quality for summer use, and (3) the changes in non-structural carbohydrate reserves associated with defoliation. The long leaf lifespan of the *Salix* spp. (6.5 months) and *Chamaecytisus palmensis* (5.5 months) indicated that the green standing biomass could be retained until needed in summer. The leaves of the *Salix* species and *Chamaecytisus palmensis* declined in N concentration and other nutrients at 3 months, which was longer than for those of most herbaceous species (1-2 months) during most times of the year. Leaf N concentration in all three species at each harvest met the recommended level (17 g kgDM^{-1}) for a diet adequate for a lactating ewe rearing a lamb. *S. matsudana* x *alba* yielded 70% more DM than *S. kinuyanagi* when cut in mid-spring. Sucrose comprised over 90% of the total soluble carbohydrate concentration in the roots of *S. matsudana* x *alba* defoliated once and three times in the growing season.

Two experiments were also conducted at Massey University to determine (1) the effect of browsing intensity and frequency on the regrowth of the *Salix* spp. and *C. palmensis*, and (2) sheep preference for these browse species at different times of the growing season. Regrowth of *S. matsudana* x *alba* and *C. palmensis* was similar under heavy or light browsing whereas heavy browsing in *S. kinuyanagi* increased regrowth in woody stem and total DM yields. *S. matsudana* x *alba* was the preferred species. Sheep biting rate, percent time spent browsing species and preference rating of species were higher in summer than autumn for *S. matsudana* x *alba* and similar for *C. palmensis* in both seasons. For *S. kinuyanagi*, these variables were higher for autumn and almost zero for summer browsing.

The two *Salix* spp. will complement *C. palmensis*, when grown in moist sites, where *Chamaecytisus* trees have low survival. The *Salix* species under proper management will provide useful supplementary feed for livestock during summer.

GLOSSARY OF TERMS AND ABBREVIATIONS USED

Browse - leaves, soft stems and fruits or pods of woody plants that serve as animal feed.

Coppice-managed - woody plants cut low to encourage regrowth from remaining stem.

Leader - dominant shoot of regrowth after cutting or undefoliated growing plant.

Lopping - cutting one or more branches of a woody plant.

Monopodial growth - shoot growth that results from the expansion of terminal buds on the main axes and its branches.

Pollard - cut back the crown (canopy) of a tree for wood or browse so that regrowth is beyond browsing height, and to reduce shade cast by the crown.

Regrowth - shoots produced from the remaining stem (s) after defoliation.

Stump - woody stem remaining after cutting trees and shrubs.

Sympodial growth - shoot growth that results from secondary axes, rather than from the expansion of true terminal buds.

AOAC - Association of Official Agricultural Chemist

CAB - Commonwealth Agricultural bureaux

CT - Condensed tannin

DM - Dry matter

DMD - Digestible dry matter

ME - Metabolisable energy

N - Nitrogen

NDF - Neutral detergent fibre

NRC - National Research Council

NWASCO - National Water and Soil Conservation Organisation

OMD - Organic matter digestibility

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CHAPTER 1

GENERAL INTRODUCTION AND OBJECTIVES

1.1 STATEMENT OF THE PROBLEM

Profitable ruminant production depends largely on the provision of adequate and quality forage throughout the year. Seasonal variation in pasture production, due to extreme climatic changes, results in shortfalls in feed supply and fluctuations in animal performance (Sheath *et al.* 1987). In New Zealand, ruminant livestock production traditionally depends on the grazing of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) swards (Hill 1975; Douglas *et al.* 1996). These pastures have low production in summer and autumn in areas prone to drought. Pasture feed shortage in dry periods can be ameliorated by using shrubs and low-growing tree species (browse species) as a source of forage for ruminant animals (Hathaway 1986a; McCabe and Barry 1988; Borens and Poppi 1990; Townsend and Radcliffe 1990). The forage provided by these browse species is browsed by livestock as a standing crop, or cut and carried to feed them.

It is estimated that 16.9 million hectares (Peter Newsome, Landcare Research, personal communication) out of a total land area of 26.5 million hectares of New Zealand, are cultivable. About half of this (8.4 million hectares) is capable of physically sustainable pastoral and cropping uses without soil conservation measures (National Water and Soil Conservation Organisation 1979), while the remainder requires some form of soil conservation to be sustainable. The predominant soil conservation method in New Zealand is the planting of trees to prevent soil erosion and sometimes to serve as windbreaks (van Kraayenoord and Hathaway 1986). Multipurpose trees that control erosion, serve as windbreaks and provide forage would be advantageous to pastoral farmers. Therefore, sustained pastoral production in less cultivable land in New Zealand will depend on the planting of more trees.

The need for inclusion of browse shrubs and trees in hill pastures in New Zealand (Hill 1975; Lambert *et al.* 1989a) and other parts of the world (Otsyina and McKell 1985; Sankary and Ranjhan 1989; Atta-Krah 1993) has been stressed. Browse shrubs and trees provide reasonable quality feed or serve as a supplement of green feed when grasses and other herbaceous materials are dry. They also provide useful shelter and contribute to

nutrient cycling and erosion control in hill pastures prone to soil slippage (Lambert *et al.* 1989a). Thus, the presence of browse species stabilises the landscape.

Many browse species have been evaluated as potential forage sources in New Zealand (Radcliffe 1986a, b; McCabe and Barry 1988; Lambert *et al.* 1989a, b, c, d; Borens and Poppi 1990; Wills *et al.* 1990; Douglas *et al.* 1996). Tagasaste (*Chamaecytisus palmensis*) has received the most attention (Radcliffe 1986a; Borens and Poppi 1990; Townsend and Radcliffe 1990; Douglas *et al.* 1996) while willows (*Salix* spp.) have been studied sparingly (Hathaway 1986a; McCabe and Barry 1988; Douglas *et al.* 1996). Even though browse shrubs and trees have potential in reducing pasture feed shortage and quality problems, their wider use is impeded by establishment, management and utilisation difficulties.

Browse willows, hybrid willow (*Salix matsudana* x *alba*) and kinuyanagi willow (*Salix kinuyanagi*) have potential as multipurpose trees able to provide green forage during summer dryness. They also act as conservation trees through mechanical reinforcement of the soil and the removal of excess soil water. As such, browse willows appear to provide an effective model for the study of multipurpose browse species. Tagasaste, an evergreen leguminous small tree and erect dorycnium (*Dorycnium rectum*), a small leguminous shrub, represent functional types of browse species that provide a comparison with the deciduous small tree browse willows.

This thesis determines the best defoliation regimes and cultural practices that influence browse yield and quality of deciduous willows and leguminous evergreen species. It also determines leaf retention and sheep preference of these species. Thus, the study provides data that help to integrate the browse willows and the leguminous species into the pastoral system as a source of fodder.

1.2 BROAD OBJECTIVES

The objectives were to:

- a) determine the effect of defoliation regimes on the yield and quality of browse species and based on the data, select productive species.
- b) determine the effects of planting stock and fertiliser use on the yield and quality of browse species and thus help to choose a reliable and cheap establishment method.

- c) determine leaf retention and quality in order to manipulate species to take advantage of browse accumulation and quality.
- d) determine the sheep preference of browse species to aid selection of those for planting either in single or mixed species plantations to meet the feed needs of the stock.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

The leaves and soft stems of shrubs and trees, referred to as browse or topfeed, are important for ruminant nutrition throughout the world (Baumer 1992), particularly in areas prone to drought (Lefroy *et al.* 1992). The role of browse plants in animal feeding was first emphasized in a publication by the Commonwealth Agricultural Bureau in 1947. The document stressed that "Specialists of herbaceous pastures must realize that more animals feed on trees and shrubs or other plant associations than on pastures of herbaceous legumes or grasses" (CAB 1947).

Several studies show the potential of browse plants in ameliorating extreme feed shortages in livestock systems based solely on herbaceous pasture species. In practice, tree establishment, management and utilization difficulties affect the provision of adequate and quality browse. Results from various experiments have revealed interesting but conflicting accounts due to the diversity in experimental locations and sites, as well as varied plant species. Many examples are published in reviews by Horne *et al.* (1986) and Stur *et al.* (1994).

This review examines literature on browse and assesses its relevance and applicability to the present research effort. However information on herbaceous pasture species is used where it gives a clearer understanding of the issues being discussed. Table 2.1 lists the common names of plant species reviewed, some of which may vary from those used elsewhere in the world.

Tagasaste is called *Chamaecytisus palmensis* throughout the thesis as this is the accepted name in New Zealand (Webb 1982)¹. There is taxonomic debate over the name and a recent paper by Francisco-Ortega *et al.* (1991)² referred to tagasaste as *Chamaecytisus proliferus* ssp. *palmensis* (Christ) Kunkel).

1. Webb, C. J. 1982. Tree lucerne: Its taxonomic status and naturalisation in New Zealand. Pp 2-5 in: Tree lucerne in New Zealand, Logan, L. A. ed. *Proceedings of a workshop held by Crop Research Division, Department of Scientific and Industrial Research*, Lincoln.

2. Francisco-Ortega, J.; Fernandez-Galvan, M. and Santos-Guerra, A. 1991. A literature survey (1696-1991) on the fodder shrubs tagasaste and escabon (*Chamaecytisus proliferus* (L.fil) Link *sensu lato*) (Fabaceae: Genisteae). *New Zealand Journal of Agricultural Research* 34: 471-488.

Table 2.1 A list of plant species mentioned in text

Common names	Botanical names
Mulga	<i>Acacia aneura</i>
Sweet thorn	<i>Acacia karroo</i>
Knob thorn	<i>Acacia nigrescens</i>
Antiaris	<i>Antiaris africana</i>
Antidesma	<i>Antidesma venosum</i>
Arachis	<i>Arachis pintoi</i>
Sagebrush	<i>Artemisia tridentata</i>
Jackfruit	<i>Artocarpus integra</i>
Badahar*	<i>Artocarpus lakoocha</i>
Saltbush	<i>Atriplex</i> spp.
Birch	<i>Betula</i> spp.
Kurrajong	<i>Brachychiton populneum</i>
Prairie grass	<i>Bromus willdenowii</i>
Calliandra	<i>Calliandra calothyrsus</i>
Cassia	<i>Cassia</i> sp.
Khirk**	<i>Celtis australis</i>
Granjeno	<i>Celtis pallida</i>
Mountain mahogany	<i>Cercocarpus breviflorus</i>
Tagasaste	<i>Chamaecytisus palmensis</i>
Codariocalyx	<i>Codariocalyx gyroides</i>
Blackbrush	<i>Coleogyne ramoisissima</i>
Erect dorycnium	<i>Dorycnium rectum</i>
Silverberry	<i>Elaeagnus</i> spp.
Eucalyptus	<i>Eucalyptus</i> spp.
Gular**	<i>Ficus glomerata</i>
Rai Khanin*	<i>Ficus semicordata</i>
Flemingia	<i>Flemingia macrophylla</i>
Gliricidia	<i>Gliricidia sepium</i>
Biul**	<i>Grewia optiva</i>
Griffonia	<i>Griffonia simplicifolia</i>
Leucaena	<i>Leucaena leucocephala</i>
	<i>Leucaena diversifolia</i>
	<i>Leucaena pallida</i>
Perennial ryegrass	<i>Lolium perenne</i>
Lotus	<i>Lotus pedunculatus</i>
Margaritaria	<i>Margaritaria descoides</i>
Lucerne	<i>Medicago sativa</i>
Black spruce	<i>Picea mariana</i>
White pine	<i>Pinus strobus</i>
Radiata pine	<i>Pinus radiata</i>
Phyllanthus	<i>Phyllanthus reticulatus</i>
Hybrid poplar	<i>Populus x euramericana</i>
Poplar	<i>Populus</i> spp.
Ginderi*	<i>Premna integrifolia</i>

Table 2.1 Continued

Common names	Botanical names
Oak	<i>Quercus</i> spp.
Weeping willow	<i>Salix babylonica</i>
Hybrid willow	<i>Salix matsudana</i> x <i>alba</i>
Kinuyanagi willow	<i>Salix kinuyanagi</i>
Sericea	<i>Sericea lespedeza</i>
Sesbania	<i>Sesbania glandiflora</i>
Sesbania	<i>Sesbania sesban</i>
Buffaloberry	<i>Shepherdia</i> spp.
	<i>Tadehagi triquetrum</i>
White clover	<i>Trifolium repens</i>
Gorse	<i>Ulex europaeus</i>
Lowbush blueberry	<i>Vaccinium angustifolium</i>
Lime pricklyash	<i>Zanthoxylum fagara</i>
Lotebush	<i>Ziziphus obtusifolia</i>

* Local name in Nepal; ** Local name in India

2.2 BROWSE SHRUBS AND TREES AS SOURCE OF FODDER FOR RUMINANTS

Woody plants, usually low growing trees and shrubs, are useful fodder for livestock and wildlife. They may be leguminous or non-leguminous, but leguminous plants are favoured because of their ability to fix nitrogen and their relatively high foliar nitrogen (protein) levels (Skerman *et al.* 1988; Gutteridge and Shelton 1994). Browse plants provide flexibility in the timing of their use, and in particular provide green feed when grasses and other herbaceous materials are dry (Stringi *et al.* 1987; Devendra 1992; Lefroy *et al.* 1992; Atta-Krah 1993; Cobbina 1994). The leaves and soft stems of browse shrubs and trees are of moderate to high forage value. The forage value of any feed relates to its accessibility, palatability, nutrient content and digestibility (Dann and Low 1988). These variables must be sufficiently high to provide the daily requirement of energy, protein and minerals for the animal. The minimum requirement depends on the animal (species, age, sex, physiological condition), the desired response, and existing climatic conditions (Devendra, 1992; Lefroy *et al.* 1992).

Poor estimates of the forage value of browse plants occur when they are from individual analysis of plant nutrient content, digestibility and palatability alone. Chemical analysis may over-estimate digestibility, particularly protein digestibility, as it does not take into account protein bound to lignin and condensed tannin (CT), as high CT (> 50 gCT/kg DM; Owen-Smith 1993) limits nitrogen concentration during rumen fermentation (Dann

and Low 1988). Digestibility could be a poor indicator of forage value, particularly browse, due to the possible lack of a relationship between digestibility and feed intake of the animal (Wilson 1977; Van Soest 1994). Mertens (1994) stressed that the relationship between food intake, digestibility and neutral detergent fiber (NDF) is very complex and the complete resolution of the linkages has been very difficult due to several animal and forage characteristics. Nonetheless, Forbes (1995) contended that intake of forages is controlled by NDF concentration, whereas intake of a more concentrated diet is controlled mainly by the energy requirement of the animal. Moreover, palatability varies with season and type of animal, and may not be adequately assessed on an occasional consumption of browse. As such, forage value estimates from pen feeding experiments with browse or herbaceous plants can be misleading. Pen feeding experiments are insensitive to the accessibility of the feed; a function of plant height, edible material and the amount of foraging required by the animal to consume sufficient feed. For these reasons assessment of the forage value of browse plants is most meaningful when determined from the response of browsing animals (Lefroy *et al.* 1992). Factors important for estimating forage value of browse species are presented in Table 2.2.

Table 2.2 Characteristics of browse species valuable as fodder to an animal

Plant material must be:
accessible
acceptable
digestible (> 55% DMD)
sufficiently high in
- energy
- protein
- minerals
non-toxic

DMD - dry matter digestibility, Adapted from Lefroy *et al.* 1992

Apart from forage value, the economic value of the browse plant is very important to the farmer. Economic value depends on plant establishment and management costs, time to productive stage, persistence under regular use, and ability to produce feed at the right time. These attributes constitute their substitution value; the cost of producing browse feed compared to other feed sources adequate for animal response (Lefroy *et al.* 1992). Compared to grasses, most leguminous fodder trees and shrubs have higher concentrations of crude protein, minerals and neutral detergent fiber (Dicko and Sikena 1992), and generally a lower concentration of acid detergent fiber and DMD (Le Houerou 1980). Nutrient levels and digestibility also decline slightly over the growing season and

hence their potential value as drought fodder for livestock (Le Houerou 1980; Baumer 1992; Atta-Krah 1993). Furthermore, the early growing season of browse species occurs in the late dormant season of grasses (Bergstrom 1992) thus providing a potential early supplement to pasture. Recent work in Northern Australia showed that the addition of *Leucaena leucocephala* into pastures increased the quality and quantity of cattle diets resulting in increased animal production (McGowan and Matthews 1992). Nevertheless, when the effect of browse on animal production was compared to that of grass, inconsistent results occurred (Lefroy *et al.* 1992) showing that the interactions between browse and grass in a mixed situation are complex.

2.3 BROWSE PLANTS IN THE WORLD

Browse species are significant in ruminant nutrition (Gutteridge and Shelton 1994) especially in arid and montane zones of Africa (Le Houerou 1980; Otsyina and McKell 1985), Asian-Pacific regions (Brewbaker 1986; Soedomo *et al.* 1986; Lefroy *et al.* 1992) and the Americas (McKell *et al.* 1972). In these areas naturally occurring browse species are essential for animal survival during the dry or cold seasons, especially because of their higher protein content than dried-out grasses (Le Houerou 1980; Otsyina and McKell 1985). There are numerous examples of browse fodder use in different parts of the world, but only a few of them will be elaborated here.

In Africa, over 250 million domestic animals depend on browse in their diet (Otsyina and McKell 1985). Many woody plants of the African savannas are browsed or topped for dry season feed for livestock such as sheep, goats and cattle (Le Houerou 1980; Skerman *et al.* 1988). Browse fodder use maintains yearly stability in livestock production in the drier parts of Africa (Otsyina and McKell 1985). Browse species such as *Antidesma venosum*, *Margaritaria descoides* and *Phyllanthus reticulatus* are browsed by goats during the dry season in Tanzania (Msangi and Hardesty 1993). Mabey and Rose Innes (1966) found high *in vivo* organic matter digestibility in cattle browsing *Antiaris africana* (670 g/kg DM) and *Griffonia simplicifolia* (700 g/kg DM) from the Accra plains, Ghana. They reported that cattle fed on *Antiaris africana* browse had weight gains of 82 g/day. In recent years, most studies on tree and shrub species as fodder sources in Africa have been on exotic species such as *Gliricidia sepium* and *Leucaena leucocephala* because of their ease of establishment and higher growth rates than most native species.

In Australia, trees and shrubs for fodder have been planted on 20,000 - 30,000 ha with *Chamaecytisus palmensis* and *L. leucocephala* on over 75% of this area (Lefroy *et al.* 1992). Other browse species used include *Acacia* spp., *Atriplex* spp., *Brachychiton populneum*, and *Salix* spp. Liveweight gains of 200-300kg/ha/year for cattle have been achieved on foliage of *L. leucocephala* (Quirk *et al.* 1990). *C. palmensis* browse fed to sheep increased clean fleece weight by 25-30% (Lefroy *et al.* 1992). Oldham *et al.* (1991) found that young ewes that grazed *C. palmensis* grew significantly more wool than their flockmates on supplemented dry pasture (Table 2.3). *Salix* fodder trials in Australia showed mean liveweight gains of 1.9 and 1.8 kg for hoggets and lambs respectively, with no ill-effect when fed as a sole diet for six weeks (Dann and Axelsen 1986).

Table 2.3. The mean (\pm sem) clean fleece weight (CFW) and mean (\pm sem) fibre diameter (FD) of young ewes grazed on *Chamaecytisus palmensis* or dry pasture over summer/autumn.

	No. of Ewes	CFW (kg)	FD (μm)
<i>Chamaecytisus palmensis</i> (31 weeks)	27	3.0 (0.08)	21.3 (0.22)
Pasture	30	2.2 (0.05)	20.5 (0.21)

Adapted from Oldham *et al.* (1991)

In India and Pakistan, fodder from *Celtis australis*, *Ficus glomerata*, and *Grewia optiva* has been used to replace concentrates for cattle and sheep in hill pastures. Fodder trees such as *Artocarpus integra* and *Sesbania grandiflora* are fed to sheep and goats in the dry season in West Java and Bali, Indonesia (Soedomo *et al.* 1986). In the hills of Nepal, fodder from *A. lakoocha*, *F. semicordata* and *Premna integrifolia* is used to supplement dry grass fed to lactating buffaloes during dry winters. These species are considered palatable and high milk producing forages by farmers (Paudel and Tiwari 1992). Also, in Bangladesh, Kibria *et al.* (1994) found that goats fed leaves of *Artocarpus* sp and *L. leucocephala* gained weight at a rate of 43.9 and 52.8 g day⁻¹ respectively.

In the temperate regions of Bhutan, *Salix babylonica* is an important fodder. Results show voluntary intake of 78 and 85 g DM/W^{0.75} and live weight gain of 330 and 64 g day⁻¹ for growing bulls and sheep respectively (Bajracharya 1990; Roder 1992).

2.4 BROWSE PLANTS IN NEW ZEALAND

The use of trees and shrubs for fodder in New Zealand dates from the nineteenth century, when British and Irish settlers introduced *Ulex europaeus* (Radcliffe 1986b). Hill (1975) reviewed the potential of shrubs and trees for increasing animal production in hill country pastures, and indicated the need for the inclusion of browse plants in some pastoral farming systems (Lambert *et al.* 1989a). Interest in the use of browse species as drought fodder was re-kindled when a farmer, Jim Pottinger, shared his experience at a farm forestry workshop in 1978. The farmer fed his 200 mixed-aged beef cows for two months on *Populus* browse during the summer of 1978. This maintained the stock and saved almost \$3000 required to purchase hay (Treeby 1978).

Most studies on browse species have concentrated on *C. palmensis* (Logan 1982; Logan and Radcliffe 1985; Radcliffe 1986a; Borens and Poppi 1990; Townsend and Radcliffe 1990) with a few studies on *Salix* species (Hathaway 1986a; McCabe and Barry 1988; Douglas *et al.* 1996) and other browse plants (Radcliffe 1986b; Howe *et al.* 1988; Lambert *et al.* 1989a, b, c, d; Wills *et al.* 1990; Douglas *et al.* 1996). McCabe and Barry (1988) and Hathaway (1986a) found that coppice-managed *Salix* spp. could be used as supplementary fodder for sheep, goats and deer during summer drought. Annual regrowth of *Salix matsudana* x *alba* (leaves and twigs < 5mm diameter) from 5-year old stools, was 5.7 t/ha edible dry matter (DM; Hathaway 1986a). *S. matsudana* x *alba* had an average total nitrogen content of 25 g/kg DM and *in vitro* organic matter digestibility (OMD) of 710 g/kg DM (Douglas *et al.* 1996). These values showed that the *Salix* spp. had relatively high edible DM yields and were of reasonable quality to supplement pasture during summer.

Five-year old *C. palmensis* trees yielded 8.4 t/ha edible DM (Radcliffe 1986a), and the foliage is palatable to sheep and goats (Lambert *et al.* 1989b). *C. palmensis* had an *in vitro* OMD of 770-850 g/kg DM and total nitrogen content of 26-40 g/kg DM. The species has the ability to retain leaf for almost 5 months, which is much longer than the 1-2 months for many pasture species (Borens and Poppi 1986). Lambs fed *C. palmensis* leaves achieved a liveweight gain of 95 g/day, which is less than for *Bromus willdenowii* and *Medicago sativa* (150 and 265 g/day, respectively) (Borens and Poppi 1990), but *C. palmensis* could serve as a very good maintenance feed.

2.4.1 Description of browse species in the study

2.4.1.1 Leguminous shrubs

2.4.1.1.1 *Chamaecytisus palmensis* (tagasaste)

C. palmensis is a fast-growing, evergreen shrub native to the Canary Islands and naturalised in most parts of New Zealand (Davies 1982; Lambert *et al.* 1989a). It grows in varied soils and climates, from Mediterranean (Snook 1984) to temperate climates (Sheppard and Bulloch 1986). It is deep rooting and drought tolerant (Davies 1982), but intolerant of frost (Snook 1986). The species is relatively free from diseases and pests (Davies 1982) but it is susceptible to root rot in poorly drained soils (Dann and Trimmer 1986; Sheppard and Bulloch 1986). In New Zealand, total yield of 17 t DM/ha (Douglas *et al.* 1996) has been achieved in a growing season. Borens and Poppi (1990) indicated that the foliage of *C. palmensis* is a good maintenance feed.



Fig 2.4a Heavily branched and low growing tagasaste (*Chamaecytisus palmensis*) tree.

2.4.1.1.2 *Dorycnium rectum* (erect dorycnium)

Dorycnium rectum originates from the Canary Islands and has yielded up to 21 t DM/ha in the Manawatu (Douglas and Foote 1994). The species establishes quickly, tolerates intense defoliation and its leaves are eaten readily by sheep and cattle. *D. rectum* has less woody growth and is lower growing than *C. palmensis*, and survives satisfactorily on damp soils (Douglas *et al.* 1996).



Fig 2.4b A cluster of erect dorycnium (*Dorycnium rectum*) plants

2.4.1.2 Non-leguminous shrubs

2.4.1.2.1 *Salix matsudana x alba* (hybrid willow)

Salix matsudana x alba has been selected for soil conservation purposes and for shelter due to its high wind tolerance and very good lower branch retention (Hathaway 1986b). It is drought-tolerant, palatable to sheep, goat, deer and cattle (McCabe and Barry 1988; Hathaway 1986a) and can be grown on a short-rotation coppicing system (Hathaway 1986a).



Fig 2.4c Coppice stump of a hybrid willow (*Salix matsudana* x *alba*)

2.4.1.2.2 *Salix kinuyanagi* (Kinuyanagi willow)

Salix kinuyanagi is a very leafy osier type willow (Slui 1990) which originates from Korea. This species is potentially useful for grazing on slightly moist, flat to gently sloping terrain, and in a cut and carry system. The edible forage has moderate nitrogen content (21g N/kg DM), relatively high lignin content (67-95 g/kg DM) and low OMD (460 g/kg DM) (Douglas *et al.* 1996).



Fig 2.4d Coppice stump of kinuyanagi willow (*Salix kinuyanagi*)

2.5 BROWSE PRODUCTION

Dry matter yields of browse species, like pasture species, are affected by several interacting factors, some of which are too complex to manipulate. Management regimes, climate, soil and herbivory affect browse yield. Climate is difficult to manipulate except for the use of irrigation to overcome soil moisture deficits. Gutteridge and Shelton (1994) have provided comprehensive yield data for some legume browse species (Table 2.5a) and Robinson (1985) has summarized the critical factors influencing browse productivity such as site and species differences, cutting height and frequency, and age of trees at harvest. Most browse yield data reported do not state the ages of the plants at harvest (Skerman *et al.* 1988), making it difficult to compare yields among species and even within species, for the development of appropriate management strategies.

2.5.1 Planting stock and its effect on browse production

There are several methods for establishing trees and shrubs. The most commonly used techniques are direct seeding, transplanted seedlings and vegetative propagation - usually rooted or unrooted stem cuttings (Hathaway 1986b; Snook 1986; Shelton 1994). The methods used depend on the species. If direct seeding is adopted, sometimes it becomes necessary to pre-treat seeds before sowing. For example, *C. palmensis* seeds should be scarified and inoculated before sowing (Snook 1986; Gonzalez-Andres and Ortiz 1996) for best results. Establishing *C. palmensis* by cuttings has sometimes been successful, but transplanted seedlings are preferred for quick and easy establishment (Snook 1986). Some species such as *Populus* and *Salix* (Hathaway 1986b) and *Gliricidia sepium* (Shelton 1994) are established more conveniently using either rooted or unrooted stem cuttings.

Tree establishment practices rely on the use of rooted stem cuttings for large scale tree plantations, especially for *Populus* spp. and *Salix* spp. (Zsuffa 1992). In New Zealand and Australia, the use of unrooted stem cuttings as planting stock in *Pinus radiata* plantation forestry is now widespread (Anon 1995). This propagation method has some advantages over seedlings such as improved tree form, improved stability against wind damage and reduced cost per plant (Zsuffa 1992; Anon 1995; Table 2.5b).

Most establishment studies on trees have compared rooted stem cuttings and seedlings. Currently, there is no comparative information on different browse species and the effect plant stock has on plant survival, growth rate and DM yield. However different plant stocks exhibit variable rooting ability (Fielding 1970), which consequently influences growth and yield characteristics of the plant. Nevertheless, Struve *et al.* (1984) reported that rooted stem cuttings of *Pinus strobus* grew equally as well as those of seedling origin in terms of survival, height and diameter at breast height. *Picea mariana* also had similar growth from rooted stem cuttings and seedlings (Wood 1984).

Aalders *et al.* (1972) found that one-year old rooted stem cuttings and seedlings of *Vaccinium angustifolium* showed different growth potential. The seedlings produced more shoots than rooted cuttings but they were thinner and taller, resulting in the two stock types having similar productivity. Fielding (1970) also reported differences in foliage yield between seedlings and cuttings of *Pinus radiata*.

Table 2.5a Dry matter yields of some browse species in response to different cutting regimes

Species	Cutting interval (weeks)	Edible DM ⁽¹⁾ (t/ha)	Woody stem ⁽²⁾ (t/ha)	Edible proportion (%)
<i>Calliandra calothyrsus</i>	6	7.2	1.6	82
	12	10.3	5.1	67
<i>Codariocalyx gyroides</i>	2	1.6	0.4	80
	6	2.1	1.1	66
	8	1.9	1.2	61
<i>Gliricidia sepium</i>	6	7.7	1.0	89
	12	8.2	1.7	83
<i>Leucaena leucocephala</i>	6	8.6	2.0	81
	8	9.2	7.8	54
	12	10.5	9.2	53
	16	10.3	18.6	36
	18	12.0	8.8	58
<i>Sesbania sesban</i>	4	2.7	0.3	90
	6	2.8	1.1	72
	8	2.7	1.8	60

¹Edible DM, leaf plus stem < 5 mm in diameter; ²Woody stem, stem > 5 mm

Adapted from Gutteridge and Shelton (1994)

Table 2.5b A comparison of probable establishment costs of *Pinus radiata* based on different planting schemes (\$/ha)

Costs	Conventional planting		Direct setting
	Seedlings	Rooted cuttings	Unrooted cuttings
Initial stocking (stems/ha)	1200	800	1500
Cost of plants	240	500	150
Cost of planting/setting	230	170	115
Cost of releasing	240	160	300
Total cost	710	830	565

Adapted from Anon (1995)

To conclude, it is evident that the difference in DM yield of stock types is species dependent. Some species may show similar productivity with different plant stocks whilst others may be different. The outstanding advantages of cuttings over seedlings are improved tree form, improved stability against wind damage and reduced cost of establishment per plant. These benefits may increase the wider use of browse species as an alternative feed source during dry periods in pastoral farming systems. Methods for establishment of selected species must be easy, reliable and quick. Farmers are less likely to adopt techniques that increase time of establishment and level of risk before economic returns are achieved.

2.5.2 Effect of fertilisers on browse yield and quality

Fertilisers increase dry matter (DM) yield and quality of plant components. The responsiveness of browse species to fertiliser depends on their external nutrient requirements for maximum growth and the fertility of the soil in which they are growing (Shelton 1994). Although trees will respond to fertiliser in nutrient deficient soils, there has been little research on yield and quality responses of browse species, especially in New Zealand. Fertiliser studies on woody plants in New Zealand have concentrated mostly on *P. radiata* (Maclaren 1993; Booth 1995).

Ericsson (1994) found that the basic nutrient requirements of all tree species were the same, but differed in quantities required per unit time depending on growth stage. He reported that the nitrogen requirement of conifers and broad-leaved species was similar to productive *P. radiata* plantations and hardly exceed 100 kg N/ha/year. However the type and amount of fertiliser applied will depend on the requirements of the trees and soil conditions such as moisture and nutrient status. Anderson *et al.* (1974) found a 70% increase in leader growth of *Cercocarpus breviflorus* in response to nitrogen fertiliser and a 24% increase in crude protein concentration of the leaves, which were browsed readily by deer.

2.6 INFLUENCE OF LEAF LIFESPAN ON BROWSE YIELD AND QUALITY

The term "leaf lifespan" refers to the time span between leaf emergence and senescence (Schoettle 1990; Gower *et al.* 1993). Kikuzawa (1983) described the leaf emergence patterns in woody plants as succeeding, intermediate and flush type. In the succeeding type, the leaves emerge one after the other over a long emergence period whilst the

flush type is characterised by simultaneous emergence of leaves. In the intermediate type, some of the leaves emerge simultaneously and the remaining leaves emerge in succession. Two subtypes of the intermediate type were identified as: (1) heterophyllous, usually one or two leaves emerge and after a time lag other leaves emerge in succession and (2) the flush and succeeding, indefinite number of leaves emerge at a flush and the remaining leaves appear in succession.

Leaf lifespan is an adaptive strategy of plants to environmental conditions (Chabot and Hicks, 1982; Kikuzawa 1986; Schoettle 1990). Studies on leaf lifespan have concentrated on the ability of plants to maximise carbon gain under the environmental constraints of its habitat (Chabot and Hicks 1982; Gray and Schlesinger 1983; Kikuzawa 1984; Schoettle 1990) rather than on its effect on forage yield and quality.

Leaf lifespan affects herbivory (Bentley 1979) and harvestable forage yield in plants (Chapman and Lemaire 1993). The effects of herbivory vary tremendously between plants with short-lived leaves and those which retain their leaves for months or years (Bentley 1979). This may be due to leaf quality changes that occur with season (Macauley and Fox 1980; Schultz *et al.* 1982) and maturity (Woodwell 1974). Seasonal changes in leaf quality strongly influence the life-history of herbivores and the patterns of seasonal abundance (Schultz *et al.* 1982). The pattern of change in nutrient content of leaves varies with the element. Studies on deciduous trees show that young leaves are usually richer in nitrogen (N), phosphorus (P), and potassium (K) than mature leaves and that Ca content increases until abscission (Woodwell 1974). Macauley and Fox (1980) reported that the condensed tannin content of *Quercus* leaves was very low in young leaves and increased as the leaves aged.

The lifespan of the leaf on the shoot determines the amount and quality of forage available to meet the nutrient and energy needs of the ruminant. Increased leaf lifespan leads to a decline in photosynthetic rate. The decline is lower in evergreen than in deciduous species from the same environment. However, plants with long-lived leaves support greater leaf mass, even though current season's leaf production is often greater for deciduous than evergreen plants (Gower *et al.* 1989, 1993). The benefit of a large leaf mass may be offset by the lower carbon gain of leaves in the lower canopy due to decreased light and increased respiration costs (Gower *et al.* 1993). Increased leaf lifespan adversely affects carbon assimilation processes at the leaf and canopy levels. For example, comparison of tree species in natural environments has shown that

specific leaf area (leaf area to dry mass ratio) and net photosynthetic rate are inversely related to leaf lifespan (Chabot and Hicks 1982; Reich *et al.* 1991, 1992; Gower *et al.* 1993).

2.6.1 Leaf lifespan and nutrient fluxes in browse plants

Escudero *et al.* (1992) found that some woody species in Central Spain increased the retention time of N and P in their leaf biomass through increased leaf lifespan and/or an increased retranslocation efficiency. Reich *et al.* (1991) also found that Amazonian tree species with short leaf lifespan generally have thin (high specific leaf area), fragile leaves high in nutrient content and photosynthetic rates. The reverse is true for species with long-lived leaves. Amazonian tree species with short-lived leaves are fast-growing and occupy relatively resource-rich environments whilst those with long-lived leaves tend to be slow-growing and occupy resource-poor sites (Uhl 1987). Reich *et al.* (1991) concluded that tree species adapted to nutrient-deficient habitats have nutrient-poor leaves, with low photosynthetic and growth rates. Also, they predominantly have carbon-based structural defences (such as leaf toughness - force required to bite through a leaf), and low rates of tissue turnover (Chapin 1980).

Extended leaf lifespan confers on the plant species the attributes of nutrient conservation (Chapin 1980), increased carbon gain (Schulze *et al.* 1977; Chabot and Hicks 1982) and nutrient-use efficiency (Chapin 1980; Chabot and Hicks 1982; Gray and Schlesinger 1983; Escudero *et al.* 1992). Conversely, short leaf lifespan and/or deciduous life cycles are an adaptation for rapid growth rate (Coley 1988), drought avoidance and other seasonal stresses such as cold winters (Reich *et al.* 1991).

Gray (1983) reported that deciduous shrubs had low redistribution of N and P and a high annual nutrient turnover, whilst the reverse applied to evergreen shrubs. This suggested that growth in the evergreen shrub was less dependent on soil nutrient as compared to deciduous shrubs (Gray 1983; Gray and Schlesinger 1983). Differences in foliar nutrient contents result from differences in internal nutrient use and cycling. The nutrient uptake rates are proportional to the tissue nutrient content (Chabot and Hicks 1982). Leaf lifespan determines (i) the photosynthetic carbon return per unit of nutrient invested in leaf production (ii) the ability of old leaves to act as a nutrient source in the production of new leaves, and (iii) the ability of old leaves to act as sinks for nutrients taken up during periods of no growth (Bargali and Singh 1994).

2.6.2 Leaf maturation and forage quality

The primary factors influencing the quality of forage are the plant species and level of photosynthetic activity. Plant tissues with high photosynthetic activity usually have greater quality (Hudson and Pinchak 1991). For example, live leaf has higher quality than live stem because of its greater photosynthetic activity. Nutrient quality declines as the rate of development or recruitment of new leaf tissue decreases and the rate of senescence increases. While the overall quality of live leaf may not change drastically with age, an increasing amount of senescent material dilutes nutrient density (Greene *et al.* 1987). As leaves mature, there are increases in structural components such as lignin and neutral detergent fibre, at the expense of cell solubles. The enhanced structural carbohydrate development lowers forage digestibility (Lambert *et al.* 1989d; Msangi and Hardesty 1993; Van Soest 1994) and consequently reduces feed intake, which affects animal performance. The slight decline in nutrient levels of the leaves of browse species with time makes them potential reserve biomass of high quality and, if retained for an extended period of time, they could be used as drought fodder (Borens and Poppi 1990).

2.7 DEFOLIATION RESPONSE OF BROWSE PLANTS

The use of browse species involves defoliation either by cutting or herbivory. Defoliation influences the productivity, quality of the forage and persistence of browse species. The impact of defoliation on browse species depends on the age and the amount and type of tissue removed as well as defoliation history. The loss of meristematic tissues affects the recovery of the browse species more than the loss of biomass, leaf area or environmental resources (Billbrough and Richards 1993; Richards 1993). Abiotic conditions that limit resource (light, water, nutrients) availability before and after defoliation can influence the recovery of browse species from defoliation (Richards 1993; Bryant 1987). Also plants with undefoliated or more herbivory-tolerant neighbours may not effectively recover from defoliation due to greater frequency of defoliation (Crawley 1983; Caldwell and Richards 1986; Bryant 1987; Richards 1993).

2.7.1 Physiological changes in plants after defoliation

Grazing or cutting causes instantaneous reduction of photosynthesis of individual plants. Besides the reduction in carbon gain, the translocation of fixed carbon temporarily stored in source tissues and phloem loading activity is stopped. The reduction in photosynthesis is often not proportional to leaf-area loss due to changes in canopy microclimate and unequal photosynthetic contribution of leaves of various ages. When mature leaves (low photosynthetic capacity) predominate on defoliated plants, there is greater reduction in canopy photosynthesis than expected from loss of leaf area. Conversely, if young leaves remain after defoliation, the reduction in photosynthesis is related more closely to leaf area loss (Richards 1993).

The supply of photosynthate to roots declines during defoliation due to reduced photosynthesis, and greater allocation to shoot meristems and leaf growth regions in defoliation-tolerant plants (Bassman and Dickmann 1985; Richards 1993). *Populus x euramericana* showed a 2.3 - 10-fold increase in assimilate allocation to expanding shoots, leaves and lateral branches a day after defoliation (Bassman and Dickmann 1985). The compensatory processes of increased export from source tissues and increased proportional allocations to growing shoot sinks contribute to the rapid re-establishment of the photosynthetic canopy after defoliation. These compensatory mechanisms become effective within hours after defoliation (Richards 1993).

Total non-structural carbohydrates (TNC) decrease in roots and remaining shoot parts after defoliation (George and McKell 1978; Culvenor *et al.* 1989; Gonzalez *et al.* 1989). The decline in soluble carbohydrate concentrations of roots after defoliation is rapid due to reduced allocation from the shoot system and continued utilisation of these reserves for root respiration (Richards 1993). Donart and Cook (1970) found that defoliation of browse plants late in the season was more detrimental than defoliation early in the season. However browse plants that replenished reserves rapidly after spring drawdown and regrowth periods, and thus minimised the part of the growing season with low reserve status, were least affected by defoliation and recovered rapidly from severe defoliation (Menke and Trlica 1981). The depletion of stored reserves (George and McKell 1978) caused by heavy and frequent defoliation results in reduced vigour, plant growth and extreme cases can result in plant death (George and McKell 1978; Menke and Trlica 1981).

2.7.2 Effect of cutting management on yield and quality of browse species

Cutting regimes imposed on browse species affect yield and quality of browse (Osman 1981ab; Asare 1985; Karim *et al.* 1991; Erdmann *et al.* 1993; Douglas *et al.* 1996). However, results have been inconsistent, a reflection of the varied plant species and experimental sites used. Less frequent defoliation tends to limit the adverse effect of intense defoliation on dry matter yield (Stockdale 1994). Defoliation after maturity during late autumn and winter generally has the least effect, either detrimental or beneficial, on regrowth or on the concentration of total non-structural carbohydrate in shrubs (Garrison, 1972).

Blake (1983) reported that coppicing of trees increased when trees were cut during the dormant season whilst coppicing decreased if trees were defoliated during active growth. Similarly, Hardesty *et al.* (1988) found that many temperate trees produced the greatest coppice growth when cut while dormant in winter. Cutting trees when dormant in the dry season or in winter maximises time for the trees to coppice and the new shoots to produce and store carbohydrates during the growing season. Cutting late in the growing season does not allow the stump time to replenish lost carbohydrates, and results in it surviving the dormant period on limited resources. As a result, minimal reserves are available for early season growth and future production is reduced.

Everitt (1983) noted that the crude protein (CP) and phosphorus (P) concentration in regrowth of *Celtis pallida*, *Zanthoxylum fagara*, and *Ziziphus obtusifolia* cut on various dates were higher than in current growth from uncut plants, at two months after cutting. Cutting created nutritious sprouts that were more palatable and readily available due to reduced plant height and restrictions to browsing such as sharp thorns, often prevalent on mature stems. As growth matured, the CP and P contents declined (Kramer and Kozlowski 1979; Everitt 1983) and no significant differences occurred between cut and uncut plants at 6 or 9 months after cutting.

2.7.2.1 Effects of height and frequency of cut on yield and quality of browse species

The effects of cutting height and frequency on yield and nutritional quality of forage from many browse plants have not exhibited a consistent pattern (Asare 1985; Karim *et al.* 1991; Erdmann *et al.* 1993; Douglas *et al.* 1996). Cutting height usually did not influence forage yield, but cutting frequency exerted greater effect on yield (Townsend

and Radcliffe 1990; Stur *et al.* 1994). Defoliation responses usually occur within a limited range of stump height, below or above which cutting height has no influence on yield and quality of forage. For example, Catchpole and Blair (1990) reported that leaf yield of *Leucaena leucocephala* was unaffected by cutting heights of 1.5-2.5 m above ground. Cutting trees to 15 cm stumps as well as frequent cutting leads to stump death (Osman 1981a, b).

In a study on *Flemingia macrophylla*, a leguminous shrub, Asare (1985) found that both height and frequency of cut affected dry matter yield and crude protein content. He stated that the reduction in dry matter yield with low cutting height was due to decreased leaf area. Further, a 90cm cutting height for *L. leucocephala* in Mauritius resulted in higher dry matter yield, than cutting to 15 and 150 cm (Osman 1981a). Guevaria *et al.* (1978) also found increased dry matter yield with less frequent cutting of *L. leucocephala*. Dry matter yield of *L. leucocephala* declined (Karim *et al.* 1991; Table 2.7) with frequent cutting due to an increased number of recovery phases, which affected the recovery of carbohydrate reserves and lowered the rate of dry matter production. Reserve or non-structural carbohydrate was affected by cutting frequency (Pound *et al.* 1980) and influenced the quantity of biomass produced from stumps of woody species (Erdmann *et al.* 1993). Many studies of temperate trees or shrubs show that cutting or pruning leads to a depletion of reserve carbohydrates (Kays and Canham 1991). However coppice shoots often grow much faster than shoots on intact plants (Cannell 1983), due to increased mobilisation of carbohydrate reserves in the roots after cutting (Blake, 1983).

The interaction between cutting height and cutting frequency significantly affects dry matter yield. Karim *et al.* (1991) found that dry matter yield of *L. leucocephala* was highest at 75 cm cutting height especially when cut three-monthly and was significantly reduced by more frequent cutting. Leaf nitrogen yields per tree for trees cut at three-monthly intervals were over twice as high as those obtained from monthly cuts (Table 2.7).

Table 2.7 Effects of cutting height and interval on dry matter yield and leaf nitrogen yield (g/tree) of *Leucaena leucocephala* over three-months.

Cutting height (cm)	Dry matter yields (g/tree)			Leaf nitrogen yields (g/tree)		
	Cutting interval (months)			Cutting interval (months)		
	1	3	Mean	1	3	Mean
25	20	60	40	0.65	1.50	1.08
50	22	71	46	0.70	1.80	1.25
75	28	126	77	0.92	3.15	2.03
100	50	96	69	1.42	2.38	1.90
Mean	30	88	59	0.92	2.21	1.56

Adapted from Karim *et al.* (1991)

Erdmann *et al.* (1993) reported a significantly greater number of shoots on *Gliricidia sepium* cut at 25cm above ground compared to those cut at 100cm. They attributed the difference to the 100cm stools not having to grow the same quantity of leaves, as many of them were retained on the stumps, while the 25cm stools were devoid of leaves. In contrast, a similar study on *L. leucocephala* showed a greater number of shoots on stools cut at 90cm (Jama and Nair 1989) compared to 30 cm cutting height. The morphological and physiological status at the time of cutting probably explains the variable responses between browse species. Therefore without an understanding of these it is difficult to identify appropriate cutting management for unrelated species (Stur *et al.* 1994). Refraining from “trial and error” cutting regimes is a requirement for better browse management. Further research is required to determine the influence of species morphology and physiology on cutting strategies that improve browse yield, quality and persistence.

2.8 BROWSE PLANTS AND RUMINANT ANIMAL INTERACTIONS

Ruminant animals interact with forage plants through grazing. The extent of this interaction depends on several plant and environmental factors. Plants may react to the grazing process by compensatory growth or through chemical defences (McNaughton 1979; Bergstrom and Danell 1987), all of which have beneficial and deleterious effects. The compensatory growth in plants after herbivory may alleviate the potentially deleterious effects of damage to vegetative and reproductive organs (McNaughton

1983). Stimulated vegetative growth and increased seed size of grazed plants may increase plant fitness if herbivory is moderate. McNaughton (1983) contended that plants have the capacity to compensate for herbivory and that at low levels of herbivory they overcompensate for damage so that fitness may be increased.

The impact of herbivory on plant growth depends on the type of tissue removed and time of removal relative to plant development. Herbivores affect growth rate directly by reducing the photosynthetic area, by altering the carbohydrate balance, by interfering with water and nutrient uptake and by weakening the physical structure of the plant. The animal injects chemicals into the plant transmitting viral diseases that cause the plant to divert some of its production to wound repair or the production of defensive chemicals (Crawley 1983; Van Soest 1994). Belsky (1986) concluded in a review that although herbivory may benefit certain plants by reducing competition or removing senescent tissue, there is no persuasive evidence to support the theory that herbivory benefits grazed plants.

2.8.1 Effects of browsing intensity and frequency on yield and quality of browse species

A plant's response to browsing depends on plant genetics, development stage, intensity and frequency of defoliation, plant parts affected, and modifying effects of environmental factors (Teaque 1985). The consequences of grazing intensity and frequency on individual plants and plant communities are well documented (Vallentine 1990). Browsing affects trees and shrubs in different ways (Miquelle 1983; Bergstrom 1992). There is considerable information on the effect of grazing on herbaceous pastures but very little on the effect of browsing on browse plants with domesticated animals.

In South Africa, Du Toit *et al.* (1990) compared heavily and lightly browsed trees of *Acacia nigrescens* with respect to several variables. They found that the net shoot extension was not significantly different between heavy and light browsing by giraffe and impala. The heavily browsed trees grew rapidly to compensate for the frequent removal of browse and had reduced condensed tannin (CT) levels and higher nitrogen and phosphorus contents in leaves compared with the lightly browsed trees. Heavy and less frequent browsing of *Coleogyne ramosissima* by goats (Provenza *et al.* 1983) and *Betula* species by moose (Danell *et al.* 1985) increased forage yield and quality compared to unbrowsed plants. Less frequently browsed plants outyielded those

browsed frequently, and had forage which was lower in CT (Provenza *et al.* 1983; Danell *et al.* 1985).

In contrast, Teaque (1985) found that light to moderate browsing of *Acacia karoo* by goats as well as less frequent defoliation of 3 to 6 months interval increased leaf yield compared to repeated heavy browsing. Leaf accumulation did not vary with browsing frequency (2, 4 or 12 weeks) under heavy defoliation.

Radcliffe (1986b) found that intense browsing of *Ulex europaeus* by goats lowered forage yield relative to light browsing. Townsend and Radcliffe (1990) and Radcliffe (1986a) also reported reduced edible forage yield from browsed *Chamaecytisus palmensis* trees compared to unbrowsed trees. It has been suggested that the canopy above sheep browsing height may have restricted edible regrowth within the browsing zone a year after browsing (Miquelle 1983; Danell *et al.* 1985). Factors such as fewer bud sites on maturing stem under the canopy, and the influence of the canopy as a sink for nutrients probably contributed to lower production under the canopy.

To conclude, it is clear that plant regrowth following browsing varies with species, time at which browsing occurs, animal species used, and frequency and intensity of browsing (Teaque 1985).

2.8.2 Browse preference of ruminants

Preference is the selective response made by the animal to plant differences and is essentially behavioural (Hodgson 1982b; Lambert *et al.* 1989b). It presumes both initiative and opportunity to choose between alternatives and implies active diet selection by the animal (Hodgson 1982b). What grazing animals ingest is determined by the animal, by the plants offered to the animal, and by the environment in which the selection occurs (Marten 1978). The preference for browse is dependent on many factors including the livestock species, season and the botanical composition of the plant community (Arnold 1987; Ngugi *et al.* 1992). Ngugi *et al.* (1992) reported that in south central Wyoming shrub communities, pronghorn utilises more *Artemisia tridentata* during the growing season compared to deer, elk, cattle and sheep.

2.8.3 Seasonal preference for browse by ruminants

Dietary selectivity appears sensitive to seasonal changes in forage plants but body size and related nutritional-energetic demands may require grazing animals to shift to a less selective foraging strategy (Schwartz and Ellis 1981). Predicting a grazing animal's diet is complicated because selectivity may vary not only between animal and within species, but with stage of plant maturity, site, weather and availability of plants (Holechek *et al.* 1984; Malechek 1984). Ruminants differ in their preference for browse. This depends if they are grazers (sheep, cattle), browsers (Grant's gazelle) or intermediate feeders (deer, elk and goats) (Jones and Wilson 1987).

Waggoner and Hinkes (1986) found that the American bison, even though a grazer, consumes *Salix* browse during summer and autumn. The summer diet comprised 94.2% *Salix* fodder, whereas the autumn shrub diet was 60% *Salix* and 40% *Elaeagnus* spp. and *Shepherdia* spp. The winter diet comprised almost entirely grasses and sedges, and shrubs were taken consistently in small quantities due to reduced availability.

2.8.4 Secondary metabolites and selective behaviour of ruminants

Ruminants select a diet from the plants available to them (Arnold 1981; Malechek and Provenza 1983; Provenza and Balph 1989; Gordon and Lascano 1993). The grazing process is a system of diet selection interacting with the animal's physiological needs and animals seek the most energy-efficient sources of forage (Stuth 1991). The discriminatory nature of a herbivore in the choice of forage is mainly due to the quality and chemical defense of the forage plants. Abundant evidence shows that food selection and ingestion is regulated by toxins rather than by inhibition of protein or carbohydrate digestion (Bryant *et al.* 1991).

Little information exists on diet selection by ruminants faced with conflicting constraints that may arise from the presence of secondary plant compounds. For example, plants with high levels of condensed tannin (CT) may contain high levels of nutrients and energy, but the astringent sensation animals probably experience when consuming them may lead to their rejection, which could be a nutritional mistake (Provenza *et al.* 1991). The rejection of CT containing plants or plant parts is presumably an evolved response by animals to the negative effect tannins have on forage digestibility and therefore animal fitness (Rhoades 1979). Thus, the avoidance of

secondary metabolites is the main cause of selective browsing by ruminants rather than selection for nutrients or energy (Bryant *et al.* 1992).

2.9 NUTRITIVE VALUE OF BROWSE FOR RUMINANTS

Nutritive value encompasses all nutritional attributes of a forage and its overall value to the consuming animal (Mertens 1994; Van Soest 1994). This term is often used in the more restrictive sense of forage quality (Hudson and Pinchak 1991; Mertens 1994) or feeding value (Ulyatt 1973; Marten 1989), including protein content and digestibility. Digestibility is a major determinant of nutritive value (Ulyatt 1973) and provides the best practical evaluation of the quality of the animal's diet (Holechek *et al.* 1982). The potential nutritive values of plant species depend on their inherent morphological, anatomical, physiological and chemical characteristics (Hudson and Pinchak 1991). Browse is usually fibrous and may contain various secondary metabolites that may decrease palatability and restrict intake (Van Soest 1994) thus impeding the animal's ability to forage adequately to meet its energy needs.

2.9.1 Effect of secondary plant metabolites on ruminants

Most browse plants contain diverse secondary metabolites that can deter animals from feeding on the foliage. Secondary metabolites vary in their potency as anti-feedants (Bryant *et al.* 1992), primarily due to toxicity of the metabolites rather than digestion inhibition (Bryant *et al.* 1991). Common secondary plant metabolites are presented in Table 2.9a (Barry and Blaney 1987). Secondary metabolites have evolved as a defence mechanism of woody plants against herbivory. This is an adaptive mechanism used by woody plants growing on low fertility soils (Jackson *et al.* 1996; Bryant *et al.* 1983) to compensate for their inability to grow rapidly beyond the reach of most browsing animals. Of all the secondary plant metabolites that affect the quality of browse, soluble phenolics occur most widely in woody plants, with tannins receiving the most attention (Rittner and Reed 1992; Robbins *et al.* 1987a). Tannins occur either as hydrolyzable or condensed tannins, but the dominant forage tannins are usually of the condensed type (McLeod 1974; Kumar and Singh 1984) in woody plants (Rittner and Reed 1992). Examples of browse species with varying concentrations of condensed tannins (CT) are presented in Table 2.9b. CT at low concentrations (20-40 g/kg DM) are nutritionally beneficial through decreased degradation of dietary protein in the rumen, and increased protein available for digestion and absorption leading to good animal performance

(Barry 1989; Waghorn *et al.* 1990).

Table 2.9a Common secondary compounds affecting the feed value of forages.

Class	Examples
Alkaloids	Pyrrrolidizine alkaloids, Fescue alkaloids
Glycosides	Cyanogenic glycosides, Coumarin, Isoflavones and coumestins
Mycotoxins	Zearalenone, Trichothecenes, Sporidesmin, Phomopsin, Lolitrems, Swainsonine, Slaframine, Ergot alkaloids.
Polyphenols	Tannins
Proteins and Amino acids	Bloat-producing protein, Mimosine, Indospicine
Simple acids and their salts	Oxalates, Nitrates, Fluoroacetate
Steroids and terpenes	Saponins

Adapted from Barry and Blaney (1987)

Table 2.9b Condensed tannin (CT) concentration (g/kg DM) in leaves harvested from browse species (estimates from butanol-HCl method; samples were prepared by freeze drying).

Species	Total CT (g/kg DM)
<i>Acacia boliviana</i>	17.5
<i>Arachis pintoii</i>	33.6
<i>Calliandra calothyrsus</i>	57.8
<i>Cassia</i> sp.	93.2
<i>Flemingia macrophylla</i> (17405)*	240.1
<i>Gliricidia sepium</i>	40.7
<i>Leucaena diversifolia</i>	92.5
<i>Leucaena leucocephala</i> cv Cunningham	60.3
<i>Leucaena pallida</i>	67.2
<i>Tadehagi triquetrum</i>	145.6

* Accession number

Adapted from Jackson *et al.* 1996

Many evergreen shrubs such as *Artemisia* spp. and *Quercus* spp. have high (> 76 gCT/kgDM) levels of CT and other anti-nutritional factors. In woody plants, results indicate a negative correlation between CT content and palatability. CT bind forage proteins and reduce their availability and digestibility, and they also restrict microbial fermentation of structural carbohydrates (Barry *et al.* 1986; Van Soest 1994). Robbins *et al.* (1987b) stressed that ruminants such as deer, that commonly consume tanniferous forages, are less affected by tannins than predominant grazers such as cattle and sheep. Provenza and Malechek (1984) showed that in *C. ramoisissima* eaten by goats, the CT was higher in current-season browse and lower in old growth. However, the current-season browse was high in crude protein content and digestibility. Thus, when goats selected against the current growth, they also selected against a higher nutritional plane.

Some studies have used polyethylene glycol (PEG) to bind with CT thereby enabling the effects of CT to be determined by comparing responses from CT (no PEG) and non-CT (+PEG) treatments. This technique was used to determine that high concentrations of CT (60-90g/kg DM) in *Lotus pedunculatus* depressed cell wall digestion, voluntary intake and liveweight gain while low concentrations (20-40 gCT/kg DM) improved nutrient utilisation by ruminants (Barry 1989). The latter occurred principally by reducing forage protein degradation in the rumen, thus simultaneously eliminating bloat and increasing amino acid supply to the animal (Barry and Blaney 1987; Waghorn *et al.* 1990; Jackson *et al.* 1996).

2.9.2 Influence of secondary metabolites on feed intake and digestibility of browse species

Nastis and Malechek (1981) found reduced voluntary intake and digestibility of cell constituents in goats fed *Quercus* browse with high CT concentration. Daily drenching with PEG of sheep fed leaves of *Acacia aneura* (Jones and Wilson 1987), or brushtail possum (Cork 1984) fed eucalyptus, resulted in increased food intake and cell wall digestion. Sheep and steers grazing *Sericea lespedeza* consumed more of the low CT containing plants than those with high CT concentrations (Kumar and Singh 1984).

2.10 SUMMARY AND CONCLUSIONS

In this chapter details of browse growth, management and use have been outlined. It is very evident that browse species are an indispensable and nutritionally beneficial component of the animal's environment and must be given due research attention.

Browse serves to alleviate feed supply and quality difficulties during drought when herbaceous pastures are limited and of low quality.

Data on browse species have been inconsistent and it is speculated that this might be due to genetic, morphological and physiological differences of the species studied coupled with differences in their environmental requirements. These attributes suggest that species may respond favourably or otherwise to proven management practices developed elsewhere, even for the same species. This will require field trials for identifying management practices appropriate for each species.

There is very little information for browse species on issues such as reliable establishment methods, leaf lifespan and quality, appropriate utilisation strategy, and preference to different types of ruminants. A better understanding of these issues and the provision of practical management guidelines for their use, will encourage wider adoption and integration of browse species into existing pastoral farming systems. The wider use of browse plants as a fodder source requires efficient means to enhance their feed advantage and reduce costs of growing and managing them, compared to other forage plants.

Most potential browse plants of temperate origin have not been studied extensively and there is the need to add more value to existing temperate species occurring on the farm landscape. The focal species for this research are two *Salix* species, which have received little attention as fodder sources, compared to *C. palmensis*. They are of immense interest because they are used already on farms for soil conservation purposes and shelter, and their use as drought or emergency fodder will enhance their multipurpose status.

CHAPTER 3

EFFECTS OF CUTTING MANAGEMENT, PLANT STOCK AND FERTILISATION ON BROWSE YIELD, YIELD COMPONENTS AND QUALITY OF *SALIX* SPP. AND *DORYCNIUM RECTUM*

3.1 INTRODUCTION

Adequate and quality feed is essential for increased ruminant production. Pastoral farmers are therefore obliged to devise practical ways of accommodating the variability in quality feed supply. Pastoral farmers in New Zealand depend mainly on the grazing of temperate pastures of *Lolium perenne* and *Trifolium repens*. In some areas these pastures have low production and are poor in quality during summer-autumn (Davies and Hunter 1986; Wills and Sheppard 1986; Lambert *et al.* 1989a).

A viable option in mitigating the adverse effect of herbaceous feed shortages is the use of multipurpose shrub and tree species as a forage source for ruminant animals (Hathaway, 1986a; Radcliffe, 1986a, b; McCabe and Barry, 1988; Borens and Poppi, 1990). However the wider use of browse species as drought fodder is constrained by establishment, management and utilisation difficulties. It is therefore necessary to identify appropriate cutting management, planting stock and fertiliser use as means to improve yield and establishment, and to reduce the establishment cost of browse species. ←

There are several conflicting results on the effect of cutting height on dry matter (DM) yield and quality of browse species (Ezenwa and Cobbina 1991; Karim *et al.* 1991; Douglas *et al.* 1996). Many researchers have reported that DM yield is more often unaffected by the cutting height of the plants above ground (Townsend and Radcliffe 1990; Stur *et al.* 1994), however, they are unequivocal on the dominant effect of cutting frequency on DM yield and quality of browse species (Osman 1981b; Townsend and Radcliffe 1990; Stur *et al.* 1994).

Part of these results have been published in the Proceedings of the New Zealand Grassland Association 58:93-97 (Oppong *et al.* 1996) and Proceedings of the XVIII International Grassland Congress, Canada (Oppong *et al.* 1997; in press)

Ease and reduced cost of establishment are among the factors that will enhance the wider use of browse species as a fodder source. Until recently, large scale tree planting relied on rooted stem cuttings, particularly for the *Salix* spp., but these are now deemed too expensive (Anon 1995). An alternative option is to use unrooted stem cuttings which is an inexpensive and easy way to handle planting stock (Zsuffa 1992; Anon 1995).

Fertiliser application for the enrichment of nutrient-deficient soils is an essential practice in crop and pasture production systems, but there have been few studies on the nutrient requirement of browse species (Everitt and Gausman, 1983). In New Zealand, fertiliser studies on woody plants are few with most effort being on *Pinus radiata* (Maclaren 1993; Booth 1995) and none on browse species, including *Salix* spp.

Three experiments were undertaken to provide practical guidelines for the effective use of browse species as ruminant feed, especially in dry summers. The objectives of these experiments were to determine: 1) the effects of cutting height and frequency on browse yield and quality of *Salix* species and *Dorycnium rectum*, a small leguminous shrub, and 2) the effects of planting stock, and nitrogen and phosphorus fertiliser on the yield and quality of the above *Salix* species. These browse species were selected because they are used already on farms for soil conservation (van Kraayenoord and Hathaway 1986). Their use as ruminant feed will enhance their multipurpose status.

3.2 MATERIALS AND METHODS

3.2.1 Plant species used

Three plant species were used in these studies. In Experiment 1, the species used were: hybrid willow (*Salix matsudana* Koidz. x *alba* L) clone 'Tangoio', Kinuyanagi willow (*Salix kinuyanagi* Kimura) and erect dorycnium (*Dorycnium rectum* (L.) Ser. in DC). *Salix matsudana* x *alba* and *Salix kinuyanagi* were used in Experiments 2 and 3. These species are described fully in section 2.4.1. The experimental sites are shown in Figure 3.1

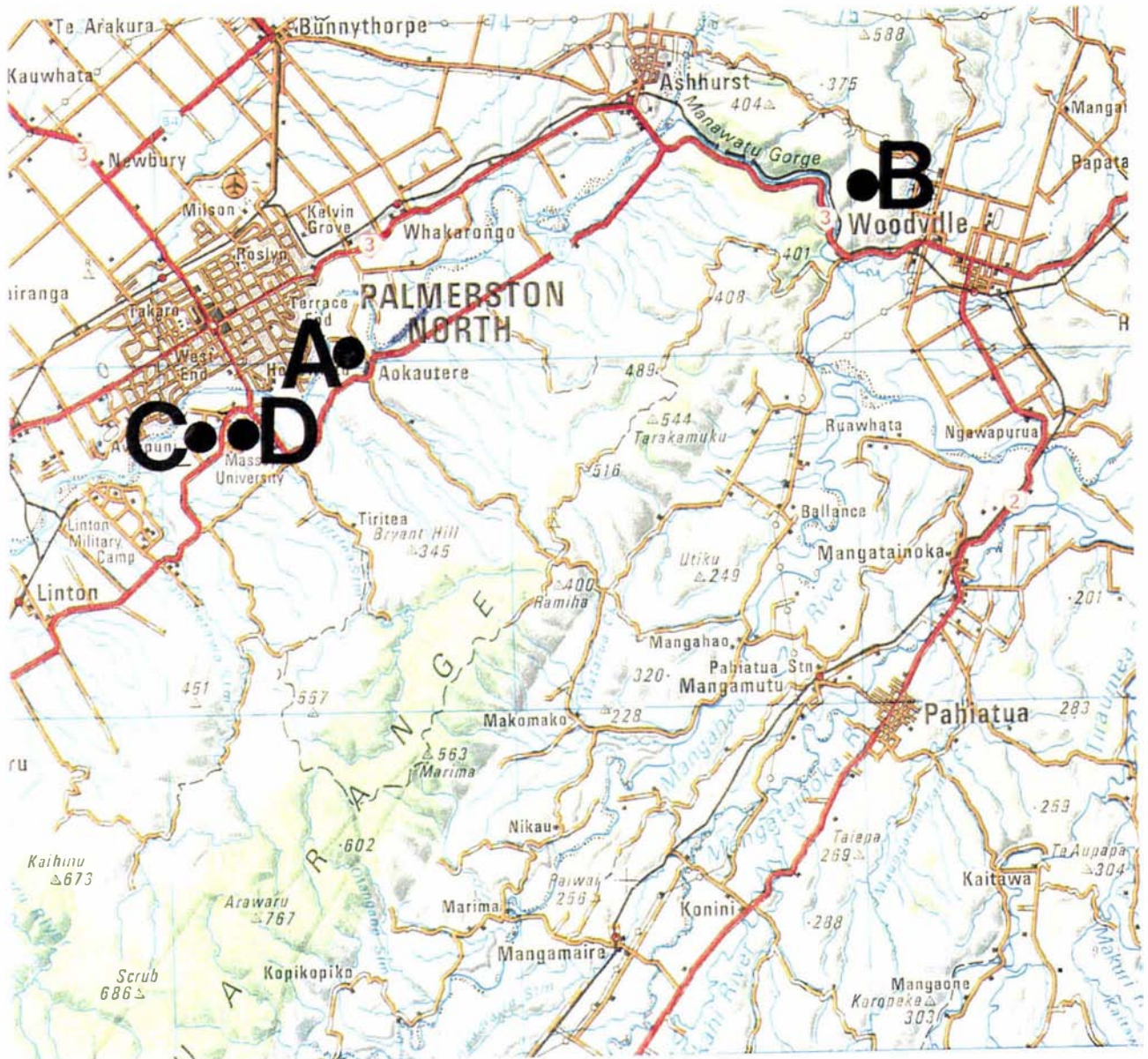
3.2.2 EXPERIMENT 1: EFFECTS OF HEIGHT AND FREQUENCY OF CUTTING ON BROWSE YIELD, YIELD COMPONENTS AND QUALITY OF *SALIX* SPP. AND *DORYCNIUM RECTUM*

3.2.2.1 Site description

The experiment was conducted on a moist, lowland site at the Horticultural Research Institute's (HortResearch) field station at Aokautere (grid reference; NZMS 260 T24 915355, Palmerston North). The long term mean annual rainfall is 995 mm with the dry months from January to April. The mean annual air temperature is 12.9 °C (Table 3.1). The mean soil temperature (30 cm depth) is 14 °C (Burgess 1988). The soil is a Manawatu silt loam, freely drained but subject to surface compaction and with medium fertility. For example, Olsen P was 17 mg/kg soil. The site had soil pH of 6.7 (determined on 1:2.5 soil : water suspension) (Table 3.2).

3.2.2.2 Experimental treatments and design

The *Salix* spp. and *Dorycnium rectum* were planted in late June 1991 and data were collected for two years (1994/95 and 1995/96 growing seasons). Plants were harvested at 3 heights above ground (Control, 80 cm, and 120 cm) and once (January 1995; 1996) or twice (January and April 1995; 1996) per year. The control heights were 10 cm (*Dorycnium rectum*) and 30 cm (*Salix* spp.). On 12 August 1994 and 18/21 August 1995 at the start of each year's experiment, all trees were cut to the above heights and the crowns trimmed to varying widths depending on cutting height. The crown widths for *Dorycnium rectum* were 10 cm (control) and 30 cm (80 and 120 cm). Those for the *Salix* spp. were 30 cm (control) and 60 cm (80 and 120 cm). The pasture between browse plant rows was mowed regularly and that within rows was killed with glyphosate (1.1 kg ai/ha). The experiment was a split plot design with cutting heights allocated to main plots and species x frequencies to sub-plots in three randomised complete blocks. Each sub-plot consisted of a row of 4-8 plants. The plant spacing was 1.5 m by 2.5 m for intra- and inter-rows respectively.



Legend

- A) HortResearch, Aokautere
- B) AgResearch Grasslands, Ballantrae
- C) AgResearch Grasslands, Palmerston North
- D) Massey University, Palmerston North

Figure 3.1 Location of the experimental sites

3.2.3 EXPERIMENTS 2 AND 3: EFFECTS OF PLANTING STOCK AND INORGANIC FERTILISERS ON BROWSE YIELD, YIELD COMPONENTS AND QUALITY OF *SALIX* SPP.

3.2.3.1 Site description

Both experiments were at AgResearch's Ballantrae Hill Country Research Station (grid reference; NZMS 260 T24 499964, Woodville). The environment is classified as summer-wet. The long term mean annual rainfall is 1210 mm with distribution similar to that at Aokautere. The long term mean annual air temperature is 12.3 °C (Table 3.3). The soil is a Wianui silt loam, poorly drained and low in soil nutrients. For example, Olsen P was 8 mg/kg soil. It is weakly gleyed and developed from weakly to moderately leached intergrades between central yellow-brown and yellow-grey earths (J.D. Cowie, personal communication). The mean soil temperature (30 cm depth) is 12.7 °C (Burgess, 1988). The soil pH was 5.5 (determined on 1:2.5 soil : water suspension).

Table 3.1 Monthly rainfall (mm) and mean air temperature ($^{\circ}\text{C}$) at Aokautere during the experiment, and long-term averages (Experiment 1).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RAINFALL												
1994	33	30	58	44	122	92	74	82	173	70	180	46
1995	54	58	142	104	108	94	121	73	106	140	102	101
1996	51	129	79	160								
Average (1935-95)	79	67	69	81	89	97	89	89	75	88	78	94
TEMPERATURE												
1994	18.1	19.0	14.6	13.9	12.2	8.5	7.9	9.7	10.2	11.9	13.7	15.9
1995	17.8	18.9	17.1	16.0	11.5	9.4	8.2	8.7	11.2	12.7	13.6	17.6
1996	18.8	18.3	15.3	15.3								
Average (1935-95)	17.4	17.6	16.3	11.4	10.9	8.7	8.7	9.1	10.7	12.5	14.2	17.4

Mean air temperature ($^{\circ}\text{C}$) = (maximum + minimum)/2

Table 3.2 Soil nutrient levels at Aokautere and Ballantrae experimental sites (sampled to 75mm depth; July 1995)^a (Experiment 1 and 2).

SITES	pH ^b	Olsen P (mg/kg)	S ^c (mg/kg)	Exchangeable cations (me/100g soil) ^d		
				K	Ca	Mg
AOKAUTERE	6.7	17	3	0.4	0.3	1.3
BALLANTRAE	5.5	8	4	0.2	0.1	0.9

^aConverted "quick-test" units assuming constant soil bulk density

^bDetermined on a 1:2.5 soil : water suspension

^cCaH₂PO₄ -extractable SO₄-S

^d1M ammonium acetate, pH 7

Table 3.3 Monthly rainfall (mm) and mean air temperature ($^{\circ}\text{C}$) at Ballantrae during the experiment, and long-term averages (Experiment 2).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RAINFALL												
1994	46	52	60	70	120	132	118	96	171	78	149	46
1995	48	63	115	156	93	131	127	117	197	147	128	70
1996	83	91	105	131	169	83	198	113	90	112	139	119
1997	66	59	128	135								
Average (1970-96)	79	79	100	92	108	111	115	100	113	110	98	105
TEMPERATURE												
1994	17.2	18.2	14.8	13.7	11.6	8.1	7.9	9.5	9.4	10.4	12.8	15.2
1995	17.2	17.8	16.7	14.6	10.9	8.7	7.5	8.0	10.4	11.5	12.8	16.4
1996	17.3	19.5	14.3	14.2	9.0	6.9	8.3	6.1	12.9	12.9	12.5	10.9
1997	NA	NA	NA	NA								
Average (1970-96)	16.7	16.8	15.8	13.1	10.5	8.7	7.8	8.6	10.0	11.6	13.3	15.2

Mean air temperature ($^{\circ}\text{C}$) = (maximum + minimum)/2; NA, not available

3.2.3.2 Experimental treatments and design

Salix matsudana x *alba* and *S. kinuyanagi* were used and data were collected for two years (1994/95 and 1995/96 growing seasons) in Experiment 2 and one year (1996/97 growing season) in Experiment 3. Each species had 2 planting stocks: 1-year-old rooted stem cuttings, and sheep poles (2.2 m long x 4.0-6.0 cm diameter unrooted stem cuttings). They were planted in October 1993 at a spacing of 5 m x 5 m. Experiment 2 was a 2x2 factorial with two species and two planting stocks in five randomised complete blocks. The same site was used for Experiment 3 but the treatments were arranged in a split-plot design with species and planting stock allocated to main plots and fertiliser application to subplots.

The fertiliser treatments were (a) no fertiliser (b) mixture of 100 kg N/ha (Urea) and 50 kg P/ha (superphosphate), equivalent to 250 g N and 125 g P per tree. Prior to imposing treatments, weeds at the base of trees were killed with a mixture of glyphosate, terbuthylazine and terbumeton (1.1, 0.25 and 0.25 kg ai/ha, respectively). The trees were topped on 21 August 1996 and the fertiliser applied on 28 August, about 60 cm from the stool. The application procedure was based on guidelines provided by Smith and Gilliam (1980). There were 4 trees per subplot. All trees were fitted with plastic 'netlon' sleeves 1.4 m high to protect them against bark damage by grazing animals. The paddock was grazed regularly with sheep. In August 1994, 1995 and 1996 all the trees were topped at a height of 1.6 m.

3.2.4 Measurements

In Experiment 1, trees were harvested to the stump heights given in Section 3.2.2.2 on 20/25 January and 3 April 1995/96. Two randomly selected trees were harvested from each subplot on each occasion. In Experiment 2, the two central trees in the row of four were harvested to the top of the 'netlon' sleeves (1.4 m above ground) in summer and autumn on 20 January and 5 April 1995/96 respectively. The same harvesting procedure as in Experiment 2 was used for Experiment 3 and the harvest was conducted in summer (7 January 1997) and autumn (8 April 1997).

Data on the number of coppice shoots, length and basal diameter of the leader were recorded. Shoot length was measured with a 2 m graduated stick and basal diameter with vernier callipers. The fresh weight was measured and the herbage subsampled and dissected into leaf, edible stem (soft stems < 5 mm in diameter) and woody stem. These were oven-dried at 80 °C for 24 hours to determine the dry weight of each component. Pasture yield was measured from October, 1994 to May, 1995 by harvesting herbage within 5 randomly allocated cages (0.186 m²) between trees at monthly intervals, using a pre-trimming technique (Lambert *et al.* 1989a). Harvested pasture was sub-sampled, separated into grass, legumes, weeds and dead matter and their dry weight determined after oven-drying at 80 °C for 24 hours.

3.2.5 Chemical analyses

Sub-samples of leaf and edible stem from each species and from pasture, in summer and autumn, were stored at -20 °C and then freeze-dried and ground with a Wiley mill to pass through a 1 mm sieve. All samples were analysed for total nitrogen (Automatic Kjeldahl method - macro; AOAC 1984), *in vitro* organic matter digestibility (Roughan & Holland 1977) and condensed tannin by a modified butanol-HCl procedure (Terrill *et al.* 1992). Condensed tannin levels were determined only for the *Salix* species since these were the main species of interest. There was no chemical analysis of the herbage from Experiment 3.

3.2.6 Statistical analyses

PROC GLM programme of SAS version 6.10 (SAS 1994) was used for all analyses. In Experiment 1, dry matter yields and yield components for the treatments were analysed as a split-split-plot design. Data from 1995 and 1996 harvests were analysed as a split-plot analysis of variance over time. Nitrogen, digestibility and condensed tannin data were also analysed as a split-plot analysis of variance.

Data for 1995 and 1996 harvests in Experiment 2 were analysed as a split-plot analysis of variance over time. The data were for summer harvests only since autumn DM yields

were negligible. Those of Experiment 3 were also analysed as a split-plot design. The nitrogen and digestibility data of Experiment 2 were analysed as a factorial analysis of variance in a randomised complete block design. Condensed tannin values were analysed as a randomised complete block design. Treatment means were compared with Fisher's protected LSD test at $\alpha = 0.05$ (Steel and Torrie 1980). Levels of significance of the differences between treatment means in all tables were denoted as follows: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; **** $p \leq 0.0001$; NS, not significant ($p > 0.05$).

3.3 RESULTS

3.3.1 Climatic conditions at the experimental sites

In 1994 three and five months of the period had monthly rainfall above the long term estimates for Aokautere and Ballantrae respectively (Table 3.1; Table 3.3). In 1995 both sites had nine months of the year with monthly rainfall higher than the long term averages. At Ballantrae, the 1995 monthly rainfall levels and patterns were similar to those of 1996 (Table 3.3). The most striking feature at both sites was that the December rainfall for the 1994/95 season was half the long term average. The 1995/96 season was wetter than the 1994/95 season.

At Aokautere in 1994, five months of the year were warmer (0.6 - 2.5 °C) whilst in 1995 nine months were warmer (0.2 - 4.6 °C) than the long term average (Table 3.1). Further, at Ballantrae in 1994, seven months had warmer (0.1 - 1.4 °C) whereas 1995 and 1996 had eight months of warmer (0.0 - 1.2 °C) temperatures than the average (Table 3.3). Temperatures were generally higher at Aokautere than Ballantrae.

3.3.2 Experiment 1

In this section treatments that showed significant ($p < 0.05$) interaction effects for the variables analysed are presented and main effects are also given where necessary.

3.3.2.1 Dry matter yield

Across all cutting heights and harvests, *Salix matsudana* x *alba* had higher total dry matter (DM), edible forage (leaf plus stem < 5 mm) and woody stem yields per tree than *Dorycnium rectum*, with *Salix kinuyanagi* intermediate (Table 3.4a). The *Salix* species had similar leaf yield which was higher ($p \leq 0.0001$) than that of *D. rectum*. Edible stem yield was higher ($p \leq 0.01$) in *S. matsudana* x *alba* than *S. kinuyanagi*. *D. rectum* and *S. kinuyanagi* had higher leaf to stem ratio ($p \leq 0.0001$) than *S. matsudana* x *alba*. Percent edible forage above winter cut height was 43%, 41% and 67% for *S. matsudana* x *alba*, *S. kinuyanagi* and *D. rectum* respectively.

Cutting height slightly affected the total DM and woody stem yield of the *Salix* species, but had no effect on *D. rectum*. *S. kinuyanagi* stumps cut to 80cm outyielded those cut at the other heights in total DM (Table 3.4b). *S. matsudana* x *alba* stumps cut to 80 and 120 cm had higher total and woody stem DM than those cut at 30 cm. Nonetheless, cutting height had no influence on total edible forage, leaf and edible stem yield as well as leaf : stem ratio. DM yields were higher in the *Salix* species than *D. rectum* (Table 3.4a). DM yields of all species were unaffected ($p > 0.05$) by cutting frequency. Harvesting either once (summer only) or twice (summer plus autumn) did not affect annual DM yield in any species (Appendix 3.1).

Within 1995 and 1996, there were differences between the species in total DM, total edible forage, edible stem, and woody stem yields (Table 3.4b). However for each species, DM yields were similar in 1995 and 1996 although the *Salix* species had slightly higher total DM in 1996 compared with 1995, whilst that of *D. rectum* was relatively low in 1996. In all species, leaf yield and leaf : stem ratio were unaffected ($p > 0.05$) by harvest time (Table 3.4b).

3.3.2.2 Yield components

The number of coppice shoots per tree did not vary with cutting height for any species (Table 3.4c), but the *Salix* species had larger and thicker leaders than *D. rectum* ($p \leq 0.05$) except at the 120 cm height. Primary regrowth (summer harvest) in all species produced larger and thicker leaders ($p \leq 0.0001$) than secondary regrowth (autumn harvest). *S. matsudana* x *alba* had about twice as many coppice shoots at the autumn harvest compared with *S. kinuyanagi* and *D. rectum* (Table 3.4c). The number of coppice shoots on *Salix kinuyanagi* and *D. rectum* significantly decreased between 1995 and 1996 harvests, but the other yield components remained similar ($p > 0.05$) for the two years (Table 3.4d).

Table 3.4a Effect of cutting management on dry matter (DM) yield of the *Salix* spp. and *Dorycnium rectum* at Aokautere over two years (Experiment 1).

SPECIES	Dry matter yield (kg DM/tree)					
	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : Stem ratio
<i>Salix matsudana</i> x <i>alba</i>	0.9 ^a	0.3 ^a	1.6 ^a	1.2 ^a	2.8 ^a	0.5 ^c
<i>Salix kinuyanagi</i>	0.8 ^a	0.1 ^c	1.3 ^b	0.9 ^b	2.2 ^b	0.6 ^{ab}
<i>Dorycnium rectum</i>	0.2 ^b	0.2 ^b	0.2 ^c	0.4 ^c	0.6 ^c	0.8 ^a
SEM	0.04	0.02	0.1	0.1	0.1	0.1
Significance	****	**	****	***	****	*

Edible stem - stem < 5 mm; Woody stem - stem > 5mm; sample size (n) = 36; SEM - standard error of the mean). Means in each column with the same letters are not significantly different at 5% significance level.

Table 3.4b Effects of cutting height and harvest year on dry matter (DM) yield of the *Salix* spp. and *Dorycnium rectum* at Aokautere over two years (Experiment 1).

		Dry matter yield (kg DM/tree)					
		Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : Stem ratio
SPECIES	Cutting height						
<i>Salix matsudana x alba</i>	30 cm	0.6	0.2	1.0 ^c	0.8	1.8 ^c	0.5
	80 cm	1.0	0.4	2.0 ^a	1.4	3.4 ^a	0.4
	120 cm	1.0	0.3	1.8 ^a	1.4	3.1 ^a	0.5
<i>Salix kinuyanagi</i>	30 cm	0.7	0.1	1.1 ^c	0.7	1.9 ^{bc}	0.6
	80 cm	1.0	0.2	1.6 ^{bc}	1.1	2.7 ^a	0.6
	120 cm	0.8	0.1	1.2 ^c	0.8	2.1 ^b	0.6
<i>Dorycnium rectum</i>	10 cm	0.2	0.2	0.3 ^d	0.4	0.7 ^d	0.8
	80 cm	0.3	0.2	0.2 ^d	0.5	0.7 ^d	0.8
	120 cm	0.2	0.2	0.1 ^d	0.4	0.5 ^d	0.8
SEM		0.1	0.03	0.1	0.1	0.2	0.1
Significance		NS	NS	*	NS	*	NS
SPECIES	Harvest Year						
<i>Salix matsudana x alba</i>	1995	0.8	0.3 ^a	1.4 ^b	1.1 ^a	2.5 ^{ab}	0.5
	1996	0.9	0.3 ^a	1.8 ^a	1.2 ^a	3.0 ^a	0.5
<i>Salix kinuyanagi</i>	1995	0.8	0.1 ^b	1.3 ^b	0.8 ^{bc}	2.1 ^b	0.6
	1996	0.8	0.1 ^b	1.3 ^b	1.0 ^b	2.2 ^b	0.6
<i>Dorycnium rectum</i>	1995	0.3	0.3 ^a	0.3 ^c	0.6 ^c	0.9 ^c	0.6
	1996	0.2	0.1 ^b	0.1 ^c	0.3 ^d	0.4 ^c	1.0
SEM		0.1	0.03	0.1	0.1	0.2	0.1
Significance		NS	***	*	*	*	NS

Edible stem - stem < 5 mm; Woody stem - stem > 5mm; sample size (n) = 36; SEM - standard error of the mean; Means in each column with the same letters are not significantly different at 5% significance level.

Table 3.4c Effects of cutting height and harvest times on yield components of the *Salix* spp. and *Dorycnium rectum* growing at Aokautere over two years (Experiment 1).

		Yield Components		
		Number of shoots	Leader length (m)	Leader diameter (mm)
SPECIES	Cutting Height			
<i>Salix matsudana x alba</i>	30 cm	39.1	1.8 ^b	12.3 ^{abc}
	80 cm	49.1	2.0 ^{ab}	13.3 ^{ab}
	120 cm	44.1	2.1 ^{ab}	13.7 ^a
<i>Salix kinuyanagi</i>	30 cm	27.1	1.7 ^b	14.4 ^a
	80 cm	34.0	1.8 ^b	13.9 ^a
	120 cm	39.3	1.6 ^b	12.7 ^{ab}
<i>Dorycnium rectum</i>	10 cm	32.6	1.1 ^{cd}	7.1 ^d
	80 cm	31.9	1.5 ^c	10.4 ^c
	120 cm	28.4	1.7 ^b	11.7 ^{bc}
SEM		3.9	0.1	0.6
Significance		NS	*	**
SPECIES	Harvest Times			
<i>Salix matsudana x alba</i>	Summer	24.8 ^c	2.8 ^a	18.8 ^a
	Autumn	63.5 ^a	1.2 ^c	7.4 ^c
<i>Salix kinuyanagi</i>	Summer	27.8 ^c	2.4 ^a	19.6 ^a
	Autumn	39.1 ^{bc}	1.0 ^{cd}	7.8 ^c
<i>Dorycnium rectum</i>	Summer	33.3 ^c	1.7 ^b	11.0 ^b
	Autumn	28.6 ^c	1.2 ^c	8.5 ^c
SEM		2.8	0.1	0.6
Significance		****	****	****

Sample size (n) = 36; SEM - standard error of the mean; Means in each column with the same letters are not significantly different at 5% significance level.

Table 3.4d Effect of cutting on yield components of the *Salix* spp. and *Dorycnium rectum* growing at Aokautere over two years (Experiment 1).

	Harvest Year	Yield Components		
		Number of shoots	Leader length (m)	Leader diameter (mm)
SPECIES				
<i>Salix matsudana</i> x <i>alba</i>	1995	42.8 ^a	2.0	14.7
	1996	45.4 ^a	1.9	11.5
<i>Salix kinuyanagi</i>	1995	39.3 ^a	1.7	13.9
	1996	27.6 ^b	1.7	13.5
<i>Dorycnium rectum</i>	1995	38.3 ^a	1.6	10.7
	1996	23.6 ^b	1.3	8.9
SEM		3.4	0.1	0.5
Significance		*	NS	NS

Sample size (n) = 36; SEM - standard error of the mean; Means in each column with the same letters are not significantly different at 5% significance level.

3.3.2.3 Browse quality

The total nitrogen (N) concentration of edible DM of all species, and condensed tannin (CT) concentration of the *Salix* spp. was similar in summer and autumn (Table 3.5a). *S. matsudana* x *alba* had higher organic matter digestibility (OMD) than *S. kinuyanagi* at the summer harvest, with *D. rectum* having digestibility between the two *Salix* spp. *S. matsudana* x *alba* and *D. rectum* had similar OMD for the autumn harvest, and were higher ($p \leq 0.05$) than *S. kinuyanagi* (Table 3.5a). N concentration and OMD of all browse species were higher ($p \leq 0.0001$) in leaf than edible stem. The leaf N concentration of *S. matsudana* x *alba* and *D. rectum* were similar, but higher than that of *S. kinuyanagi*. Moreover, the leaf OMD of *S. matsudana* x *alba* was higher than that of *S. kinuyanagi* with *D. rectum* having leaf digestibility between the two *Salix* species. The edible stem of *S. kinuyanagi* had the highest OMD whilst those of *S. matsudana* x *alba* and *D. rectum* had similar values. There were also differences ($p \leq 0.0001$) in total CT concentration between leaf and edible stem of the *Salix* species. The total CT concentration was lower in *S. matsudana* x *alba* than in *S. kinuyanagi* leaves ($p \leq 0.0001$) and levels of CT in each species were higher in summer than autumn, but not statistically different. The total CT concentration in the edible foliage of *S. kinuyanagi* (255 g/kg DM) was four times higher than in *S. matsudana* x *alba* (59 g/kg DM) (Table 3.5a, b).

3.3.2.4 Pasture herbage accumulation and quality

In summer, the herbage harvested from the Aokautere site comprised 50% dead matter and weed, whereas that from Ballantrae had 90% dead matter and weed (Table 3.6a). The autumn herbage had 25-30% dead matter and weed for both sites. Herbage accumulation rate at Aokautere was higher in summer than autumn but the reverse occurred at Ballantrae. At both sites, herbage N concentration was higher in autumn than in summer.

3.3.2.5 Edible forage yield of the browse species and pasture in 1995 harvests

The order from greatest to least for edible forage yield per hectare at the Aokautere site was *S. matsudana* x *alba*, *S. kinuyanagi*, *D. rectum* and pasture (Table 3.6b). The pasture consisted of *Poa pratensis* L. (23%), *Poa annua* L. (4%), *Lolium perenne* L. (4%) and *Trifolium repens* (22%) and other species (47%).

Table 3.5a Effects of harvest times and plant part on browse quality of the *Salix* spp. and *Dorycnium rectum* growing at Aokautere (Experiment 1).

		Nutritive Value (g /kg DM)		
		Nitrogen	Organic matter digestibility	Total condensed tannin
SPECIES	Harvest times			
<i>Salix matsudana x alba</i>	Summer	19	691 ^a	65
	Autumn	22	648 ^b	53
<i>Salix kinuyanagi</i>	Summer	15	611 ^c	275
	Autumn	20	615 ^c	234
<i>Dorycnium rectum</i>	Summer	20	664 ^b	ND
	Autumn	24	666 ^b	ND
SEM		0.5	8.8	7.5
Significance		NS	*	NS
SPECIES	Plant part			
<i>Salix matsudana x alba</i>	Leaf	32 ^a	908 ^a	45 ^d
	Edible stem	9 ^d	431 ^c	73 ^c
<i>Salix kinuyanagi</i>	Leaf	25 ^b	715 ^c	290 ^a
	Edible stem	9 ^d	512 ^d	219 ^b
<i>Dorycnium rectum</i>	Leaf	33 ^a	874 ^b	ND
	Edible stem	12 ^c	456 ^c	ND
SEM		0.5	8.8	7.5
Significance		****	****	****

Sample size (n) = 36; SEM - standard error of the mean; Means in each column with the same letters are not significantly different at 5% significance level.

Table 3.5b Constituents of total condensed tannin in the *Salix* spp. under cutting at Aokautere (Experiment 1).

SPECIES	Condensed Tannin level (g/kg DM)*			
	Extractable	Protein-bound	Fibre-bound	Total
<i>Salix matsudana</i> x <i>alba</i>	34	25	0.9	59
<i>Salix kinuayanagi</i>	133	119	1.5	255
SEM	3	5	0.2	8
Significance	****	****	NS	****

* Values are for leaf plus edible stem samples; Sample size (n) = 24; SEM - standard error of the mean

Table 3.6a Herbage accumulation rate (kg DM/ha/day), herbage quality and composition of pasture growing at Aokautere and Ballantrae during 1994/95 (Experiments 1 and 2).

VARIABLES	Sites			
	Aokautere		Ballantrae	
	Summer	Autumn	Summer	Autumn
Herbage accumulation rate (kg DM/ha/day)	40	29	13	39
Nitrogen (g/kg DM)	26	37	22	37
OMD (g/kg DM)	638	715	ND	ND
Total CT (g/kg DM)	8	7	0	6
HERBAGE COMPOSITION				
Grass (kg DM/ha)	500	375	45	814
Legume (kg DM/ha)	120	200	0	36
Weeds (kg DM/ha)	420	295	90	217
Dead matter (kg DM/ha)	210	0	268	73

OMD - Organic matter digestibility; CT - Condensed tannin; ND, not determined.

Table 3.6b Edible forage yield from trees and pasture growing at Aokautere over the two harvesting times during 1994/95 (Experiment 1).

Forage types	Harvest period	Edible forage yield (kg DM/ha)
<i>Salix matsudana x alba</i>	S + A	2945
<i>Salix kinuyanagi</i>	S + A	2245
<i>Dorycnium rectum</i>	S + A	1650
Pasture	January (S)	430
	April (A)	400

S+A - Summer plus Autumn; edible pasture estimated as 70% of total live grass and legume yield.

3.3.3 Experiment 2

The interaction effects of the treatments, *Salix* species and planting stock, were not significant and therefore only main effects are presented (Table 3.7).

3.3.3.1 Dry matter yield

S. matsudana x *alba* had significantly higher total DM, edible forage (leaf plus stem < 5 mm), leaf, edible stem and woody stem yields than *S. kinuyanagi*. *S. matsudana* x *alba* yielded 144% more edible forage than *S. kinuyanagi* but it was less leafy than *S. kinuyanagi* (Table 3.7). DM yields were similar ($p > 0.05$) between planting stock in both species. Leaf and edible forage yields were higher in 1996 than 1995 and the 1996 harvest was leafier than in 1995 ($p \leq 0.05$).

3.3.3.2 Yield components

S. matsudana x *alba* had more coppice shoots, and larger and thicker leaders than *S. kinuyanagi*. Planting stock had no effect on yield components. Material harvested in 1996 had larger leaders than that harvested in 1995 (Table 3.7).

Table 3.7 Effect of planting stock on dry matter (DM) yield and yield components of the *Salix* spp. growing at Ballantrae over two years (Experiment 2).

	Yield Components			Dry matter yield (g DM/tree)					
	Number of shoots	Leader length (m)	Leader diameter (mm)	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : Stem ratio
SPECIES									
<i>Salix matsudana</i> x <i>alba</i>	19	1.0	7.8	36.4	16.1	30.6	52.5	83.1	0.8
<i>Salix kinuyanagi</i>	8	0.6	6.8	17.1	4.3	9.0	21.5	30.5	1.4
SEM	1	0.01	0.1	1.4	0.7	2.5	2.0	4.0	0.1
Significance	***	****	**	***	***	**	***	***	**
PLANT STOCKS									
Unrooted stem (Pole)	14	0.8	7.2	26.8	9.2	20.8	36.0	56.9	1.1
Rooted stem (O/1)	14	0.8	7.4	26.7	11.2	18.8	37.9	56.7	1.0
SEM	1	0.1	0.5	5.3	1.3	6.1	6.6	12.6	0.1
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS
HARVEST YEARS									
1995	14	0.7	7.1	20.4	9.4	16.5	29.8	46.3	1.2
1996	14	0.9	7.5	33.1	11.0	23.1	44.1	67.2	1.0
SEM	1	0.04	0.3	3.2	1.2	3.2	4.2	7.3	0.1
Significance	NS	***	NS	**	NS	NS	*	NS	*

O/1 rooted stem - one year old rooted stem cutting; Pole - 2.2 m long x 4-6 cm diameter unrooted stem cutting; Sample size (n) = 40; SEM - standard error of the mean

3.3.3.3 Browse quality

Leaves of *S. matsudana* x *alba* had higher N concentration and OMD than those of *S. kinuyanagi* (Table 3.8). In both species, N concentration in the leaves was over twice that in the edible stem but their edible stem N concentration was similar. Both species had higher ($p \leq 0.001$) leaf OMD values than their edible stems. Total CT concentration was higher in *S. kinuyanagi* than in *S. matsudana* x *alba*, but there was no significant difference in total CT concentration between leaves and edible stems (Table 3.8). Extractable CT was higher in *S. kinuyanagi* than in *S. matsudana* x *alba*. Leaves of *S. matsudana* x *alba* had higher extractable and protein-bound CT concentrations than edible stems. Leaves and edible stems of *S. kinuyanagi* had similar extractable CT concentrations whereas levels of protein bound CT in the leaves were twice those in edible stems. The extractable CT concentration comprised 50-60% of the total CT. Fibre-bound CT concentration was negligible in both species.

3.3.4 Experiment 3

Results presented are mainly significant ($p < 0.05$) interaction effects (Table 3.9)

3.3.4.1 Dry matter yield and yield components

Fertiliser use (nitrogen plus phosphorus) did not significantly affect DM yield and yield components (Table 3.9). *S. kinuyanagi* was about twice as leafy as *S. matsudana* x *alba*. In both species, leader length and diameter, and edible stem DM were higher in summer than autumn harvest. *S. kinuyanagi* had higher leaf to stem ratio in autumn than summer whilst *S. matsudana* x *alba* had a similar ratio in both periods. Although the DM yields were not significantly affected by fertilisation, *S. kinuyanagi* responded more to fertilisation than *S. matsudana* x *alba*.

Table 3.8 Browse quality of the *Salix* spp. growing at Ballantrae (Experiment 2).

SPECIES	Plant part	Nutritive Value (g kg/DM)					
		Nitrogen (g/kg DM)	OMD (g/kg DM)	Condensed Tannin (g/kg DM)			
				Extractable	Protein-bound	Fibre-bound	Total
<i>Salix matsudana x alba</i>	leaf	16.7 ^a	858 ^a	110 ^b	75 ^{bc}	1.3	186
	edible stem	6.5 ^c	506 ^d	82 ^c	38 ^d	1.1	121
<i>Salix kinuyanagi</i>	leaf	14.2 ^b	681 ^b	139 ^{ab}	163 ^a	0.5	303
	edible stem	6.5 ^c	562 ^c	186 ^a	88 ^b	0.2	274
SEM		0.4	8	8	3	0.4	11
Significance		**	****	*	**	NS	NS

Sample size (n) = 8; SEM -standard error of the mean; Means in each column with the same letters are not significantly different at 5% significance level; OMD - Organic matter digestibility; ND, not determined.

Table 3.9 Effect of inorganic fertiliser use on dry matter (DM) yield (g DM/tree) and yield components of the *Salix* spp. growing at Ballantrae during 1996/97 (Experiment 3).

		Yield Components			Dry matter yield (g DM/tree)					
		Number of shoots	Leader length (m)	Leader diameter (mm)	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : stem ratio
SPECIES	Fertiliser use									
<i>Salix matsudana x alba</i>	N + P	26	0.9	8.2	48.3	16.3	42.9	76.6	95.4	0.8 ^b
	unfertilised	24	1.0	8.0	49.6	16.3	45.7	79.0	98.3	0.8 ^b
<i>Salix kinuyanagi</i>	N + P	17	0.9	7.7	81.7	7.1	70.2	100.1	147.6	1.4 ^a
	Unfertilised	10	0.8	7.0	42.7	4.1	30.5	50.5	73.5	1.6 ^a
SEM		3	0.04	0.4	11.9	1.7	12.0	15.4	22.7	0.1
Significance		NS	NS	NS	NS	NS	NS	NS	NS	*
SPECIES	Harvest times									
<i>Salix matsudana x alba</i>	Summer	27	1.1 ^a	8.7 ^b	73.6	24.6 ^a	63.4	98.1	161.5	0.8 ^c
	Autumn	23	0.8 ^b	7.6 ^c	24.3	8.0 ^b	25.2	57.5	32.3	0.7 ^c
<i>Salix kinuyanagi</i>	Summer	15	1.2 ^a	9.2 ^a	96.8	8.1 ^b	85.5	104.9	190.4	1.1 ^b
	Autumn	13	0.6 ^b	5.5 ^c	27.6	3.1 ^c	15.1	45.8	30.6	1.8 ^a
SEM		1.1	0.03	0.3	7.2	1.5	9.4	6.7	19.7	0.1
Significance		NS	****	**	NS	***	NS	NS	NS	****

Sample size (n) = 40; SEM -standard error of the mean; Means in each column with the same letters are not significantly different at 5% significance level.

3.4 DISCUSSION

In Experiments 1 and 2, the browse species provided reasonable quality feed in summer and autumn, which could be a useful supplement to pasture at those times of the year. *S. matsudana* x *alba* consistently outyielded *S. kinuyanagi* in total DM and edible forage yields (above cutting height). These results were in contrast to those reported by Douglas *et al.* (1996) who found that total and edible DM yields of *S. kinuyanagi* (5.15 t DM ha⁻¹ and 1.84 t DM ha⁻¹) were higher than *S. matsudana* x *alba* (4.32 t DM ha⁻¹ and 1.19 t DM ha⁻¹). With a tree density of 2670 per hectare based on the planting spacing used, total and edible DM yields for *S. matsudana* x *alba* (7.48 t DM ha⁻¹ and 3.20 t DM ha⁻¹) and *S. kinuyanagi* (5.87 t DM ha⁻¹ and 2.40 t DM ha⁻¹) (Table 3.4a) in Experiment 1 were higher than in the experiments by Douglas *et al.* (1996). Nevertheless, the edible forage yield of *S. matsudana* x *alba* was less than the 5.7 t DM ha⁻¹ found by Hathaway (1986a). The differences were possibly due to the age of the plants at harvest. This study involved trees aged 3-4 years compared with those in other studies aged 1-year (Douglas *et al.* 1996) and 5-years (Hathaway 1986a). The effect of tree age on DM yield is corroborated by Adejumo (1992) who reported increased DM yield with age in the browse tree *Gliricidia sepium*. The practical implication is that as the trees aged, edible forage yield increased due to increased coppiced stump diameter (Blake 1983), better root development and increased number of potential growing points (Adejumo 1992).

The total DM of *S. kinuyanagi* trees cut at 80 cm was greater than at other heights. Total and woody stem DM of *S. matsudana* x *alba* was also greater when cut at 80 and 120 cm than when cut at 30 cm (Table 3.4b). However cutting height did not significantly influence leaf, edible stem and edible forage yield in any species. The influence of cutting height is known to be species specific, and usually has no effect on regrowth of stumps (Blake 1983; Stur *et al.* 1994). The advantage of edible forage yield being uninfluenced by cutting height is that the *Salix* species can be harvested at a height which keeps current growth within reach of browsing animals (Oppong *et al.* 1996). Also in cut and carry systems, tree forage can be harvested conveniently leaving a short stump without any appreciable reduction in subsequent regrowth.

An explanation for this is that regrowth of the *Salix* species is initiated close to the cut surface and the number of potential growing points may depend on the stump diameter. Therefore regrowth following cutting depends largely on root carbohydrate reserves (Kays and Canham 1991). Stump height of the *Salix* species had no effect on the number of coppice shoots as also reported for *Populus* species (Blake 1983). Stump height may increase, decrease or has no effect on shoot numbers depending on the tree species (Blake 1983). For example, Stur *et al.* (1994) reported that stump height increased shoot number per tree of *Leucaena* species. It has been proposed that DM yield may be more dependent on leader length or leader basal diameter than stump height (Etienne 1989). The differences in shoot numbers, leader length and leader basal diameter between primary (summer harvest) and secondary regrowth (autumn harvest) of *S. matsudana* x *alba* and *S. kinuyanagi*, supported a similar finding with *Leucaena* (Stur *et al.* 1994). The increased shoot numbers, leader length and basal diameter in response to cutting height might be due to compensatory growth (Kramer and Kozlowski 1979) aimed to restore adequate levels of reserve carbohydrates for future regeneration.

Harvesting once (summer) or twice (summer and autumn) did not affect DM yield in any of the species (Appendix 3.1), as found by Tarawali *et al.* (1996). The total DM yield of *D. rectum* (2.4 t DM ha⁻¹; Table 3.4b) in the 1995 harvest equalled that found by Douglas *et al.* (1996), but provided twice as much edible forage (1.7 t DM ha⁻¹ vs. 0.8 t DM ha⁻¹). However the low yield and subsequent decline (1.1 t DM ha⁻¹) in the 1996 harvest suggested the potential of this species as a fodder in dry environments in the lower North Island is limited and casts uncertainty about its persistence under defoliation.

The low yields of the *Salix* species at Ballantrae in 1994/95 and 1995/96 seasons were possibly due to low soil fertility and harsh climatic conditions such as low temperatures and strong winds (van Kraayenoord & Hathaway 1986, Oppong *et al.* 1996). Poor regrowth after the summer harvests during the above period suggested inadequate carbohydrate storage in the roots as a result of low above-ground primary growth (Menke & Trlica 1981, Oppong *et al.* 1996) and also number of growing points. To test the hypothesis that low soil fertility was one of the causes for lower yields at this site a fertiliser experiment was conducted. However, nitrogen and phosphorus fertiliser

application in 1996 did not increase the DM yield of the *Salix* species, suggesting that low temperatures and strong winds (Table 3.3; Appendix 3.2; Grace 1977) restricted potential yield advantages from the fertiliser application. The exposed Ballantrae site apparently provided environmental conditions at the limit of adaptation of the *Salix* species. The slight improvement in DM yield (Table 3.7) at Ballantrae between 1995 and 1996 may be due to older trees having greater root development and increased number of potential growing points (Adejumo 1992). The fertiliser experiment should be conducted over a longer period than the one reported here and possibly higher fertiliser rate than that in this study may be necessary if fertiliser effects are to be detected.

It is suggested that *S. matsudana* x *alba* and *S. kinuyanagi* be utilised only once during the growing season in environments such as Ballantrae. DM yields were not affected by planting stock, which was in agreement with the findings of Stace (1996) for *Populus* species. The use of unrooted stem cuttings for the *Salix* species would reduce the initial capital outlay in establishing and managing the plants, and this stock type is recommended. Nevertheless, a comparison of planting stocks of the *Salix* spp. in an environment that resulted in better growth than at Ballantrae would be prudent, for example at Aokautere.

The high edible forage yield obtained from the *Salix* species and *D. rectum*, relative to pasture, was as expected in summer (Douglas *et al.* 1996). This browse forage supplemented the pasture in summer and early autumn, and provided support for the integration of browse species into pastoral farming systems where pasture production is low and may be of low quality over summer (Lambert *et al.* 1989a).

Nitrogen contents of the *Salix* species and *D. rectum* growing at Aokautere were above the recommended level in an adequate diet for a lactating ewe with a single lamb (NRC 1975). The organic matter digestibilities for *S. matsudana* x *alba* and *S. kinuyanagi* in the two experiments were similar, but that of *S. kinuyanagi* (613 g/kg DM) was higher than estimates (400-500 g/kg DM) reported by Douglas *et al.* (1996). The reasons for the lack of agreement between the values for *S. kinuyanagi* were unclear, but could be due to differences in CT concentration of the herbage samples used.

The condensed tannin levels of the *Salix* species were higher than for legumes such as *Hedysarum coronarium* (34-38 g/kg DM) and *Lotus corniculatus* (19-24 g/kg DM) (Douglas *et al.* 1993) and comparable to those of *Gliricidia sepium* (41 g/kg DM), *Leucaena diversifolia* (93 g/kg DM) and *Flemingia macrophylla* (240 g/kg DM) (Jackson *et al.* 1996). Total condensed tannin (CT) levels for the *Salix* species were higher at Ballantrae than at Aokautere, possibly due to low soil fertility, low temperatures and strong winds at Ballantrae (Douglas *et al.* 1993). The leaves of *S. matsudana x alba* have a CT concentration (45 g/kg DM) within the acceptable limit (< 50 gCT/kg DM; Owen-Smith 1993) for livestock and can, therefore, be browsed without any deleterious effects. Despite the higher total CT of *S. kinuyanagi*, sheep were observed browsing leaves and soft stems of the species (Chapter 6 of this thesis), which supports the contention that the biological activity of CT does not depend only on their concentration (Clausen *et al.* 1990). The CT structure is very important (Zucker 1983; Owen-Smith 1993) and must be investigated. McCabe & Barry (1988) demonstrated that *Salix* leaves were a nutritionally acceptable supplement to pasture for livestock during dry summers. In addition to its good forage quality and high yield, *S. matsudana x alba* is one of the most drought tolerant *Salix* species, and may be established outside traditional growing areas (Douglas *et al.* 1996).

3.5 CONCLUSIONS

S. matsudana x alba and *S. kinuyanagi* have potential as drought fodder in addition to their traditional roles in soil conservation. *S. matsudana x alba*, especially the leaves, can be used as a maintenance feed for sheep during summer drought as a result of its satisfactory feed quality and edible forage yield during dry summers and early autumn. The potential role of *S. kinuyanagi* as a supplementary drought fodder should not be discounted despite its high CT level. Its relatively high edible forage yield is advantageous, but the nature of the CT in *S. kinuyanagi* must be characterised and its effect on ruminants determined. The relatively low yield of *D. rectum* and its decline with use, indicated that it will not provide adequate forage during dry summers in the lower North Island (Douglas *et al.* 1996).

The results showed that *Salix* growth was site dependent. The Ballantrae data also indicated that plant stock type did not affect production and conducting a similar experiment at a more appropriate site for the *Salix* species, such as at Aokautere, may provide useful information upon which appropriate conclusions can be drawn. It is also suggested that the fertiliser studies should be conducted over a longer period than reported here.

CHAPTER 4

LEAF DEVELOPMENT PATTERNS AND THE EFFECT OF LEAF MATURITY ON LEAF QUALITY OF *SALIX* SPP. AND *CHAMAECYTISUS PALMENSIS*

4.1 INTRODUCTION

The lifespan of a leaf has several complex implications for the plant, herbivory and management of the plant for other uses. Leaf lifespan influences nutrient fluxes and forage availability (Bentley 1979; Escudero *et al.* 1992; Reich *et al.* 1992; Bargali and Singh 1994) of plants and determines when it is appropriate to use the forage from these plants. For example, the effects of herbivory vary tremendously between plants with short-lived leaves and those which retain their leaves for months or years (Bentley 1979). Coley (1988) and Escudero *et al.* (1992) provided a list of browse species and their leaf lifespans which ranged from 3.9 - 64 months. Examples are *Salix atrocinerea* (8.2 months), *Populus nigra* (7.4 months) and *Quercus rotundifolia* (24.5 months).

Browse species often serve as standing green feed reserved for use when quality herbaceous feed is not available. Therefore, browse species must maintain high accumulated herbage mass of reasonable quality until needed. The lifespan of the leaf determines the quantity and quality of herbage and nutrients available to meet the nutrient and energy needs of the ruminant. Reich *et al.* (1992) showed strong relationships between leaf lifespan, net photosynthetic rate, leaf nitrogen concentration, specific leaf area, and leaf toughness (amount of force needed to penetrate), which may result from the necessity for allocation trade-offs that enhance either productivity, nutrient conservation or defence. Species with long-lived leaves tend to have immobile chemical defences such as tannins and lignins, while those with short-lived leaves recover quickly from defoliation or possess mobile low molecular weight chemical defences such as alkaloids or monoterpenes (Coley 1988). These chemical defences tend to reduce the intake and digestibility of the forage.

Results from the cutting management experiments in Chapter 3 indicated the potential of *Salix matsudana* x *alba* and *Salix kinuyanagi* as supplementary fodder in a dry summer. *Salix* species would be browsed only once or twice each year and their leaf lifespan will likely affect feed quality and defoliation management. The leaf lifespan and the effect of leaf age on feed quality are unknown for *S. matsudana* x *alba* and *S. kinuyanagi*. This experiment aimed to determine the leaf lifespan of the *Salix* spp., and for comparison, that of an evergreen browse species, *Chamaecytisus palmensis* and measure the effect of leaf maturation on leaf quality.

4.2 MATERIALS AND METHODS

4.2.1 Site description

The experiment was conducted on a cool, moist, lowland site at the AgResearch Grasslands, Fitzherbert campus, Palmerston North (grid reference; NZMS, Palmerston North 260 S24 2718663). The long-term mean annual rainfall is 995 mm and the dry months are January to April. The long-term mean annual air temperature is 12.9 °C (Table 3.1). The mean soil temperature (30 cm depth) is 14 °C (Burgess, 1988). The soil is a Manawatu silt loam, imperfectly to poorly drained and of high fertility. For example, Olsen P was 27 mg/kg soil. The soil pH was 5.2 (determined in 1:2.5 soil : water suspension) (Table 4.1).

Table 4.1 Soil nutrient levels at Fitzherbert (AgResearch) experimental site (sampled to 75mm depth; July 1995)^a

pH ^b	Olsen P (mg/kg)	S ^c (mg/kg)	Exchangeable cations (me/100g soil) ^d		
			K	Ca	Mg
5.2	27	4	0.4	0.1	1.3

Superscripts a, b, c and d mean the same as in Table 3.2

4.2.2 Experimental treatments, procedures and design

Plant species used were hybrid willow (*Salix matsudana* x *alba*) clone Tangoio, Kinuyanagi willow (*Salix kinuyanagi*) and tagasaste (*Chamaecytisus palmensis*). The trees were planted in October 1994 and aged one year at the commencement of the experiment and they were spaced 1.5 m x 2.5 m within and between rows, respectively. The experiment comprised four randomised complete blocks and each plot (experimental unit) had 26 trees, planted in two rows of 13 trees.

On 4 September 1995, 80 leaf buds were tagged per plot for leaf emergence and senescence counts. Between 15 and 20 leaf buds were tagged per tree. The tree tags (No. 53R, Globe, New Zealand Ltd.) were metal eyeletted, threaded and knotted. The leaf buds were tagged at the point just proximal to bud emergence and distributed at random over the canopy. Leaf emergence counts started on 28 September 1995 and ended on 21 December 1995. A leaf was regarded as emerged when the lamina became separated from the axis of the shoot and fully expanded (normally two weeks for deciduous plants; Kramer and Kozlowski 1979). Leaves were defined as senesced when approximately 80% of the lamina turned yellow and the petiole was scarred and ready to separate from the shoot.

The emergence and senescence observations were conducted every two weeks. Tags for emergence and senescence counts were labelled with numbers and the first three letters of the name of each species. The tags on the emerged leaves were marked and tag numbers recorded to note time of emergence. Leaf senescence counts were also conducted as for leaf emergence to estimate leaf lifespan which was defined as the time between emergence and senescence (Gower *et al.* 1993). The *Salix* species had simple leaves whilst *C. palmensis* had compound (trifoliate) leaves. Leaf lifespan was classified as short, where mean leaf lifespan was less or equal to one hundred days and long, where more than one hundred days (Kikuzawa 1983). Plot 2 of *S. kinuyanagi* could not be tagged due to poor establishment of the trees and leaf lifespan was therefore estimated as a missing value. The missing value was calculated using the procedure described by Steel and Torrie (1980) for randomised complete blocks.

Three hundred and twenty additional leaf buds per plot were tagged on 5 - 8 September 1995 for leaf quality assessment. The leaves were sampled at 1 (spring), 3 (summer) and 6 (autumn) months after emergence. At each sampling, the leaf area was estimated using 40 leaves for the *Salix* species and 40 leaflets for *C. palmensis*. The dry weight (80 °C for 24 hours) of the leaves was also determined and used to calculate the specific leaf area at each sampling time. The sampled leaves were stored at -20 °C. One hundred and twenty tagged leaves were sampled for each species at first sampling and eighty for the other two samplings.

4.2.3 Chemical analyses

The frozen leaf samples were freeze-dried and ground with a Wiley mill to pass through a 1mm sieve. All samples were analysed for total nitrogen (Automatic Kjeldahl method - macro; AOAC 1984), *in vitro* digestibility (Roughan and Holland 1977) and neutral detergent fiber (Goering and Van Soest 1970).

4.2.4 Data analyses

The leaf lifespan data were subjected to analysis of variance assuming a randomised complete block design. Nutrients and digestibility data were analysed as repeated measures in time. PROC GLM of SAS was used (SAS 1994). Fisher's protected LSD was used to compare means at $\alpha = 0.05$. The leaf emergence and senescence counts were expressed as percentages and graphed to show trends. Emergence and senescence rates were calculated by dividing counts at each sampling time with sampling intervals (days) and also graphed to indicate trends. Levels of significance of the difference between treatment means in all tables are denoted as follows: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; **** $p \leq 0.0001$; NS, not significant ($p > 0.05$).

4.3 RESULTS

4.3.1 Leaf development pattern and lifespan

Figure 4.1 shows the leaf emergence and senescence patterns of the *Salix* species and *C. palmensis*. *S. kinuyanagi* leaves were the first to emerge and onset of leaf emergence for the other species was two weeks later. *S. matsudana* x *alba* and *S. kinuyanagi* completed leaf emergence in three months (within spring) whilst *C. palmensis* continued into the fourth month. Seven weeks (26/10/95) into spring, 97% of the leaves of *S. kinuyanagi*, 94% of *S. matsudana* x *alba* and 87% of *C. palmensis* had emerged. Senescent leaves appeared on *C. palmensis* towards the end of February (summer) whilst those of the willows occurred in March (autumn.). Thus the willow leaves started to senesce 5.5 months after emergence whilst those of *C. palmensis* started after 4.5 months. Approximately 90% of *C. palmensis* leaves senesced within six months after emergence. Within the same time-frame, *S. matsudana* x *alba* and *S. kinuyanagi* had 35% and 51% senescent leaves respectively.

Figure 4.2 presents the leaf emergence and senescence rates of the *Salix* species and *C. palmensis*. All species had high emergence rate (1 leaf day⁻¹) within the first six weeks of spring. This rate declined to 1 leaf month⁻¹ in all species seven weeks into spring. The leaves stopped emerging by the end of spring in all species. However *C. palmensis* resumed emergence at a lower rate of 2 leaves month⁻¹ at the beginning of December until the end of the month. Senescence rate was highest in February-March for *S. kinuyanagi* and *C. palmensis* (1 leaf week⁻¹), and lowest (1 leaf month⁻¹) for *S. matsudana* x *alba* which rose to 3 leaves month⁻¹ by mid April. Thereafter senescence rate declined in all species. The decline was uniform in *C. palmensis* but fluctuated in the *Salix* species.

Table 4.2 shows that all species had long leaf lifespans but that the *Salix* species had a longer ($p \leq 0.01$) leaf lifespan than *C. palmensis*. The *Salix* leaves had a mean lifespan of 6.5 months, while *C. palmensis* leaves lived for 5.5 months.

4.3.2 Effect of leaf maturation on leaf characteristics and quality

Chamaecytisus palmensis leaves aged one month had similar nitrogen (N) concentration as those of *S. matsudana* x *alba* which was higher than that of *S. kinuyanagi* (Table 4.3). At three months, leaves of *C. palmensis* had higher nitrogen (N) concentration than both of the *Salix* spp. leaves. *C. palmensis* leaves at six months had a much higher N concentration than *S. matsudana* x *alba* and *S. kinuyanagi* leaves. *S. matsudana* x *alba* leaves at the three sampling times had higher *in vitro* organic matter digestibility (OMD) than *C. palmensis* leaves, with *S. kinuyanagi* the least. Ash concentration increased with leaf maturity in the three species. *S. matsudana* x *alba* leaves showed the highest ash concentration at all sampling times. *S. kinuyanagi* leaves at one and three months were higher in ash concentration than *C. palmensis* but both had similar values at six months. *S. kinuyanagi* maintained the highest concentration of neutral detergent fibre (NDF) over the sampling period whilst NDF in *S. matsudana* x *alba* leaves was the lowest at one and three months. Nonetheless six month old leaves of *C. palmensis* and *S. matsudana* x *alba* had similar ($p > 0.05$) NDF concentrations (Table 4.3).

Leaves of *S. matsudana* x *alba* decreased in N and increased in ash concentrations with leaf maturity. *S. kinuyanagi* and *C. palmensis* had a reduction in N concentration at three months compared with leaves aged one month, and maintained similar values at six months. Ash concentration remained the same for *S. kinuyanagi* throughout the sampling period but was higher for leaves of *C. palmensis* aged six months compared with those aged one and three months. Levels of OMD and NDF declined as the leaves aged but differences were not statistically significant (Table 4.3).

S. kinuyanagi leaves consistently had higher leaf area than *C. palmensis* leaves with *S. matsudana* x *alba* intermediate. For each species leaves aged one month had similar leaf weight. At three months, *S. kinuyanagi* leaves were the heaviest with the leaves of *C. palmensis* weighing the least. However *S. matsudana* x *alba* and *C. palmensis* had similar values for leaves aged six months. *S. kinuyanagi* and *C. palmensis* had the highest specific leaf area (SLA) for leaves aged one month and six months respectively. *C. palmensis* and *S. matsudana* x *alba* leaves aged three months had similar ($p \geq 0.05$)

SLA values, which were higher than for *S. kinuyanagi* (Table 4.4).

Leaf area and weight increased with leaf age in the *Salix* species but remained similar ($p \geq 0.05$) in *C. palmensis*. SLA decreased in *S. kinuyanagi* and increased in *C. palmensis* with age but that of *S. matsudana* x *alba* leaves remained similar after three months (Table 4.4).

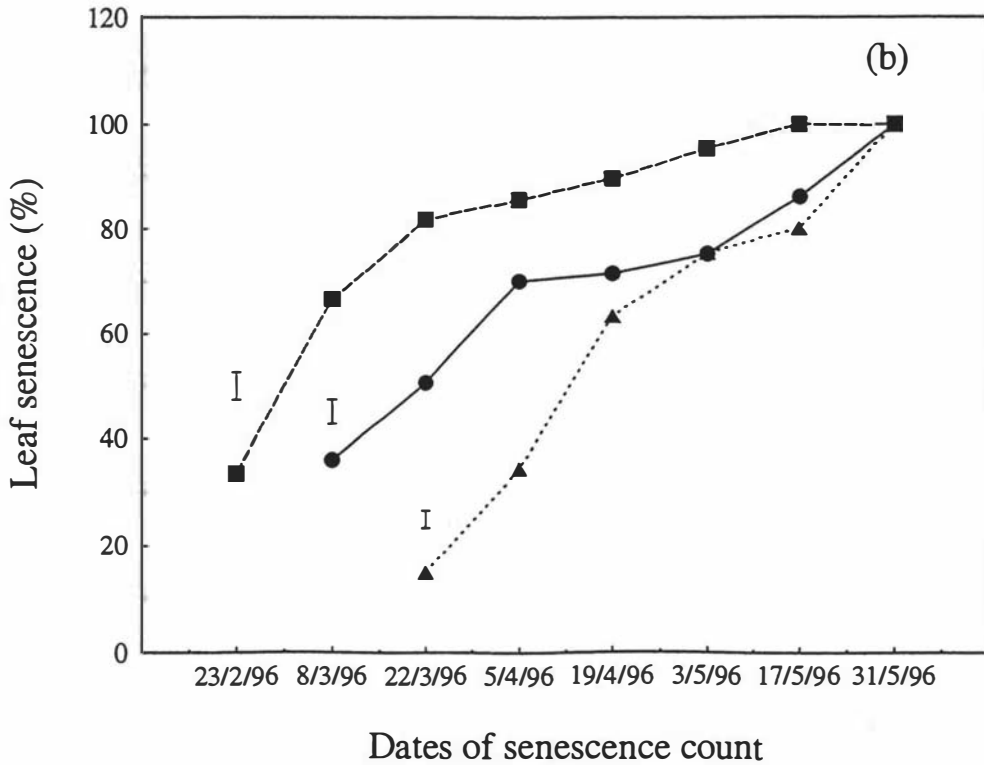
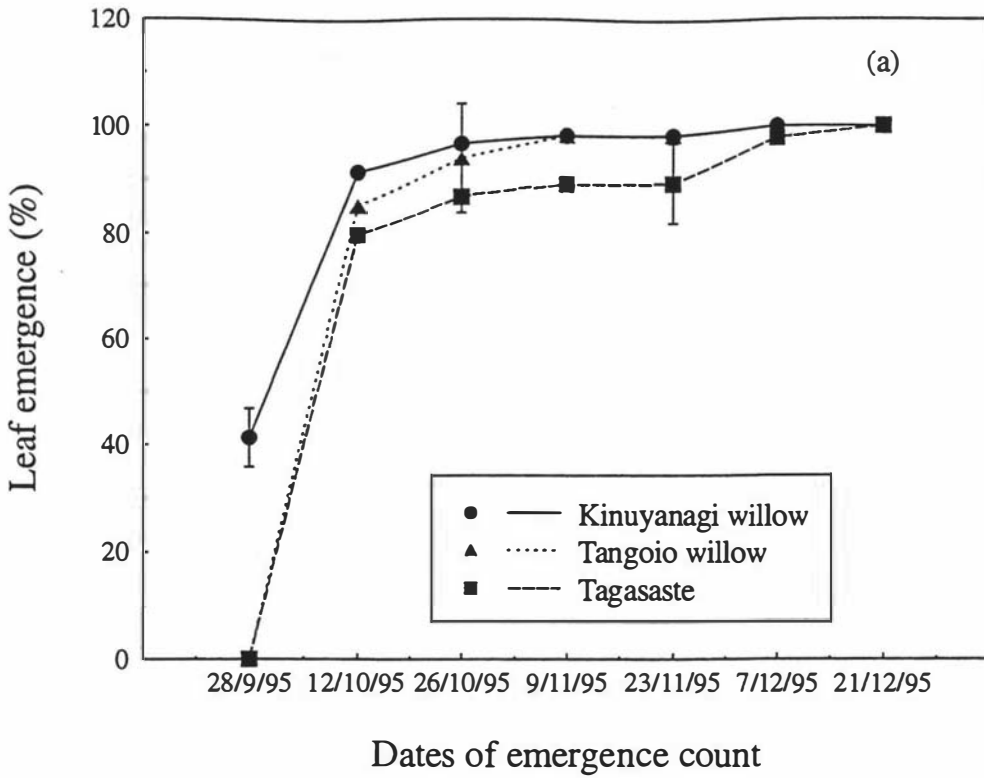


Figure 4.1 Patterns of leaf (a) emergence and (b) senescence of Tangoio willow, Kinuyanagi willow and Tagasaste during 1995/96. Vertical bars show \pm standard error of the mean.

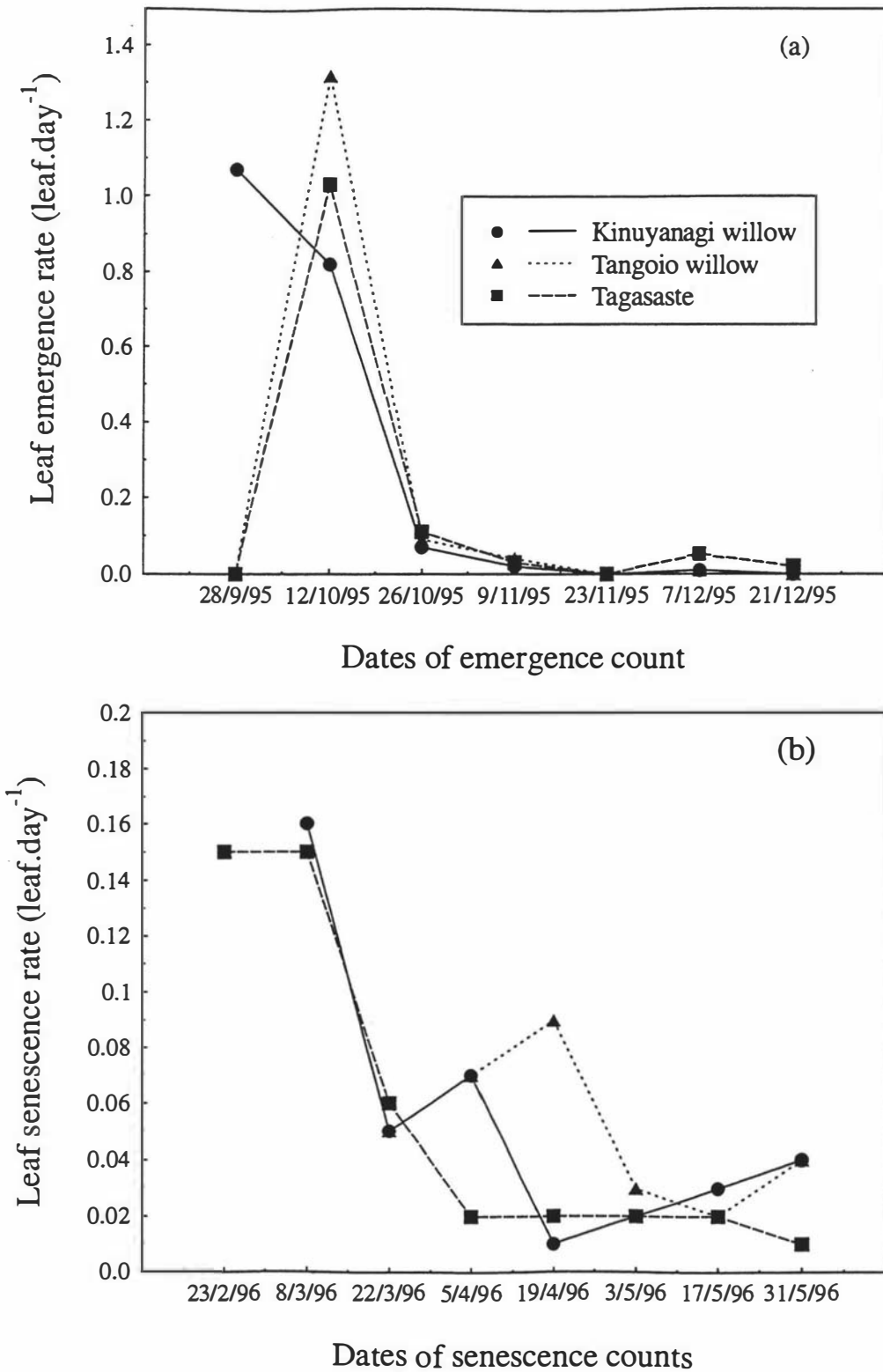


Figure 4.2 Patterns of leaf (a) emergence and (b) senescence rate of Tangoio willow, Kinuyanagi willow and Tagasaste during 1995/96.

Table 4.2 Leaf lifespan of the *Salix* spp. and *Chamaecytisus palmensis* during 1995/96.

Species	Leaf lifespan (days)	Range of leaf lifespan (days)
<i>Salix matsudana</i> x <i>alba</i>	193 ^a	190-195
<i>Salix kinuyanagi</i>	191 ^a	181-197
<i>Chamaecytisus palmensis</i>	164 ^b	147-184
SEM	4.4	-
Significance	**	-

Means with the same letters in a column are not significantly different at 5% significance level; SEM, standard error of the mean; n=12

Table 4.3 Nutritive value of leaves of the *Salix* spp. and *Chamaecytisus palmensis* aged one, three and six months.

NUTRITIVE VALUE / SPECIES	LEAF AGE			SEM (AGE)
	1 MONTH	3 MONTHS	6 MONTHS	
NITROGEN (g/kg DM)				
<i>Salix matsudana</i> x <i>alba</i>	31 ^{abA}	23 ^{bB}	17 ^{cC}	1 ^{**}
<i>Salix kinuyanagi</i>	28 ^{bA}	24 ^{bB}	22 ^{bB}	
<i>Chamaecytisus palmensis</i>	35 ^{aA}	31 ^{aB}	30 ^{aB}	
SEM	2	1	1	
Significance	NS	**	****	
IN VITRO OMD (g/kg DM)				
<i>Salix matsudana</i> x <i>alba</i>	857 ^{aA}	834 ^{aA}	827 ^{aA}	10 ^{NS}
<i>Salix kinuyanagi</i>	744 ^{cA}	697 ^{cA}	688 ^{cA}	
<i>Chamaecytisus palmensis</i>	818 ^{bA}	786 ^{bA}	785 ^{bA}	
SEM	7	13	9	
Significance	****	***	****	
ASH (g/kg DM)				
<i>Salix matsudana</i> x <i>alba</i>	83 ^{aC}	97 ^{aB}	118 ^{aA}	3 ^{**}
<i>Salix kinuyanagi</i>	59 ^{bA}	62 ^{bA}	65 ^{bA}	
<i>Chamaecytisus palmensis</i>	42 ^{cB}	49 ^{cB}	64 ^{bA}	
SEM	4	2	3	
Significance	***	****	****	
NDF (g/kg DM)				
<i>Salix matsudana</i> x <i>alba</i>	249 ^{bA}	221 ^{cA}	210 ^{bA}	16 ^{NS}
<i>Salix kinuyanagi</i>	357 ^{aA}	358 ^{aA}	387 ^{aA}	
<i>Chamaecytisus palmensis</i>	318 ^{aA}	283 ^{bA}	253 ^{bA}	
SEM	15	14	16	
Significance	**	***	***	

Means in the same column followed by same lowercase letters (a, b..) or in the same row followed by same uppercase letters (A, B..) are not significantly different at 5% significance level. SEM, standard error of the mean; Leaf age, months after leaf emergence; OMD, organic matter digestibility; NDF, neutral detergent fibre; n=27.

Table 4.4 Vegetative characteristics of leaves of the *Salix* spp. and *Chamaecytisus palmensis* aged one, three and six months.

LEAF CHARACTERISTICS / SPECIES	LEAF AGE			SEM (AGE)
	1 MONTH	3 MONTHS	6 MONTHS	
LEAF AREA /LEAF(cm ²)				
<i>Salix matsudana</i> x <i>alba</i>	6.6 ^{abB}	10.5 ^{bA}	11.2 ^{bA}	0.3 ^{****}
<i>Salix kinuyanagi</i>	8.6 ^{aC}	13.2 ^{aB}	15.1 ^{aA}	
<i>Chamaecytisus palmensis</i>	3.7 ^{bA}	4.4 ^{cA}	3.9 ^{cA}	
SEM	1.0	0.7	1.1	
Significance	**	***	***	
LEAF WEIGHT/LEAF (g×10 ⁻²)				
<i>Salix matsudana</i> x <i>alba</i>	4.7 ^{aB}	8.7 ^{bA}	9.4 ^{bA}	1.0 ^{****}
<i>Salix kinuyanagi</i>	5.7 ^{aC}	11.6 ^{aB}	19.0 ^{aA}	
<i>Chamaecytisus palmensis</i>	3.8 ^{aA}	3.5 ^{cA}	2.5 ^{bA}	
SEM	1.0	1.0	1.0	
Significance	NS	****	***	
SPECIFIC LEAF AREA (cm ⁻² g ⁻¹)				
<i>Salix matsudana</i> x <i>alba</i>	140 ^{bA}	121 ^{bB}	119 ^{bB}	3 ^{****}
<i>Salix kinuyanagi</i>	151 ^{aA}	141 ^{aB}	79 ^{cB}	
<i>Chamaecytisus palmensis</i>	97 ^{cC}	126 ^{bB}	156 ^{aA}	
SEM	3	3	6	
Significance	****	*	****	

Means in the same column followed by same lowercase letters (a, b..) or in the same row followed by same uppercase letters (A, B..) are not significantly different at 5% significance level. SEM, standard error of the mean; Leaf age, months after leaf emergence; n=27.

4.4 DISCUSSION

The results from this experiment showed that leaf lifespan and nutrient components of the leaves of the *Salix* species and *Chamaecytisus palmensis* could be useful in determining their management and potential forage value.

Both *Salix* species had a long leaf lifespan (6.5 months) and exhibited only a moderate decline in feed quality of their leaves over time. Thus the *Salix* species could be kept as green standing feed until needed in summer, which provides further evidence of their potential as browse fodder. The mean leaf lifespan of *C. palmensis* (5.5 months) was similar to that reported by Borens and Poppi (1990). The leaf lifespans of the *Salix* spp. and *C. palmensis* are comparable to those of browse species such as *Betula pubescens* (6.6 months) and *Quercus pyrenaica* (5.5 months) reported by Escudero *et al.* (1992), and *Salix sachalinensis* (6 months) reported by Kikuzawa (1983).

Following the classification given by Kikuzawa (1983; Section 2.6), the leaf emergence pattern of the *Salix* species fitted into the intermediate type and more specifically, the flush and succeeding subtype whilst *C. palmensis* fell into the succeeding type. Kikuzawa (1983) grouped *Salix sachalinensis* and *S. subfragilis* into the flush and succeeding subtype and thus supported the appropriateness of classifying *S. matsudana* x *alba* and *S. kinuyanagi* as intermediate leaf emergence types.

Leaf emergence pattern and lifespan are phenological characteristics of woody species which influence their morphology and habitat requirements (Kikuzawa 1983). The *Salix* species and *C. palmensis* on the basis of their leaf emergence patterns, were determined to have indeterminate (sympodial) and determinate (monopodial) shoot growth respectively (Kramer and Kozlowski 1979). Such morphological differences dictate the need for management requirements that control the height and canopy size of the species, if fodder production is the prime objective, so that the foliage could be easily harvested by stock or by cutting. Whether direct browsing or cut and carry systems are employed, the *Salix* spp. must be trimmed to make edible material accessible to harvest. *C. palmensis* must be topped to encourage branching (Edwards *et al.* 1997) and prevent edible material getting out of reach of browsing animals. The long leaf lifespan of the

three species indicated that they could survive harsh environments (Kikuzawa 1983) such as flooded and low fertility soils for the *Salix* spp., and dry and poor soils in the case of *C. palmensis*. Thus the leaf lifespan sets the environmental limits for good establishment and improved yields.

The leaves of the *Salix* species and *C. palmensis* have long lifespans and only decline slightly in feed quality at 3 months. This is much longer than the leaf lifespan of temperate grasses and herbaceous legumes at most times of the year (Borens and Poppi 1990). At 6 months, leaf digestibility and N concentration of these browse species were: *S. matsudana* x *alba* (827 g OMD kg⁻¹ DM; 17 g N kg⁻¹ DM), *S. kinuyanagi* (688 g OMD kg⁻¹ DM; 22 g N kg⁻¹ DM) and *C. palmensis* (785 g OMD kg⁻¹ DM; 30 g N kg⁻¹ DM). These values contrast with spring/summer growth of temperate pastures which declines rapidly over 1-2 months in digestibility (800 to 650 g DMD kg⁻¹ DM) and N concentration (53 to 11.2 g N kg⁻¹ DM) (Holmes 1980), to maintenance or sub-maintenance levels (Borens and Poppi 1990).

Chamaecytisus palmensis leaves consistently had a higher N concentration compared to the *Salix* species. Presumably this was due to it being a legume and having the ability to fix nitrogen, whilst the *Salix* species are non-leguminous and do not have the capacity to symbiotically fix nitrogen. Msangi and Hardesty (1993) also noted that *Leucaena leucocephala*, a legume, had higher N concentration than the native non-leguminous species. The N concentration of *C. palmensis* was similar to that of *L. leucocephala*, but that of the *Salix* spp. was also similar to the N concentration of some leguminous browse shrubs such as *Acacia seyal* and *Medicago arborea* (Brewbaker 1986).

The decline in leaf N concentration as the leaves matured is corroborated by several studies (McLeod 1973; Borens and Poppi 1990; Msangi and Hardesty 1993). Loss of N may be due to retranslocation into the new leaves and other storage organs prior to leaf abscission (Woodwell 1974; Forwood and Owensby 1985; Escudero *et al.* 1992) as well as increases in structural carbohydrates (Van Soest 1994) associated with leaf maturity. Nonetheless, the N concentrations in the leaves of all species at each harvest met the level (17 gN/kg DM) recommended for an adequate diet for a lactating ewe with a single lamb (NRC 1975). Nitrogen concentrations pooled over sampling times

for the *Salix* spp. and *C. palmensis* were similar to those obtained at a similar site at Aokautere (Douglas *et al.* 1996).

The ash concentrations of the *Salix* spp. and *C. palmensis* were consistent with the values reported by McLeod (1973) in Australia, Msangi and Hardesty (1993) in Tanzania and those for *C. palmensis* in New Zealand (Ryde 1982; Borens and Poppi 1990). *S. matsudana* x *alba* had the highest mineral (ash) concentration but it is impossible to indicate any mineral deficiencies at this stage since individual values are not available. Douglas *et al.* (1996) reported sodium deficiency in the *Salix* spp. and *C. palmensis* at Aokautere whilst Lambert *et al.* (1989d) found that phosphorus and sodium were deficient in *C. palmensis* at Ballantrae for an adequate diet for a lactating ewe with a lamb. Studies to determine the concentrations of individual mineral components of the three species at different leaf ages would be necessary to aid in their management for the provision of quality fodder.

The *in vitro* organic matter digestibilities (OMD) of the *Salix* spp and *C. palmensis* were relatively high. The OMD values showed that *S. matsudana* x *alba* leaves were more digestible than *C. palmensis* leaves of similar age, with *S. kinuyanagi* the least. The high OMD of *S. matsudana* x *alba* leaves compared to those of *C. palmensis* and *S. kinuyanagi*, may be due to low NDF and relatively low secondary metabolites, particularly condensed tannin (CT; Opong *et al.* 1997). For example leaves of *S. kinuyanagi* aged 6 months had higher N concentration than those of *S. matsudana* x *alba* but had the lowest digestibility. It has been suggested that high CT (> 50 gCT/kg DM) concentrations reduce the digestibility of forages as a result of the N-CT complex formation that reduces their solubility and degradation by rumen bacteria (Waghorn *et al.* 1990).

Salix kinuyanagi had the highest NDF (cell wall content) concentration (357-387 g/kg DM) among the species which suggested that its forage was potentially the least digestible (Gonzalez-Andres and Ortiz 1996). The NDF concentration of *S. kinuyanagi* was similar to that of *Medicago arborea* (340 g/kg DM) and about half that of *Ulex europaeus* (640 g/kg DM) reported by Lambert *et al.* (1989d). Further, the low NDF concentration of *S. matsudana* x *alba*, which indicated high quality feed (< 250

gNDF/kg DM; Mertens 1994) suggested high potential intake of leaves (Van Soest 1994) compared to those of *C. palmensis* and *S. kinuyanagi*, and this species also had the highest digestibility of the three species. Thus increased plant fiber resulted in lower digestibility as well as reduced forage intake (Kilcher 1981).

The decline over time in specific leaf area (SLA) of the *Salix* species suggested that the leaves thickened as they aged. In contrast *C. palmensis* leaves had increased SLA, which showed that they became thinner and more fragile as leaves aged.

4.5 CONCLUSIONS

The *Salix* species (6.5 months) and *C. palmensis* (5.5 months) produced long lived leaves that retained their feed quality after a moderate decline in nitrogen concentration between 1 and 3 months of age. The results suggested that the leaves of the *Salix* spp. and *C. palmensis* could be browsed between 3 and 6 months after emergence with only minor changes in feed quality, as measured by N concentration and digestibility. The effects of leaf maturation on the concentrations of individual mineral components of the three species should be determined to provide additional information on feed quality. This would enable identification of critical times when possible nutrient deficiencies occur, and would therefore assist in scheduling browsing or cutting management.

CHAPTER 5

EFFECTS OF SEASON AND FREQUENCY OF CUT ON BROWSE YIELD, YIELD COMPONENTS AND RESERVE CARBOHYDRATE LEVELS OF *SALIX MATSUDANA* X *ALBA* AND *SALIX KINUYANAGI*

5.1 INTRODUCTION

The time of initial cut and frequency of harvest of regrowth during the growing season influence dry matter yield and persistence of woody browse plants (Osman 1981b; Blake 1983; Kays and Canham 1991). Blake (1983) found that regrowth was maximised when temperate tree species such as *Eucalyptus obliqua*, *E. occidentalis* and *Plantanus occidentalis* were cut in winter or early spring and minimised when cut in midsummer. Hardesty *et al.* (1988b) tested this hypothesis and found differences in regrowth yield of *Auxemma oncocalyx*, *Caesalpinia pyramidalis*, *Croton hemiargyreus*, *Mimosa acutistipula* and *Mimosa caesalpinifolia* cut in different seasons. For example cutting late in the dry season maximised the yield of *A. oncocalyx* whilst an early dry season cut maximised the yields of *C. pyramidalis* and *M. acutistipula*. Frequency of harvests also greatly affects dry matter (DM) yields. For example, DM yields of *Leucaena leucocephala* under frequent cutting were lower than those under less frequent cutting (Guevaria *et al.* 1978; Osman 1981b; Karim *et al.* 1991).

Reduced regrowth after defoliation has been linked to the depletion of non-structural carbohydrates in the roots and remaining shoot parts (George and McKell 1978; Culvenor *et al.* 1989; Gonzalez *et al.* 1989; Erdmann *et al.* 1993). Kramer and Kozlowski (1979) showed that deciduous temperate trees have different seasonal carbohydrate cycles from those of evergreens. They found that the deposition of starch, the primary non-structural root carbohydrate reserve, begins shortly after leaf expansion and reaches a peak when shoot growth ceases in *Populus* spp. and *Morus alba* (Loescher *et al.* 1990). Thus in deciduous trees, maximum starch yield occurs in spring and late summer or early autumn (Kramer and Kozlowski 1979).

Woody plants use stored root carbohydrate reserves to support regrowth after cutting provided there is no residual leaf. Since root reserves exhibit their largest fluctuations during the growing season, cutting aboveground stems at different times and intensities within the growing season may affect stored root reserves available for subsequent regrowth (Kays and Canham 1991). Plants such as *Opuntia polyacantha* that replenish reserves rapidly after spring draw-down and during each regrowth period are least affected by defoliation, and also recover better from severe (removal of 90% of foliage) defoliation (Menke and Trlica, 1981). There is little information in New Zealand on the effect of time of initial cut on regrowth of woody browse plants such as the *Salix* species and none on how regrowth depends on non-structural carbohydrate reserves of the plant.

It is desirable to maintain adequate and quality standing biomass on the *Salix* spp. until needed in summer. When trees are cut in winter and regrowth allowed to stand until mid-late summer, regrowth will decline in feed quality (Chapter 4) and in direct browsing use, large quantities of edible forage will be beyond the reach of the grazing animal (Douglas *et al.* 1996). An important management option would be selecting a suitable time within the growing season that the trees could be cut and still regrow high dry matter yields of quality browse. The objectives of this experiment were 1) to determine the appropriate time to cut or browse willows to optimise regrowth and maintain quality browse and 2) to determine the changes in nonstructural carbohydrate reserves associated with defoliation.

5.2 MATERIALS AND METHODS

5.2.1 Site description

The details are the same as those in Section 4.2.1.

5.2.2 Experimental treatments and design

The species used were hybrid willow (*Salix matsudana* x *alba*) clone 'Tangoio' and Kinuyanagi willow (*Salix kinuyanagi*). The trees were planted in October 1994 and aged two years at the commencement of the experiment and they were spaced 1.5 m x 2.5 m within and between rows, respectively. The experiment was a split-plot design with treatments arranged in four randomised complete blocks. Species were allocated to main plots and cutting treatments to subplots. The experimental period was from 30 August 1996 to 4 April 1997. There were four cutting treatments. 1. Winter cut (30 August 1996) with regrowth cut three times (18 November 1996, 4 February and 4 April 1997) over the experimental period. 2. Spring cut (18 November 1996) with regrowth cut twice (4 February and 4 April 1997). 3. Summer cut (4 February 1997) with regrowth cut once (4 April 1997). 4. Control plants, cut in winter (30 August 1996) and allowed to grow throughout the season and sampled three times (18 November 1996, 4 February and 4 April 1997) over the experimental period. Treatments 1 and 4 had eight plants each per subplot while treatments 2 and 3 had six and four plants per subplot respectively. The number of plants allocated to each treatment depended on the number of harvests over the entire growing season (4 to 8 plants per subplot). The trees were cut to a stump height of 30 cm.

5.2.3 Measurements

The number of shoots and the length and basal diameter of the leader of each tree were recorded at each harvest. Basal diameter was measured with vernier callipers. Two plants per subplot were harvested at each cutting time. All regrowth was harvested at an average of 10 weeks (9 - 11 weeks) growth after cutting. The harvested regrowths were taken to

the laboratory for further analyses. The fresh weight was measured and the herbage subsampled and dissected into leaf, edible stem (soft stem < 5 mm in diameter) and woody stem components. These were oven-dried at 80 °C for 24 hours to determine the dry weight of each component. Samples of the lateral roots (6-8 mm in diameter) from the same stumps were excavated, washed, excised and put in vials (one per stump) placed inside an ice box for about 3 hours, while in the field. The vials were later stored at -20 °C until analysis.

5.2.4 Carbohydrate analyses

The sampled roots were freeze-dried and ground with a Wiley mill to pass through a 1 mm sieve. Only root samples of *Salix matsudana x alba* were analysed because it is the most widely planted species (Hathaway 1986c). Unreplicated root samples for control and winter cut plants were analysed for sucrose, fructose and glucose using high performance liquid chromatography (HPLC) (Sturgeon 1990) at AgResearch Grassland, Palmerston North. This was conducted for samples at each sampling date (30 August 1996; 18 November 1996; 4 February 1997 and 4 April 1997). Glucose concentration was converted to equivalent starch concentration by multiplying by 0.9 (Moore and Hatfield 1994).

5.2.5 Data analyses

Split plot analysis of variance was performed on the primary regrowth (regrowth after initial cut) data for each cutting treatment using the procedure, PROC GLM of SAS version 6.10 (SAS 1994). Variables analysed included leaf, edible stem, woody stem, and total and edible dry matter, and leaf to stem biomass ratio. This was to test the effect of time of first cut on subsequent regrowth. The same analysis was performed on the total edible and dry matter yields for all the treatments over the experimental period. All regrowth data for winter cut and spring cut plants were analysed as repeated measures. Fisher's protected LSD was used to compare means at $\alpha = 0.05$ (Steel and Torrie 1980). Levels of significance of the difference between treatment means in all

tables were denoted as follows: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; **** $p \leq 0.0001$; NS, not significant ($p > 0.05$).

Root non-structural (reserve) carbohydrate contents for control and winter cut plants of *S. matsudana* x *alba* were graphed to show trends.

Relationships between the yield components and edible DM yields of the *Salix* species were established using standardised partial regression analysis procedures (SAS 1994). Coefficients (parameter estimators) of the independent variables (yield components) were examined to determine the most important parameter. The parameter with the largest value in comparison to the others was considered the most important.

5.3 RESULTS

5.3.1 Effect of time of initial cut on regrowth

Table 5.1 shows the response of *Salix matsudana* x *alba* and *Salix kinuyanagi* to the time of initial cut with respect to yield components and dry matter (DM) yield. Number of shoots of both species were similar irrespective of the time of first cut. *S. matsudana* x *alba* regrowth had longer and thicker leaders than *S. kinuyanagi* when cut in mid-spring. Winter cut trees of *S. kinuyanagi* had thicker leaders than those of *S. matsudana* x *alba*. *S. matsudana* x *alba* significantly outyielded *S. kinuyanagi* in leaf, edible stem, woody stem, total and edible DM yields when cut in mid-spring. *S. kinuyanagi* had similar winter (regrowth after initial winter cut) and spring (regrowth after initial spring cut) regrowth but *S. matsudana* x *alba* showed a greater spring than winter regrowth. The time of initial cut did not alter the leaf-stem ratio of *S. matsudana* x *alba* but did in *S. kinuyanagi*. Both species had similar leaf-stem ratio for spring regrowth. However the leaf-stem ratios of *S. kinuyanagi* were higher than those of *S. matsudana* x *alba* for winter and summer regrowth (regrowth after initial summer cut).

5.3.2 Effect of winter or spring initial cuts on subsequent regrowth

Results obtained when the three harvests from initial winter cut treatment were analysed showed no consistency. In the first harvest, *Salix kinuyanagi* had higher regrowth in leaf DM, total edible DM and leaf to stem ratio than *Salix matsudana x alba* (Table 5.2). However *S. matsudana x alba* had similar regrowth yield as *S. kinuyanagi* in the second harvest but produced larger leaders. In the third harvest, *S. matsudana x alba* produced more shoots and had higher edible stem yield than *S. kinuyanagi*. Nonetheless *S. kinuyanagi* had more leafy material when compared with *S. matsudana x alba*.

There was a pattern in the harvest from the spring cut treatment. *S. matsudana x alba* trees produced larger and thicker coppice shoots than *S. kinuyanagi* in the first harvest (Table 5.3). It also had greater regrowth in edible stem and total edible DM yield than *S. kinuyanagi*. Both species were similar in yield components and regrowth yield in the second harvest.

5.3.3 Effects of time and frequency of cut on dry matter yield

Salix kinuyanagi outyielded *S. matsudana x alba* in the control treatment with respect to most attributes (Table 5.4). *S. kinuyanagi* produced about twice as much leaf, woody stem, total and edible DM as *S. matsudana x alba* and had a 30% higher leaf to stem ratio. Both species showed similar DM yields in the initial cut in winter, spring and summer treatments except for total edible DM yield in summer cut trees which was higher in *S. kinuyanagi* than *S. matsudana x alba*. Further, leaf to stem ratios of winter and summer cut trees of *S. kinuyanagi* were higher than those of *S. matsudana x alba* (Table 5.4).

Table 5.1 Effect of time of initial cut on the primary regrowth (g DM/tree/day) of the *Salix* spp. growing at a high fertility lowland site.

		Yield components			Regrowth biomass (g DM/tree/day)					
		Number of shoots	Leader length (m)	Leader diameter (mm)	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : stem ratio
SPECIES	Initial cuts									
<i>Salix matsudana</i> x <i>alba</i>	winter cut	38	1.0 ^c	8.9 ^c	0.9 ^c	0.2 ^c	1.1 ^b	1.1 ^c	2.2 ^c	0.7 ^b
	spring cut	48	1.8 ^a	13.6 ^a	3.1 ^a	1.0 ^a	3.2 ^a	4.1 ^a	7.4 ^a	0.7 ^b
	summer cut	39	1.1 ^c	7.9 ^c	1.3 ^c	0.4 ^b	1.3 ^b	1.7 ^{bc}	2.9 ^b	0.8 ^b
<i>Salix kinuyanagi</i>	winter cut	32	1.0 ^c	10.6 ^b	2.3 ^b	0.3 ^c	1.8 ^b	2.5 ^b	4.3 ^{bc}	1.1 ^a
	spring cut	35	1.3 ^b	10.6 ^b	2.0 ^b	0.4 ^b	2.1 ^b	2.5 ^b	4.5 ^b	0.8 ^b
	summer cut	40	0.9 ^c	7.4 ^c	2.0 ^b	0.2 ^c	1.2 ^b	2.2 ^{bc}	3.4 ^c	1.5 ^a
SEM		4	0.1	0.6	0.3	0.1	0.3	0.4	0.7	0.1
Significance		NS	*	**	**	***	*	**	**	***

Means with the same letters in a column are not significantly different at 5% significance level. Primary regrowth, regrowth following initial cut; Leaf : Stem ratio, leaf divided by total stem (edible plus woody stem); SEM, standard error of the mean; n=24.

Table 5.2 Differences in regrowth biomass (g DM/tree/day) of the *Salix* spp. growing at a high fertility lowland site from three harvests after initial winter cut.

SPECIES /HARVEST	Yield components			Regrowth biomass (g DM/tree/day)					
	Number of shoots	Leader length (m)	Leader diameter (mm)	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : stem ratio
FIRST HARVEST									
<i>Salix matsudana</i> x <i>alba</i>	38	1.0	8.9	1.0	0.2	1.2	1.1	2.3	0.7
<i>Salix kinuyanagi</i>	32	1.0	10.6	2.3	0.3	1.8	2.6	4.4	1.1
SEM	4	0.1	0.5	0.3	0.04	0.2	0.4	0.6	0.03
Significance	NS	NS	NS	*	NS	NS	*	NS	****
SECOND HARVEST									
<i>Salix matsudana</i> x <i>alba</i>	33	1.7	13.2	2.5	0.9	3.4	3.4	6.8	0.8
<i>Salix kinuyanagi</i>	29	1.3	11.3	2.7	0.6	2.8	3.3	6.1	0.8
SEM	3	0.1	0.9	0.5	0.1	0.5	0.6	1.1	0.1
Significance	NS	*	NS	NS	NS	NS	NS	NS	NS
THIRD HARVEST									
<i>Salix matsudana</i> x <i>alba</i>	32	0.9	6.2	0.5	0.2	0.6	0.7	1.3	0.7
<i>Salix kinuyanagi</i>	24	0.7	5.9	0.6	0.1	0.3	0.7	1.0	1.4
SEM	4	0.1	0.4	0.1	0.02	0.1	0.1	0.1	0.1
Significance	*	NS	NS	NS	**	NS	NS	NS	***

Leaf : Stem ratio, leaf divided by total stem (edible plus woody stem); SEM, standard error of the mean; n=24.

Table 5.3 Differences in regrowth biomass (g DM/tree/day) of the *Salix* spp. growing at a high fertility lowland site from two harvests after initial spring cut.

SPECIES /HARVEST	Yield components			Regrowth biomass (g DM/tree/day)					
	Number of shoots	Leader length (m)	Leader diameter (mm)	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : stem ratio
FIRST HARVEST									
<i>Salix matsudana x alba</i>	48	1.8	13.6	3.1	1.0	2.6	4.1	6.7	1.1
<i>Salix kinuyanagi</i>	35	1.3	10.6	2.0	0.4	2.1	2.4	4.5	0.8
SEM	5	0.1	0.5	0.4	0.1	0.6	0.5	0.9	0.3
Significance	NS	**	**	NS	**	NS	*	NS	NS
SECOND HARVEST									
<i>Salix matsudana x alba</i>	36	0.9	6.3	0.7	0.3	0.6	1.0	1.6	0.8
<i>Salix kinuyanagi</i>	31	0.8	6.2	1.1	0.5	0.7	1.5	2.3	1.0
SEM	3	0.3	0.3	0.2	0.2	0.1	0.2	0.2	0.2
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS

Leaf : Stem ratio, leaf divided by total stem (edible plus woody stem); SEM, standard error of the mean; n=24.

Table 5.4 Effects of time and cutting frequency on cumulative dry matter (DM) yield (g DM/tree) of the *Salix* spp. growing at a high fertility lowland site.

		Dry Matter Yields (kg DM/tree)					
		Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : Stem ratio
SPECIES	Cutting treatments						
<i>Salix matsudana x alba</i>	Control	0.29 ^c	0.13	0.70 ^b	0.42 ^b	1.11 ^b	0.4 ^d
	3 - cuts (Winter cut)	0.31 ^b	0.11	0.31 ^c	0.42 ^b	0.73 ^b	0.7 ^c
	2 - cuts (Spring cut)	0.30 ^b	0.09	0.31 ^c	0.39 ^{bc}	0.70 ^b	0.8 ^c
	1 - cut (Summer cut)	0.08 ^d	0.02	0.08 ^d	0.10 ^d	0.17 ^c	0.8 ^c
<i>Salix kinuyanagi</i>	Control	0.75 ^a	0.07	1.16 ^a	0.82 ^a	1.97 ^a	0.6 ^c
	3 - cuts (Winter cut)	0.43 ^b	0.08	0.38 ^c	0.50 ^b	0.89 ^b	1.0 ^b
	2 - cuts (Spring cut)	0.23 ^b	0.05	0.21 ^c	0.28 ^{bc}	0.49 ^{bc}	0.9 ^{bc}
	1 - cut (Summer cut)	0.12 ^d	0.01	0.07 ^d	0.13 ^c	0.20 ^c	1.5 ^a
SEM		0.05	0.02	0.08	0.06	0.13	0.1
Significance		****	NS	**	**	**	**

Means with the same letters in a column are not significantly different at 5% significance level; SEM, standard error of the mean; n=32.

5.3.4 Reserve carbohydrate changes with season

Fig 5.1 shows the changes in sucrose, fructose, glucose and starch concentrations for control and winter cut trees. The sucrose concentration was higher than all other carbohydrate components and comprised over 90% of total reserve carbohydrate concentration. Starch, glucose and sucrose concentration of the control trees increased from late winter to mid-spring then declined in early autumn (Fig 5.1) whereas those of the trees harvested three times after the initial winter cut showed further reduction until mid-spring. The sucrose concentration of the harvested trees increased in mid-summer and declined slightly in early autumn.

5.3.5 Relationships among yield components and DM yield

The standardised partial regression equations of the edible DM yields derived for the *Salix* species are given below:

Salix matsudana x alba:

$$\text{Log edible DM (g DM/tree)} = 0.62\log S + 1.37\log L + 0.73\log D + 0.63$$

$$R^2 = 90\% \quad p < 0.0002$$

Salix kinuyanagi:

$$\text{Log edible DM (g DM/tree)} = 1.01\log S - 0.15\log L + 1.39\log D + 1.59$$

$$R^2 = 64\% \quad p < 0.04$$

(S, number of coppice shoots; L, leader length; D, leader diameter)

Based on the value of the parameter estimators, the standardised partial regression equation for *S. matsudana x alba* data showed that leader length was the most important in determining edible DM but the number of coppice shoots and leader diameter were also influential. Conversely, for *S. kinuyanagi*, leader diameter and number of coppice shoots were important in determining edible DM. The results suggested that the *Salix* spp. are morphologically different and this could affect their biomass production.

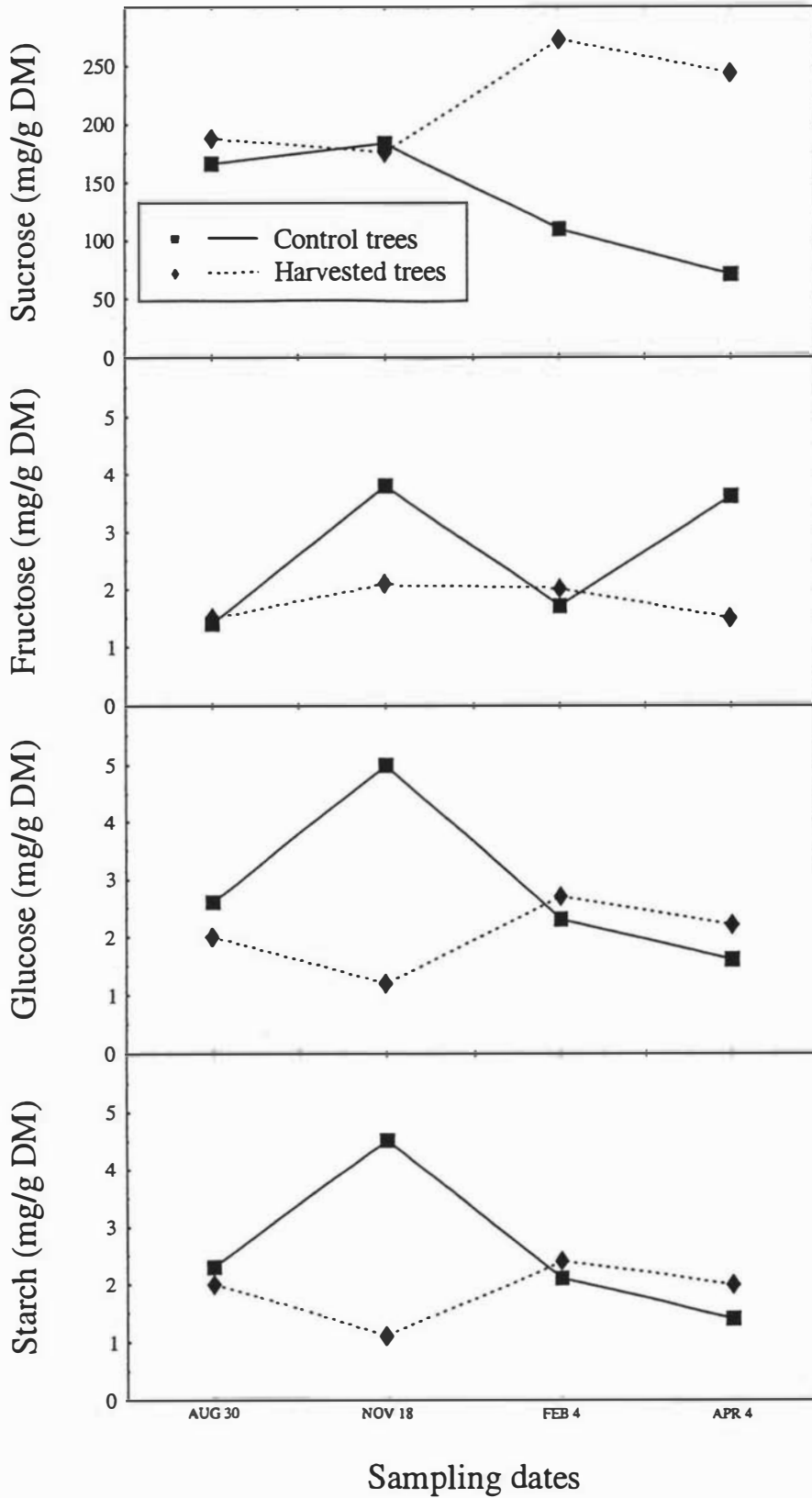


Figure 5.1 Comparison of main constituents of root reserve carbohydrates of Tangoio willow trees when cut in late winter or harvested several times during 1996/97.

5.4 DISCUSSION

The two species differed in their response to time of initial cut and cutting frequency. *Salix matsudana* x *alba* had greater regrowth than *Salix kinuyanagi* when trees were first cut in mid spring. *S. matsudana* x *alba* possibly had higher root non-structural carbohydrate concentrations than *S. kinuyanagi* which enabled more regrowth (Kays and Canham 1991; Kozłowski *et al.* 1991). *S. kinuyanagi* had a flush of growth earlier in spring than *S. matsudana* x *alba* (Chapter 4), which likely depleted the stored root reserves to a greater extent by the time of spring cutting. *S. matsudana* x *alba* had high root reserves mid-spring and supported maximum regrowth. Kramer and Kozłowski (1979) found that carbohydrate reserves in deciduous trees begin to decrease in late winter and decreased rapidly in early spring when carbohydrates are being depleted by accelerated respiration and growth of new tissues. *S. matsudana* x *alba* had an extended dormant period and therefore, when cut in mid-spring produced larger and heavier regrowth than when cut in other periods during the growing season (Belanger 1979).

Further, Figure 5.1 showed that the control treatment of *S. matsudana* x *alba* maintained high reserve carbohydrate concentration in mid-spring which could have contributed to increased coppice growth. However reserve carbohydrate concentration in mid-summer was extremely low which may account for the reduced regrowth for both species. It should be noted that root carbohydrate reserves were determined only in *S. matsudana* x *alba* due to financial constraints. Therefore, any inference made in relation to reserve carbohydrate for *S. kinuyanagi* is speculative. There is the need to determine the root carbohydrate reserves in *S. kinuyanagi* with season, to substantiate its effect on the coppice growth of the species. Coppice growth is maximised when trees are cut during the dormant period and minimised when cut between early to mid summer when tree canopies have developed fully and carbohydrate reserves are low (Blake 1983; Kramer and Kozłowski 1979; Kozłowski *et al.* 1991; Kozłowski and Pallardy 1997).

The second harvest after the initial cut in winter or spring did not differ between *S. matsudana* x *alba* and *S. kinuyanagi*. The species might have attained a similar root reserve carbohydrate level and therefore gave a similar amount of regrowth.

A single cut in winter with regrowth harvested in autumn gave the highest DM yield in both species compared with initial cuts in other seasons and more frequent harvests of regrowth. With a tree density of 2670 per ha, based on the tree spacing used in the experiment (Section 5.2.2), *S. matsudana* x *alba* produced 1.1 t DM ha⁻¹ and 3.0 t DM ha⁻¹ for edible and total DM respectively whilst *S. kinuyanagi* yielded 2.2 t edible DM ha⁻¹ and 5.3 t total DM ha⁻¹ in the control treatment (Table 5.4). This is supported by the findings of Douglas *et al.* (1996) which showed that a single low cut (30 cm above ground) of *S. matsudana* x *alba* and *S. kinuyanagi* yielded more herbage than double or triple cuts at the same height. *S. kinuyanagi* outyielded *S. matsudana* x *alba* in the control treatment as was found by Douglas *et al.* (1996) at a nearby site where *S. kinuyanagi* yielded higher in the first year of growth than *S. matsudana* x *alba*.

However *S. matsudana* x *alba* outyielded *S. kinuyanagi* in the third year of growth (Oppong *et al.* 1996) which suggested better root development (Adejumo 1992). It was suggested in Chapter 3 that root development and distribution should be determined to test the hypothesis that there are links between DM yields of both species and root growth. Guevara *et al.* (1978) also found that less frequent cutting resulted in the highest DM yield for *Leucaena leucocephala* but the proportion of woody stem material increased, which supports the findings of this study. Nonetheless, a single cut in summer with regrowth harvested in autumn resulted in reduced total DM yield due to low carbohydrate reserves at time of cut which produced minimum coppice growth (Kramer and Kozlowski 1979; Blake 1983; Kozlowski *et al.* 1991; Kozlowski and Pallardy 1997).

The differences in importance of yield components in the relationship between edible DM yield and yield components of both species showed that they are morphologically different (Section 5.3.5). Stur *et al.* (1994) stressed that optimum defoliation practises differed with species which have contrasting growth habits and the use of a common

management system may advantage some species while disadvantaging others. The leader length and leader basal diameter were found to be the most important determinants of edible DM for *S. matsudana* x *alba* and *S. kinuyanagi*, respectively. This finding is supported by Etienne (1989) who reported that DM yield of woody plants is dependent on leader length and leader basal diameter. Cutting in mid spring gives the trees three months of growth to maximise yield and maintain high feed quality for use in mid summer. This is the most likely time of the year that fodder from these species would be useful in supplementing pasture in New Zealand's pastoral system. The spring management option will be suitable for *S. matsudana* x *alba* as a result of the potential increase in DM yield and quality. The spring cutting of trees may reduce the excess shade on pasture and potential pasture production will not be adversely affected.

Results of the carbohydrate analyses must be interpreted cautiously because root samples were not replicated (due to financial constraints) and may be highly variable. Notwithstanding, the data provided a useful trend upon which conclusions could be drawn. The greater sucrose content compared to fructose and glucose is in contrast to earlier reports (Kozlowski 1992). The reasons for this are unclear and detailed investigation is recommended. Surprisingly, root sucrose content increased with frequent defoliation. Since the coppice shoots still had photosynthetically active leaves during harvests, it is most likely that current photosynthate was being translocated as sucrose (Kozlowski 1992) to the roots for storage, as a means of avoiding defoliation stress in subsequent defoliation activity.

5.5 CONCLUSIONS

Salix matsudana x *alba* outyielded *Salix kinuyanagi* when first cut in mid-spring. However *S. kinuyanagi* had similar DM yields when the trees were cut in winter or mid-spring. Moreover *S. kinuyanagi* produced higher total edible yield after the initial winter cut. Trees cut initially in summer showed reduced DM yield and this treatment is not recommended for both species. In New Zealand, browse fodder would be required to supplement pasture in summer and the standing green feed must be of the right

quality and quantity and at browsing height. Therefore, spring cutting would provide large quantities of quality fodder in summer and *Salix matsudana* x *alba* seemed the most appropriate species for achieving high productivity with this management. Further, when planted in tree-pasture plantations, spring cutting of trees may allow the pasture to yield more in spring and the trees to produce large amounts of quality browse in summer.

CHAPTER 6

BROWSING MANAGEMENT AND SHEEP PREFERENCE OF *SALIX* SPECIES AND *CHAMAECYTISUS PALMENSIS*

6.1 INTRODUCTION

Browse species are used by ruminants in browsed or cut and carry systems. The use of either of these systems depends on how accessible and acceptable the forage is to the animal, and the practical expediency to the farmer. The method used to feed livestock affects intake and brings about fluctuations in animal production. In addition, browsing may increase (Miquelle 1983; Danell *et al.* 1985) or decrease (Radcliffe 1986a; Townsend and Radcliffe 1990) browse regrowth and yield. However the effect of browsing depends on the plant's genetics, the intensity and frequency of defoliation, developmental stage at defoliation, plant parts affected and the modifying effects of the environment such as light, temperature, and soil nutrients and moisture (McNaughton 1979; Teague 1985).

There are few studies on the impact of browsing animals on the regrowth and forage quality of woody plants (Danell and Bergstrom 1989). In New Zealand most browsing evaluations have been conducted on *Chamaecytisus palmensis* (Radcliffe 1986a; Borens and Poppi 1990; Townsend and Radcliffe 1990) but *Salix* species have been investigated (Hathaway 1986a). Townsend and Radcliffe (1990) found that browsed *Chamaecytisus palmensis* had lower edible yields than when cut or browsed and trimmed. The browsed trees also became woody with fewer bud sites (Townsend and Radcliffe 1990). The fewer potential growth buds resulted in reduced regrowth since these buds occur largely on the smaller and softer stems that were also browsed. Hathaway (1986a) also found increased DM yields in *S. matsudana* x *alba* when several *Salix* species had intensive browsing once a year for three years but they did not determine the effect of browsing intensity and frequency on the yield of the species.

Further, the feeding value of forages is a function of intake and nutritive value (Ulyatt, 1981). Forage intake is influenced by the preference of animals, and is modified by the availability of the forage (Hodgson, 1979). In New Zealand only a few studies on browse preferences have been conducted (Lambert *et al.* 1989b; Douglas unpublished data; Pande and Kemp unpublished data). Preference ratings are useful for selecting the most acceptable browse species for inclusion into pastoral systems and such studies could be useful in formulating browsing strategies (Lambert *et al.*, 1989b).

Depending on the farmers' circumstances, the selection of species that are resilient to browsing may be the most convenient and economical option. Thus, browse species selected for pastoral systems should not be judged solely on cutting management since the final destination of browse is the digestive system of the animal and its conversion into animal products. Browse species that maintain productivity under browsing may be favoured by pastoral farmers. There is little information on the effect of browsing and animal preferences for browse species to warrant wider use of browse fodder in well-developed pastoral systems such as those in New Zealand. Two experiments were conducted to (1) determine the effect of browsing intensity and frequency on the regrowth of the *Salix* spp. and *C. palmensis* and (2) to determine sheep preference for these browse species at different times of the day and year.

6.2 MATERIALS AND METHODS

6.2.1 Site description

The climatic conditions were the same as those described in Chapter 3 and were based on climatic data from the nearest (~ 2 km) weather station, (AgResearch Grasslands, Palmerston North). The soil is an Ashhurst silt loam, that is, a shallow and stony soil associated with yellow-grey earths and it is excessively well drained (Cowie 1976). It has medium fertility, for example, Olsen P of 20 mg/kg soil and soil pH of 5.2 (Table 6.1).

Table 6.1 Soil nutrient levels at Massey University experimental site (sampled to 75mm depth; July 1995)^a

pH ^b	Olsen P (mg/kg)	S ^c (mg/kg)	Exchangeable cations (me/100g soil) ^d		
			K	Ca	Mg
5.2	20	4	0.3	0.1	0.8

The explanations for the superscripts a, b, c and d are the same as those in Table 3.2

6.2.2 Experimental plants

The three browse species used were hybrid willow (*Salix matsudana x alba*) clone 'Tangoio', Kinuyanagi willow (*Salix kinuyanagi*) and tagasaste (*Chamaecytisus palmensis*). The same experimental plants were used in both experiments.

6.2.3 Plant establishment and management

The site was sprayed with glyphosate (1.1 kg ai/ha) and cultivated by chisel plough a week before planting. Stakes of the *Salix* species were planted on 8/9 September 1994 whilst seedlings of *C. palmensis* were transplanted on 21/22 September 1994. In autumn 1995 the site was sown with *Lolium perenne* and *Trifolium repens* as cover plants to control the ingress of weeds. Subsequently, the pasture within tree rows was killed with a mixture of glyphosate, terbuthylazine and terbumeton (1.1, 0.25 and 0.25 kg ai/ha, respectively). The between row pasture was mowed regularly. The species were browsed by sheep when they were aged 16 months and had the following mean heights and crown diameters; *Salix matsudana x alba* (1.7 m ; 1.8 m), *Salix kinuyanagi* (1.7 m ; 2.3 m) and *Chamaecytisus palmensis* (1.9 m ; 3.1 m).

6.2.4 Experimental treatments, procedures and design

Experiment 1: The treatments were three browse species (*Salix matsudana* x *alba*, *Salix kinuyanagi* and *Chamaecytisus palmensis*); two browsing intensities - heavy (removal of leaves and edible stem less than 5 mm in diameter) and light (removal of leaves only) browsing, and two frequencies of browsing - once (summer) and twice (summer and autumn). The 12 treatments were arranged in four randomised complete blocks with each plot (experimental unit) comprising a row of 8 trees. One row had 4 trees and was considered a missing plot. The trees had intra-row spacing of 2 m and inter-row of 4 m and each plot was enclosed with an electric fence. Four groups of six mature Romney ewes were used in the experiment with mean weights of 63 kg and 64 kg for summer and autumn, respectively. The groups were allocated randomly to the plots. The summer browsing spanned from 6 - 20 February 1996 and that of autumn, 22 - 28 April 1996. Before each browsing, the animals were kept in an adjacent paddock with the same browse species for a week, to become accustomed to them.

Experiment 2: The treatments were three browse species (*S. matsudana* x *alba*, *S. kinuyanagi* and *C. palmensis*), two browsing times and two seasons. The times were morning (9.30 - 11.30 hr) and evening (15.00 - 17.00 hr), which are peak grazing periods for sheep grazing temperate pastures (Hodgson 1982a). The two seasons were summer (February 1997) and autumn (April 1997). The experiment was a split plot design with four randomised complete blocks. The trees were cut to 1.2m above ground in late August 1996 for summer browsing and cut in February 1997 to the same height for autumn browsing. Each subplot comprised a row of 4-8 trees of each browse species, that is, three rows in an area of 192 m². The trees were spaced as in Experiment 1. Pasture between the trees was killed with glyphosate (1.1 kg ai/ha) about four weeks before the observation period so that the browse species were the only live forage available. Preference for the browse species by six Romney ewes (with mean weights of 56 kg and 55 kg for summer and autumn respectively) was determined with the interval sampling technique (Hodgson 1982a). The sheep were identified using coloured markers on their backsides. The animals were allowed to become accustomed to the browse species in a nearby paddock with the same forages for a week, then were held there when not on the experimental plots. The

sheep were not fasted, to prevent any bias in their preference for the browse species (John Hodgson, personal communication), and were allowed free choice of all browse species in each plot. The observation period was 2 hours whilst the frequency of the observations was 2 minutes.

6.2.5 Measurements

Experiment 1: Two plants within each row were selected a week before browsing and their crown diameters measured at the mid-point of the tree canopy (0.8-1.0 m aboveground). Crown diameter (CD) was measured with a 7.5 m diameter tape. Tree mass of the *Salix* species was removed to a stump height of 30 cm whilst that of *Chamaecytisus palmensis* to 50 cm stump height to optimise regrowth and maintain it within reach of the browsing animal. The fresh herbage was oven dried at 80 °C for 24 hours to determine the dry matter (DM) of each species. These data were used to determine the following regression functions relating dry matter (g/tree) and crown diameter of all the species based on the techniques developed by Rittenhouse and Sneva (1977) and Rutherford (1979) using Microsoft Excel for windows version 7 programme (Microsoft Corp. 1995):

Chamaecytisus palmensis : $DM = 119.6CD^{2.09}$ $R^2 = 83\%$ $p \leq 0.0001$

Salix matsudana x *alba* clone 'Tangoio': $DM = 193.1CD^{1.29}$ $R^2 = 63\%$ $p \leq 0.01$

Salix kinuyanagi : $DM = 57.7CD^{2.66}$ $R^2 = 64\%$ $p \leq 0.05$

A day before summer and autumn browsing, another pair of randomly selected trees from each treatment were tagged and their crown diameters recorded. Twenty-five percent of tree mass of one of the pair was sub-sampled to estimate dry matter of leaf, edible and woody stem components. The crown diameter of the second tree of the pair was measured post-browsing to estimate dry matter not consumed, using the equations above. No regrowth yield was determined after the autumn browsing until the following spring, because the *Salix* species were dormant during winter whilst *C. palmensis* was assumed to have negligible growth during winter (Dann and Trimmer 1986; Radcliffe 1986a; Oldham *et al.* 1994). The final regrowth of trees browsed once or twice during the season

was estimated at the end of the following spring (20 December 1996; Figure 6.1). The regrowth was estimated from a randomly selected pair of trees not previously sampled. Similarly, the crown diameters were measured for estimating regrowth dry matter and sub-sampled as before to determine leaf, edible and woody stem components.

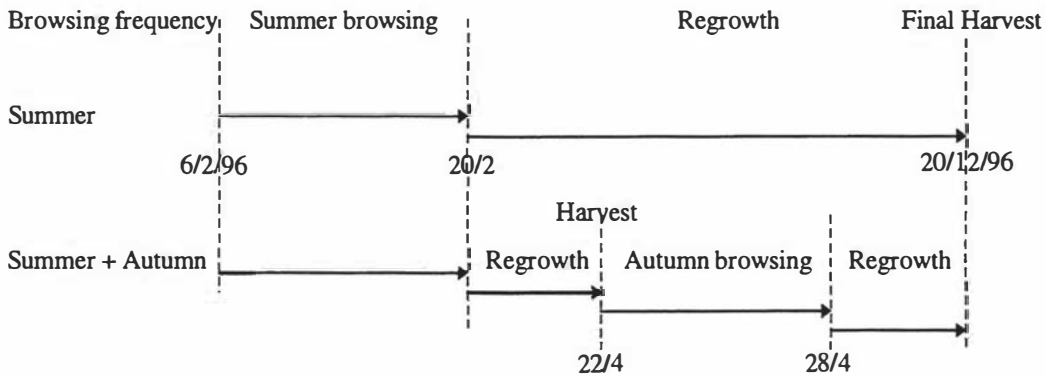


Figure 6.1 Schematic diagram of browsing and harvesting sequence in Experiment 1

Experiment 2: The activity of each sheep was recorded as browsing or idling (all other activities apart from browsing). Sheep activities were recorded using binoculars of 10 x 50 magnification and each animal was observed every 2 minutes. The species browsed and the number of bites on the species during this time interval were recorded. The recordings were conducted on all the animals over the entire observation period of 2 hours. The procedure was repeated for each subplot in the morning and evening and for eight subplots in each browsing season. The total number of bites on each browse species over the browsing period (four days for each season) was used to determine its preference rating.

Plant numbers, spreads (crown diameters) and mean heights per row were recorded. The foliage densities of the browse species per row were ranked visually on 1 (trees with least dense foliage in canopies) - 10 (trees with most dense foliage in canopies) scale. These variables were used to estimate relative abundance values (RAV) of each browse species in each plot (Appendix 6.1). This was expressed in terms of browse species density (Whittaker 1975; Etienne 1989). The proportion of browsing observations (PBO) for each browse species and RAV were used to calculate the browsing preference index (BPI)

(Ellis *et al.* 1976; Silen and Dimock 1978; Loehle and Rittenhouse 1982), using the formula:

$$\text{BPI} = (\text{PBO}_i/\text{RAV}_i) / \sum_i (\text{PBO}_i/\text{RAV}_i)$$

where i = individual browse species; n = all the browse species

6.2.6 Statistical analysis

In Experiment 1, analyses of variance were performed on leaf, edible stem, woody stem and total and edible dry matter yields, using the PROC GLM programme of SAS (SAS 1994). Pre- and post-browsing data were analysed as a split-plot over time. Data from Experiment 2 were analysed as a split-plot analysis of variance using the SAS package. Fisher's protected LSD was used to compare treatment means at $\alpha = 0.05$. Levels of significance of the difference between treatment means in all tables are denoted as follows: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; **** $p \leq 0.0001$; NS, not significant ($p > 0.05$).

6.3 RESULTS

6.3.1 Experiment 1

In this section, significant ($p < 0.05$) interaction effects of the estimated variables are presented but main effects are also included when they provide useful information.

6.3.1.1 Browsing effect on regrowth of browse species

Sheep browsing significantly affected regrowth of leaf, edible stem, woody stem, and total and edible DM of the three species. The mean regrowth of *Salix kinuyanagi* and *Chamaecytisus palmensis* was higher ($p \leq 0.05$) than for *Salix matsudana* x *alba*. *C. palmensis* had higher edible stem yield than those of the *Salix* species, which were similar (Table 6.2).

6.3.1.2 Effects of browsing frequency and intensity

Regrowth of the species when browsed twice (summer and autumn) was higher ($p \leq 0.01$) in leaf, edible stem, woody stem and total and edible DM, than when browsed once (summer) (Table 6.2). Regrowth of *S. matsudana* x *alba* and *C. palmensis* was not affected by browsing intensity ($p \geq 0.05$; Table 6.3). Heavy browsing of *S. kinuyanagi* resulted in higher ($p \leq 0.01$; Table 6.3) regrowth in woody stem and total DM, than light browsing.

6.3.1.3 Pre- and post-browsing dry matter yield

Post-browsing DM yields after 7 months regrowth were significantly higher for leaf, edible stem, woody stem and total and edible DM yields, than pre-browsing DM yields (Table 6.4). The interaction between species and browsing stage for these variables was only significant in leaf DM yield ($p \leq 0.05$). This was because post-browsing leaf DM yield was higher in *S. kinuyanagi* (0.8 vs. 0.3) than pre-browsing DM yield, but similar in *S. matsudana* x *alba* (0.6 vs. 0.4 kg DM/tree) and *C. palmensis* (1.0 vs. 0.7) (Appendix 6.2).

Table 6.2: Effect of browsing on regrowth biomass (g DM/tree/day) of the *Salix* spp. and *Chamaecytisus palmensis* between 6 February and 20 December 1996 (Experiment 1).

	Regrowth biomass (g DM/tree/day)				
	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM
SPECIES					
<i>Salix matsudana</i> x <i>alba</i>	1.5 ^b	0.6 ^b	1.9 ^b	2.0 ^b	3.9 ^b
<i>Salix kinuyanagi</i>	3.7 ^a	0.5 ^b	4.9 ^a	4.2 ^a	9.1 ^a
<i>Chamaecytisus palmensis</i>	4.5 ^a	1.2 ^a	3.5 ^a	5.7 ^a	9.5 ^a
SEM	0.6	0.2	0.5	0.7	1.1
Significance	***	*	***	**	***
BROWSING FREQUENCY					
Summer only	2.3 ^b	0.4 ^b	2.6 ^b	2.7 ^b	5.4 ^b
Summer and autumn	4.1 ^a	1.1 ^a	4.4 ^a	5.2 ^a	9.6 ^a
SEM	0.5	0.2	0.4	0.6	0.9
Significance	**	**	**	**	**

Means in a column followed by the same letters are not significantly different at 5% significance level

Table 6.3: Effect of browsing intensity on the regrowth biomass (g DM/tree/day) of the *Salix* spp. and *Chamaecytisus palmensis* between 6 February and 20 December 1996 (Experiment 1).

		Regrowth biomass (g DM/tree/day)				
		Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM
SPECIES	BROWSING INTENSITY					
<i>Salix matsudana</i> x <i>alba</i>	Light	1.4	0.6	1.8 ^{bc}	2.0	3.8 ^c
	Heavy	1.6	0.5	1.9 ^{bc}	2.1	4.0 ^c
<i>Salix kinuyanagi</i>	Light	2.7	0.2	3.5 ^{bc}	2.9	6.4 ^{bc}
	Heavy	4.7	0.8	6.2 ^a	5.5	11.7 ^a
<i>Chamaecytisus palmensis</i>	Light	5.3	1.4	4.3 ^b	6.7	11.0 ^{ab}
	Heavy	3.8	1.0	3.2 ^{bc}	4.8	8.0 ^{abc}
SEM		0.8	0.3	0.6	1.0	1.6
Significance		NS	NS	*	NS	*

Means in a column followed by the same letters are not significantly different at 5% significance level

Table 6.4: Difference between pre- (16 months) and post-browsing biomass of the *Salix* spp. and *Chamaecytisus palmensis* between 6 February and 20 December 1996 (Experiment 1).

	BIOMASS (kg DM/tree)				
	Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM
BROWSING STAGE					
Pre-browsing	0.5	0.1	0.4	0.6	1.0
Post-browsing	0.8	0.2	0.9	1.0	1.9
SEM	0.1	0.03	0.1	0.1	0.2
Significance	***	*	**	***	***

6.3.2 Experiment 2

6.3.2.1 Sheep preference for browse species

6.3.2.1.1 Effect of species

Sheep biting rate when browsing *S. matsudana* x *alba* and *C. palmensis* was 11 bites/minute which was twice that for *S. kinuyanagi* (Table 6.5). Sheep spent more time (18%) browsing *S. matsudana* x *alba* than *S. kinuyanagi* and *C. palmensis* (12% vs. 11%) but the values were not significantly different. Sheep spent 40% of the browsing period feeding on the species and 60% of time idling (defined as a combination of resting, ruminating and feeding on dead pasture). The percent time spent browsing was higher in summer (45%) than in autumn (38%) for all three species. The browse preference indices showed that *S. matsudana* x *alba* was 3-5 times more preferred than *S. kinuyanagi* and *C. palmensis* ($p \leq 0.001$; Table 6.5).

6.3.2.1.2 Effect of time of day

The biting rate of sheep on all browse species was higher in summer than autumn for morning browsing and similar ($p > 0.05$) for afternoon browsing. However there were no differences between morning and afternoon browsing on percent time sheep spent browsing and the preference rating of the three species (Table 6.6).

6.3.2.1.3 Effect of season

Sheep biting rate, percent time spent browsing and preference rating were higher in summer than autumn for *S. matsudana* x *alba* whilst for *S. kinuyanagi*, values for these attributes in autumn were considerably higher than those in summer. There was no seasonal effect ($p \geq 0.05$) on the biting rate of sheep, percent time spent browsing and preference rating of *C. palmensis* although the data suggested a decline in all variables for autumn forage (Table 6.6).

Table 6.5: Sheep preference for the *Salix* spp. and *Chamaecytisus palmensis* during summer (February 1997) and autumn (April 1997) (Experiment 2).

SPECIES	Bite rate (bites/minute)	Proportion of browsing time in each browsing period (%)	Browsing preference indices (%)
<i>Salix matsudana x alba</i>	11.1 ^a	18.1	63.6 ^a
<i>Salix kinuyanagi</i>	5.4 ^b	12.1	24.4 ^b
<i>Chamaecytisus palmensis</i>	11.2 ^a	11.4	12.0 ^b
SEM	0.9	2.5	5.2
Significance	**	NS	***

Browse preference indices - preference rating adjusted for browse availability; Means in a column followed by the same letters are not significantly different at 5% significance level

Table 6.6: Effects of season and time of day on sheep preference for the *Salix* spp. and *Chamaecytisus palmensis* (Experiment 2)

		Bite rate (bites/minute)	Proportion of browsing time in each browsing period (%)	Browsing preference indices (%)
SPECIES				
	Browsing season			
<i>Salix matsudana</i> x <i>alba</i>	Summer	14.6 ^a	27.5 ^a	82.4 ^a
	Autumn	7.5 ^b	8.9 ^{bc}	44.8 ^b
<i>Salix kinuyanagi</i>	Summer	1.8 ^c	1.5 ^{bc}	0.8 ^{cd}
	Autumn	9.0 ^b	22.7 ^a	48.0 ^b
<i>Chamaecytisus palmensis</i>	Summer	12.4 ^a	16.1 ^{ab}	16.8 ^c
	Autumn	10.1 ^{ab}	6.7 ^{bc}	7.3 ^{cd}
SEM		0.9	2.7	4.6
Significance		****	****	****
BROWSING TIME				
Morning	Summer	10.6 ^a	16.4	33.3
	Autumn	7.4 ^b	10.4	33.3
Afternoon	Summer	8.6 ^{ab}	13.6	33.3
	Autumn	10.3 ^a	15.1	33.3
SEM		0.8	2.2	0.04
Significance		***	NS	NS

Browse preference indices - preference rating adjusted for browse availability

Means in a column followed by the same letters are not significantly different at 5% significance level

Appendix 6.1 Procedure for calculating relative abundance (RAV) and browse preference indices (BPI) of the *Salix* spp. and

6.4 DISCUSSION

Results from Experiment 1 showed that the browse species responded differently to sheep browsing. *S. kinuyanagi* and *C. palmensis* had higher regrowth compared to that of *S. matsudana x alba* and they seemed better adapted to browsing than *S. matsudana x alba*. Radcliffe (1982) found that *C. palmensis* responded better to browsing than *S. matsudana x alba* and *S. viminalis* clone 'Gigantea', an osier *Salix* species. In contrast to Radcliffe's findings, *S. kinuyanagi*, an osier, showed a similar response to browsing as *C. palmensis*. This pattern of response by *S. kinuyanagi* is not well understood but may be due to morphological differences between this species and the osier *Salix* used in Radcliffe's study. *Salix kinuyanagi* has its growing buds on the main shoots and therefore escaped damage whilst in *S. matsudana x alba*, these buds occurred mostly on the edible stems which were browsed or damaged during browsing. Further results in Section 5.3.4 show that the length and basal diameter of the dominant coppice shoot was more important for estimating DM yield in *S. matsudana x alba* and *S. kinuyanagi* respectively, indicating differences in morphology of the two species. There also seemed to be differences in the use and storage of carbohydrate reserves as shown in the differences in DM yield when *S. matsudana x alba* and *S. kinuyanagi* were first cut in mid-spring (Section 5.3.1), and this might have also affected their capacity to show compensatory growth.

There were no differences in leaf, edible stem and total edible DM regrowth between heavy and light browsing regimes in the three species. Du Toit *et al.* (1990) reported that net annual shoot regrowth of heavily browsed *Acacia nigrescens* was not significantly different from that in lightly browsed trees. They suggested that the response was due to compensatory growth which alleviated the potential deleterious effects of tissue damage to either vegetative or reproductive organs (McNaughton 1983). All the species showed compensatory growth although it seemed to be higher in the *Salix* species than *C. palmensis*. The higher regrowth in woody stem and total DM yield resulting from heavy browsing in *S. kinuyanagi* compared to light browsing may be due to high compensatory growth. A greater proportion of this growth was woody stem which served as storage tissue for reserve carbohydrates that may provide the potential growing buds adequate nutrients for regrowth.

The *Salix* species potentially benefited from heavy browsing since there was no decline in edible DM yield (Benjamin *et al.* 1995) but in contrast, this component was reduced in *C. palmensis* browsed heavily. The decline in edible DM yield following heavy browsing in *C. palmensis* is similar to the findings of Townsend and Radcliffe (1990). Molyneux and Ralph (1992) reported that browsing was usually more damaging to evergreen than deciduous species and further supported the findings on *C. palmensis* under heavy browsing in this study. Evergreen species store carbon and nutrient reserves in their leaves whereas deciduous trees store them in stems and roots (Kramer and Kozlowski 1979). Leaf removal places substantial strain on plant reserves and regrowth following browsing is greatly reduced (Bryant *et al.* 1983; Molyneux and Ralph 1992).

Across the *Salix* spp. and *C. palmensis*, browsing twice in the growing season increased regrowth compared to once. This is corroborated by Oldham *et al.* (1994) who found that *C. palmensis* trees browsed twice by cows and calves during the growing season increased forage yield due to substantial compensatory growth. In contrast to the findings of this study, Kay (1997) reported reduced browse yield after repeated browsing of *Salix* spp. by elk in Yellowstone National Park. Furthermore, results of the cutting experiment in Chapter 5 showed that *Salix* trees cut in late winter and harvested once in autumn yielded more DM than trees harvested three times including autumn harvest. This response is similar to the findings of Kay (1997) with *Salix* spp. The results discussed here are for one year and it is suggested that this experiment should be conducted for 3 - 4 years to establish the long term response of the browse species to herbivory.

The trees used in Experiment 2 (preference study) were the same as in Experiment 1 since they were the only trees available. The resulting inferences regarding preference were made on the assumption that there was no residual treatment effect from Experiment 1 on the results of the second experiment. If there was an effect, there was no appropriate statistical technique to resolve the problem. However, if preference rating of each species had been based on the edible biomass consumed by the animal, then any residual effect could have been adjusted for by using the edible biomass data from Experiment 1 as a covariate in the analysis of the data for Experiment 2.

Nonetheless, Experiment 2 showed that *Salix matsudana x alba* was the most preferred by sheep and that their preference for *S. kinuyanagi* and *C. palmensis* was similar. McCabe and Barry (1988) and Douglas (unpublished data) also found that *S. matsudana x alba* was the most preferred species compared to *S. viminalis*, and *S. kinuyanagi* and *C. palmensis* respectively. The relatively high biting rate of sheep browsing *S. matsudana x alba* and *C. palmensis* compared to *S. kinuyanagi* may be due to differences in condensed tannin (CT) concentration. In an earlier study (Chapter 3), *S. kinuyanagi* had a high CT concentration which may be responsible for its reduced acceptability to sheep (Kumar and Singh 1984; Provenza and Malechek 1984; Silanikove *et al.* 1996) leading to the extremely low summer values for percent time sheep spent browsing and preference rating of the species. The summer CT concentration was higher than the autumn levels even though it was not statistically different within species (Table 3.5a). The biting rate of sheep on temperate pastures is 31- 49 bites min⁻¹ (Hodgson 1982a), about four times that obtained in the present study. The difference in leaf structure and density of the species compared to the grass/legume sward may be responsible for the low sheep biting rate on the browse species. Hodgson (1982a) defined forage intake as the product of grazing time, biting rate and forage intake per bite which shows that biting rate is an important parameter in forage intake. The low values obtained with the browse species in this study may cause reduced intake and subsequent decline in animal production (Hodgson 1990).

In all three species the biting rate of sheep was higher in the summer mornings than autumn mornings whereas that of autumn afternoons appeared higher than summer afternoons. The differences might be due to behavioural responses of the sheep to variable weather conditions. The warm summer mornings offered a more conducive condition to browse than the cold and windy autumn mornings. The summer afternoons were hot and possibly this caused reduced browsing.

There were variations between seasons in biting rate of sheep, percent time sheep spent browsing and preference rating of the *Salix* species. These variations may be due to structural and chemical differences of the browse (Provenza and Malechek 1984). *S. kinuyanagi* had higher values for the browsing variables in autumn than in summer and *S. matsudana x alba* showed higher values for the same variables in summer than autumn. A

possible explanation for the improved autumn preference rating of *S. kinuyanagi* compared to *S. matsudana* x *alba* may be due to the new leaves which resulted from regrowth of the trees when topped after summer browsing. The new leaves of *S. kinuyanagi* were larger than those of *S. matsudana* x *alba* and might be responsible for increased bite size and improved forage intake. Similarly Miquelle (1983) also found that moose browsing *Betula* spp. and *Sorbus americana* avoided regrowth because of reduced bite size, thus making it less efficient to ingest. Owen-Smith (1993) reported that unpalatable woody species may be acceptable in the new leaf stage even though CT levels in leaves may still be high (>50 gCT/kg DM). This may be due to the high protein concentration as well as high digestibility of young leaves compared to mature leaves (Vallentine 1990; Papachristou and Papanastasis 1994).

The biting rate of sheep, percent time sheep spent browsing and preference rating of *C. palmensis* tended to be higher in summer than in autumn. The low sheep preference rating for *C. palmensis* may be related to its small and hairy leaves which influenced bite size and depressed forage intake (Miquelle 1983; Hodgson 1990). Certain morphological features such as dense pubescence and texture (Malechek and Provenza 1983), thorns and spines (Bergstrom 1992) may also reduce the acceptability to stock of plant species. Reduced intake of *C. palmensis* may also be due to increased secondary metabolites resulting from heat and water stress during summer (Edwards *et al.* 1997) as well as odour from leaves. Arnold and Hill (1972) noted that the senses of taste and smell were also responsible for preference rating of species by animals. The preference rating of *C. palmensis* in this study is similar to those of several workers (Lambert *et al.* 1989b; Douglas unpublished data; Pande and Kemp unpublished data). However the intake of *C. palmensis* is high when provided as a sole diet and has been acclaimed as a useful fodder especially for dry summers (Borens and Poppi 1990; Oldham *et al.* 1994).

Ruminants may show preference differences for the same forage when presented as chopped or cut forage compared to those growing outdoors and it is difficult to speculate whether the present preference rating may be different when the *Salix* species and *C. palmensis* are presented indoor as chopped or cut forage. For example, Pande and Kemp (unpublished data) compared outdoor preference rating of the same species with the

indoor rating reported by Lambert *et al.* (1989b) and found that species such as *Ulex europaeus*, *Robinia pseudoacacia* and *Ceanothus griseus* were rated differently. They suggested that the variation might be due to the mode of presentation of the material and the fact that hay was used as a standard for comparison in the study of Lambert *et al.* (1989b).

6.5 CONCLUSIONS

All three browse species showed adaptability to browsing. Browsing twice in the growing season did not adversely affect regrowth. *S. matsudana* x *alba* was the most preferred species but preference declined dramatically in autumn. The high autumn preference for *S. kinuyanagi* suggested that a mixed plantation of both the *Salix* species may be ideal to meet sheep fodder requirements. *C. palmensis* must be grown alone to boost its use, as it is less preferred when in association with the *Salix* spp.

CHAPTER 7

GENERAL DISCUSSION, CONCLUSIONS AND RESEARCH NEEDS

7.1 INTRODUCTION

New Zealand pastoral farming depends largely on grazing temperate pastures, based on *Lolium perenne* and *Trifolium repens*. During dry summers, these pastures decline in production due to high temperatures and soil moisture deficits. To maintain profits through sustained animal production, pastoral farmers have to grapple with moderating the effect of herbaceous feed shortages. The planting of fodder trees in appropriate environments could provide the needed forage for livestock such as cattle, deer, goats and sheep during dry summers. It has been observed that the planting of fodder trees such as *Salix matsudana* in moist gullies which become dry during summer, has a much greater potential than drought tolerant pastures (Anon 1991) and that *Salix matsudana* could provide large amounts of feed to finish, flush and maintain livestock during dry summers (Hewson 1993).

The advantage of fodder trees is that they use deep soil moisture to produce green biomass in dry summers when conventional pastures are senescent. This in-built drought resistance could improve the stability of many grazing systems (Dann and Low 1988). Moreover, data derived from the New Zealand Land Resource Inventory suggested that 8.5 million hectares of cultivable land nationally, requires some form of soil conservation to maintain sustainable pastoral production (National Water and Soil Conservation Organisation 1979). This should involve mostly the use of trees.

Effective browse species required in New Zealand pastoral systems need to:

- Maintain high quality edible biomass through periods of environmental stress
- high organic matter digestibility

- high protein content
- relatively low anti-nutritive and toxic factors
- long leaf lifespan
- Have edible biomass that is accessible to livestock, or readily cut, carried and fed
- Survive heavy browsing
- Have forage that can ideally be harvested more than once during the growing season.

In addition to the above attributes, the ideal browse species must also possess the following characteristics:

- Uses other than browse such as soil and water conservation, and shelter. That is, they should be multipurpose
- Easily used in drought or other periods of stress such as flood damage
- Trees must not unduly affect pasture growth
 - deciduous trees may be desirable since leaf loss in autumn will not inhibit pasture growth in winter to the same extent as by evergreens
- Species must be quickly and easily established in the field to minimise the period of non-grazing of pasture.

In this thesis, several field experiments were conducted to provide practical information in respect of the growth, management and use of deciduous *Salix* browse as effective supplementary livestock fodder during dry summers. The experiments were also conducted at different sites which provided information on the environmental limits of the *Salix* species. The experimental sites are shown in Figure 3.1. The experiments aimed to determine: (1) the most appropriate cutting management as might be practised in a cut and carry system; (2) quick and reliable methods for establishing browse *Salix* species; (3) leaf lifespan of the *Salix* species and the influence of leaf maturation on forage quality and (4) the response of the *Salix* species to browsing and sheep preference for the species at different times of the year.

The *Salix* species were compared to *Chamaecytisus palmensis* and *Dorycnium rectum* in some experiments. These two species are legumes and are browse species that provide a useful comparison with the deciduous browse *Salix*. The *Salix* species responded differently to some of the management options used, compared to the legumes, because of differences in morphology and physiology but there were also similarities between the species.

The effects of cutting, browsing and cultural practices on browse yield and quality of *Salix matsudana x alba* and *Salix kinuyanagi*, as well as leaf maturation and its effect on leaf quality, are presented in Table 7.1 as they are the main species of interest in this study.

7.2 EFFECT OF CUTTING AND BROWSING ON BROWSE YIELD AND QUALITY

At Aokautere near Palmerston North, *Salix matsudana x alba* yielded more than *Salix kinuyanagi* (20-30%) and *Dorycnium rectum* (45-75%) in total and edible DM. *S. matsudana x alba* had more woody material than *S. kinuyanagi* (10-30%) and *D. rectum* (80-90%) over two years (Section 3.3.21; Table 3.4b). However *S. kinuyanagi* had a higher leaf to stem ratio than *S. matsudana x alba* (Chapters 3 and 5; McCabe and Barry 1988). The edible DM yield was influenced by the edible stem yield, defined as stems less than 5 mm in diameter, based on experience and literature. It is presumed that the amount of smaller stems ingested may depend on the kind of livestock and the softness of the stem but sheep used in the browsing experiment (Chapter 6) did not consume soft stems more than 5 mm in size.

At AgResearch Grasslands, Palmerston North, *S. kinuyanagi* trees aged two years had higher total and edible DM yields than *S. matsudana x alba* when harvested once in autumn (Section 5.3.3). A similar result was obtained by Douglas *et al.* (1996) with trees aged one year growing at Aokautere. The consistently higher DM yield of *S. kinuyanagi* compared to *S. matsudana x alba* in the first two years of tree establishment could be due to differences in root development and distribution (Adejumo 1992). Root excavation (Chapter 5) showed that *S. matsudana x alba* was deep-rooted and the roots

had a narrow spread while *S. kinuyanagi* had shallow but widely distributed roots. This suggested that during the first two years of tree establishment, *S. matsudana* x *alba* channels resources into root development and distribution at the expense of canopy growth. To test this hypothesis, root studies for the first three years of tree establishment of the *Salix* species are required.

Table 7.1 Responses to cutting, browsing and cultural practices, and the leaf lifespan and browse quality of the *Salix* trees.

CUTTING MANAGEMENT

- ◆ *Salix matsudana* x *alba* outyielded *Salix kinuyanagi* by 20-30% 3-4 years after establishment
- ◆ *S. matsudana* x *alba* yielded 70% more when cut in mid-spring than late winter
- ◆ Cutting to 30 cm stump height yielded similar edible forage to greater heights in both *Salix* species over two years. Thus low cutting will keep regrowth within reach of animals and make mechanical harvesting easier without penalty to forage yield
- ◆ Harvesting biomass twice annually did not reduce subsequent regrowth in areas with good growing conditions. Trees in relatively poor areas should be harvested only once annually
- ◆ Unrooted cuttings had DM yields similar to those of rooted cuttings

BROWSING MANAGEMENT

- ◆ Edible DM yield of the *Salix* species was not reduced under heavy browsing
- ◆ Across species, browsing twice increased DM yield compared with browsing once
- ◆ In summer *S. matsudana* x *alba* was the most preferred by sheep, whilst *S. kinuyanagi* was rejected
- ◆ Sheep preference for both species was similar in autumn

LEAF LIFESPAN

- ◆ Both species had a leaf lifespan of 6-6.5 months, and so leaves could be retained as green biomass until needed in summer or early autumn

BROWSE QUALITY

- ◆ Both species had initial leaf nitrogen concentration of 2.8-3.1% which declined to 2.3 by three months
 - ◆ *S. matsudana* x *alba* leaves (84%) had higher OMD than those of *S. kinuyanagi* (71%)
 - ◆ *S. kinuyanagi* browse had a CT concentration four times more than *S. matsudana* x *alba* (255 g/kg DM vs. 59 g/kg DM)
-

OMD, organic matter digestibility; CT, condensed tannin

Salix matsudana x *alba* yielded 40% more than *S. kinuyanagi* (Table 5.1) when trees of both species were first cut in mid-spring. High reserve carbohydrate in the roots of *S. matsudana* x *alba* (Section 5.3.4; Fig.5.1) might account for this response. The physiological and morphological differences (Section 5.3.4; 5.3.5) between both *Salix* species indicated that they should be managed differently even under a cut and carry system (Stur *et al.*1994). *Dorycnium rectum* showed reduced total and edible DM yield with cutting over two years which suggested that the species does not persist under annual cutting and an appropriate cutting regime should be determined.

Stump height did not influence total edible and leaf DM yields of the species (Table 3.4b). Thus cutting trees to a low stump height (30 cm) will keep edible growth at browsing height and in a cut and carry system, ease mechanical harvesting of edible forage without reduction to subsequent regrowth (Oppong *et al.* 1996). Cutting the *Salix* spp. once or twice within the growing season did not increase or decrease DM yields ($p > 0.05$; Appendix 3.1; Tarawali *et al.*1996; Oppong *et al.* 1997). The *Salix* trees had increased DM yield when browsed twice compared to once, suggesting that the species responded to browsing differently than cutting. A similar finding was made by Hardesty and Box (1988a) who reported that browsed trees of the Brazilian caatinga produced regrowth during the dry season (dormant season or winter) when the trees are normally leafless whereas cut trees did not produce any regrowth. Browsing the *Salix* trees twice in the growing season is the best practical approach to optimise browse consumption of the species. More coppice shoots in the secondary regrowth of *S. matsudana* x *alba* were probably due to compensatory growth for restoring adequate levels of reserve carbohydrates for future regeneration (Kramer and Kozlowski 1979).

At Ballantrae near Woodville, *S. matsudana* x *alba* produced more DM than *S. kinuyanagi* even during the first two years of tree establishment (Section 3.3.3.1), suggesting it is more tolerant of the poor soils, low temperatures and strong winds at Ballantrae. Douglas *et al.* (1996) indicated that *S. matsudana* x *alba* is perhaps the most drought-tolerant of the *Salix* species which may offer opportunities for establishing stands outside relatively moist areas, where the *Salix* spp. are traditionally grown. The DM yields of the *Salix* spp. growing at AgResearch Grasslands, Palmerston North and

Aokautere were higher than those at Ballantrae (Chapter 3 and 5) an expression of the effect of site differences (Oppong *et al.* 1996) on DM yield. Low soil fertility and extreme climatic conditions (van Kraayenoord & Hathaway 1986) were assumed to be responsible for the low yields at Ballantrae. However a subsequent fertiliser experiment at the site (Table 3.9) failed to support the low soil fertility hypothesis, which suggested that low temperatures and strong winds might account for the low yields (Table 3.3; Appendix 3.2; Grace 1977; van Kraayenoord & Hathaway 1986). It is proposed that a long term fertiliser experiment with higher fertiliser rates be conducted. Furthermore, experiments to define temperature and wind speed limits of the *Salix* spp. could provide useful information.

At Ballantrae, rooted and unrooted stem cuttings of *S. matsudana* x *alba* and *S. kinuyanagi* produced similar DM yields (Table 3.7) which has also been found using poplars growing at a similar site (Stace 1996). The use of unrooted stem cuttings for growing the *Salix* spp. is recommended since it would reduce the cost of establishing and managing the trees compared to rooted stem cuttings. Although financial analyses were not conducted in these experiments, results from a comparative study on the establishment and management costs of different stock types of radiata pines (Anon 1995) provided the basis for such a conclusion. The effect of rooted and unrooted stem cuttings on DM yield of the *Salix* spp. in an environment more favourable for their growth than at Ballantrae, should be determined.

Regrowth in *S. matsudana* x *alba* and *C. palmensis* was unaffected by heavy browsing (Section 6.3.1.2) but this browsing intensity increased the woody stem and total DM yields of *S. kinuyanagi*. Increased regrowth occurred when all the species were browsed twice compared with once during the growing season. This response might be due to compensatory growth which moderated the potential deleterious effect of tissue damage (McNaughton 1983; Oldham *et al.* 1994). The absolute regrowth data for *C. palmensis* showed a decline with heavy browsing since browsing can damage evergreens more than deciduous species (Molyneux and Ralph 1992) since evergreen species store their carbon and nutrient reserves in their leaves whereas deciduous trees store theirs in stems and roots (Kramer and Kozlowski 1979).

The removal of the leaves through browsing places considerable stress on plant reserves and the regrowth of evergreens after browsing is greatly reduced (Bryant *et al.* 1983). Pasture herbage accumulation at Aokautere and Ballantrae was low during summer and 50-90% of the DM yield comprised dead matter and weeds when harvested every month (Table 3.6a). During summer-autumn, over a period of 120 days (January-April), *S. matsudana* x *alba* accumulated 3 t DM ha⁻¹ of edible material (Table 3.6b) whereas edible pasture accumulation was 1.6 t DM ha⁻¹, assuming a monthly edible pasture production of 0.4 t DM ha⁻¹ (Table 3.6b). Assuming a 57 kg ewe with a maintenance requirement of 10.5 MJ ME day⁻¹, then a pasture (metabolisable energy content of 10.5 MJ ME kg DM⁻¹) intake of 1 kg DM day⁻¹ is required (Milligan *et al.* 1987), indicating that the above amount of pasture can maintain 13 ewes ha⁻¹ over the 120 days while the additional DM from browse can also maintain 25 ewes ha⁻¹ over the same period. These values suggest that browse fodder could provide valuable supplementary forage during dry summers and that the inclusion of browse species in some pastoral systems is warranted (Lambert *et al.* 1989a).

Edible material from *S. matsudana* x *alba* is of comparable feed quality to lucerne hay and *Populus* spp., but slightly lower than that of *C. palmensis* (Table 7.2). *S. matsudana* x *alba* being of similar quality to lucerne hay is useful since in New Zealand, lucerne hay is the most frequently used feed supplement during summer drought (McCabe and Barry 1988). *S. matsudana* x *alba* will also complement *C. palmensis* because it could be planted on moist sites where *C. palmensis* would not grow well. However *S. kinuyanagi* is slightly lower in digestibility due probably to its high condensed tannin (CT) concentration, but it is still useful because of its relatively high DM yield and nitrogen concentration.

CT concentration was higher in *S. kinuyanagi* than *S. matsudana* x *alba* and more so at Ballantrae where the growth of the species is affected by low temperatures and strong winds (Table 3.5a; Table 3.8). This was in agreement with the findings of Douglas *et al.* (1993) who found that the CT concentration of several forage shrubs was higher where plant growth was limited by environmental factors. N concentration and OMD were higher in leaf than edible stem of the *Salix* spp. as well as *D. rectum* (Table 3.5a; Table

3.8), findings which were similar to those of Van Soest (1994) and Lambert *et al.* (1989d) for other species. The high CT in *S. kinuyanagi* compared to *S. matsudana* x *alba* may have affected its acceptability to ruminants as shown in Chapter 6.

7.3 LEAF MATURATION AND ITS EFFECT ON LEAF QUALITY

In the experiment reported in Chapter 4, leaves of the *Salix* spp. and *C. palmensis* aged 3 months declined in nitrogen (N) concentration, but the N concentration in all the species at each harvest attained the level (17 gN/kg DM) recommended for an adequate diet of a lactating ewe rearing a single lamb (NRC 1975).

The ash concentrations obtained for the species do not indicate which elements are deficient but Douglas *et al.* (1996) found that sodium was deficient in the *Salix* spp. and *C. palmensis* at Aokautere. Furthermore Lambert *et al.* (1989d) found at Ballantrae that sodium and phosphorus concentrations in *C. palmensis*, were lower than the requirement of a diet adequate for a lactating ewe with a lamb. It is recommended that studies be conducted to determine the concentration of individual mineral components of the three species at different leaf ages. Table 7.3, derived from published values, shows that the *Salix* spp. are comparable to *Populus deltoides*, *C. palmensis* and pasture in individual mineral element concentrations. Nonetheless, the sodium concentration of the browse species did not meet the requirement for a diet adequate for growing, pregnant or lactating sheep and cattle. All the species were also deficient in phosphorus while *C. palmensis* was deficient in sulphur and magnesium for a diet adequate for growing or lactating cattle (Grace 1983). None of the species mentioned in Table 7.3 had mineral element concentrations which were at levels considered toxic to ruminants (Grace 1983).

Table 7.2 Nutritive value of some browse species and lucerne hay in New Zealand

SPECIES	Plant part	Nitrogen g/kg DM	Digestibility g/kg DM	CT g/kg DM	ME MJ/kg DM	Site	Source
<i>Chamaecytisus palmensis</i>	leaf + edible stem	32	820	ND	ND	Aokautere	Douglas <i>et al.</i> 1996
<i>Populus deltoides</i>	leaf	29	740	ND	12	Pohangina valley	Guevaria-Escobar *
<i>Salix matsudana x alba</i>	leaf + edible stem	21	670	59	10 [#]	Aokautere	In this study
<i>Salix kinuyanagi</i>	leaf + edible stem	18	613	255	9 [#]	Aokautere	In this study
Lucerne Hay		24	640	ND	10	North Otago	Phipps 1989

[#] McCabe and Barry 1988; CT, condensed tannin; ME, metabolisable energy; ND, not determined; * unpublished data

Table 7.3 Mineral element concentrations in edible material (leaf + edible stem) of some browse species and pasture

SPECIES	P ²	K	S	Ca	Mg	Na	Cu	Fe	Mn	Zn	Source
<i>Chamaecytisus palmensis</i>	0.24	1.65	0.16	0.47	0.13	0.02	6	74	139	47	Douglas <i>et al.</i> 1996
<i>Populus deltoides</i>	0.22	2.53	0.40	1.26	0.44	0.08	10	242	134	157	Guevaria-Escobar *
<i>Salix matsudana x alba</i>	0.26	1.74	0.26	0.68	0.23	0.03	8	73	50	92	Douglas <i>et al.</i> 1996
<i>Salix kinuyanagi</i>	0.27	1.55	0.19	0.51	0.16	0.02	6	62	140	59	Douglas <i>et al.</i> 1996
Pasture	0.22	1.76	0.21	0.70	0.23	0.12	6	98	70	27	Douglas <i>et al.</i> 1996
Recommended ¹ sheep	0.20	0.36	0.15	0.29	0.12	0.09	5	30	25	25	Grace 1983
cattle	0.32	0.58	0.18	0.44	0.19	0.12	7	40	25	25	Grace 1983

¹Recommended level for a diet adequate for growing and lactating sheep and cattle; * unpublished data

²Units are % DM for macro-elements (P, K, S, Ca, Mg, Na) and mg/kg DM for micro-elements

The OMD of *S. matsudana x alba* leaves was higher than those of *C. palmensis* and *S. kinuyanagi* as a result of its low NDF and anti-nutritive factors, particularly CT (Tables 3.5a; 4.3; Oppong *et al.* 1997). Low NDF of *S. matsudana x alba* leaves implied greater potential intake (Mertens 1994; Van Soest 1994) than leaves of *C. palmensis* and *S. kinuyanagi* and moreover, this species was more digestible than *C. palmensis* and *S. kinuyanagi*. This is corroborated by Kilcher (1981) who reported that increased NDF lowered digestibility and reduced forage intake. The high CT concentration (> 290 gCT/kg DM) of *S. kinuyanagi* leaves (Oppong *et al.* 1997) has the potential to reduce their digestibility due to the formation of N-CT complexes which reduce their solubility and degradation by rumen bacteria (Waghorn *et al.* 1990). The relatively low CT concentration (< 50 g / kg DM; Table 3.5a) of *S. matsudana x alba* leaves shows its potential for improved nitrogen utilisation and subsequent high animal performance (Barry 1989; Waghorn *et al.* 1990).

7.4 SHEEP PREFERENCE FOR BROWSE SPECIES

S. matsudana x alba was most preferred by sheep whilst *S. kinuyanagi* and *C. palmensis* had similar preference ratings (Tables 6.5 and 6.6). Biting rates of sheep for *S. matsudana x alba* and *C. palmensis* (11 bites/minute), and *S. kinuyanagi* (5 bites/minute) were 10-30% lower than the rate obtained on temperate pastures (31-49 bites/minute; Hodgson 1982a). Biting rate is an important determinant of herbage intake and the low values for the browse species could reduce voluntary feed intake and subsequently affect animal production (Hodgson 1982a; 1990). The browsing time was higher in summer (45%) than autumn (38%) for all species, suggesting increased voluntary intake in summer, which will be beneficial to the animals. However, within seasons browsing time on each species varied, being least in summer for *S. kinuyanagi* and autumn for *C. palmensis*.

Preference for the *Salix* spp. by sheep also varied between summer and autumn. *S. matsudana x alba* was much preferred to *S. kinuyanagi* in summer whilst in autumn they had similar preference ratings (Table 6.6). The reason for the low preference for *S. kinuyanagi* in summer may be due to its high CT concentration, which reduces the

species acceptability to sheep (Kumar and Singh 1984; Provenza and Malechek 1984; Silanikove *et al.* 1996). The increased preference rating of *S. kinuyanagi* in autumn was possibly due to the newly emerged leaves, after the trees were topped in summer. Owen-Smith (1993) found that woody species at the mature leaf stage are unpalatable, but become acceptable in the new leaf stage even though CT concentration in the leaves may still be high (> 50 gCT/kg DM). This might be accounted for by the high nutrient levels of young leaves which nullifies the adverse effect of high CT.

The high biting rate of sheep achieved in summer mornings and autumn afternoons compared to those of summer afternoons and autumn mornings may be due to the weather conditions. Summer mornings were warm and calm, and probably encouraged sheep to browse more than the cold and windy autumn mornings. The summer afternoons were extremely hot and likely caused reduced browsing. The high preference rating of *S. matsudana* x *alba* is consistent with the findings of McCabe and Barry (1988) and Douglas (unpublished data).

Although the browsing study was conducted with sheep, the *Salix* species and *C. palmensis* are also utilised by other livestock. McCabe and Barry (1988) found that goats and deer could be maintained on *Salix matsudana* x *alba* fodder during dry summers. Furthermore, 200 mixed aged beef cattle maintained condition when fed *Populus* browse for two months during summer. Edwards *et al.* (1997) found that *Chamaecytisus* browse could be used under continuous and rotational browsing regimes in Southern Australia. They reported that under both browsing systems, liveweight gains of young cattle peaked at 1.0-1.5 kg/head/day in winter and spring, and declined to maintenance levels by late summer-autumn.

7.5 PRACTICAL IMPLICATIONS OF SALIX BROWSE IN NEW ZEALAND PASTORAL SYSTEMS

Fodder from trees may help alleviate pasture feed shortage during dry summers. In New Zealand, *Chamaecytisus palmensis* is a favoured species because of its high edible DM yield and moderate browse quality (Radcliffe 1986a; Douglas *et al.* 1996; Tables 7.2; 7.4). Even though *C. palmensis* is regarded as a satisfactory browse species it is not

suitable for all environments. *Salix* spp. and *Populus* spp. are comparable in DM yield and quality and may complement *C. palmensis* since they are suitable for moist and seasonally flooded sites such as gullies (Hathaway 1987; Anon 1991) which are unsuitable for growing *C. palmensis*. These trees may not only be used as feed but also have soil conservation and amenity value, and provide shade during dry summers (Anon 1991). An additional advantage is that they avoid frost damage during winter since they are dormant at that time of the year. It should also be noted that fodder from trees may be free from the larvae of disease causing parasites and the tall stature might reduce dietary larval challenges (Lambert *et al.* 1989a). *Salix* spp. have an advantage over *Populus* spp. since they can be coppice-managed on shorter rotations than *Populus* spp. (Hathaway 1986a).

Three of the species used in this study had a long leaf lifespan varying from 5.5 months for *C. palmensis*, to 6.5 months for the *Salix* spp. (Table 4.2; Section 4.3.1). The leaf lifespan of *C. palmensis* was similar to that found by Borens and Poppi (1990) and that of *Quercus pyrenaica* (5.5 months; section 4.4) reported by Escudero *et al.* (1992). The leaf lifespan of the *Salix* spp. was also comparable to that of *Betula pubescens* (6.6 months) found by Escudero *et al.* (1992). The long leaf lifespan means that the leaves of the three species can be retained as green biomass for use during summer and early autumn.

The *Salix* spp. showed sympodial (indeterminate) shoot growth and must be trimmed periodically to improve the availability and accessibility of edible material for browsing animals, and ease mechanical harvesting in cut and carry system. *C. palmensis* has monopodial (determinate) shoot growth and must be topped to encourage low branching (Edwards *et al.* 1997) and maintain edible material at browsing height.

The *Salix* spp. also had an intermediate type of leaf emergence whilst that of *C. palmensis* was the succeeding type (Kikuzawa 1983). Moreover, the *Salix* spp. are deciduous whereas *C. palmensis* is evergreen. These characteristics suggest that the *Salix* spp. are morphologically and physiologically different from *C. palmensis*. Therefore cutting or browsing regimes suitable for the *Salix* spp. may not be appropriate for *C. palmensis* (Stur *et al.* 1994).

Table 7.4 Comparative edible (leaf plus stem < 5 mm in diameter) dry matter yields of some browse species in New Zealand.

SPECIES	Tree age (years)	Edible dry matter yield (t DM/ha)	Source
<i>Chamaecytisus palmensis</i>	1	2.9	Douglas <i>et al.</i> 1996
	5	8.4	Radcliffe 1986a
<i>Populus x euramerica</i> clone 'Flevo'	4	2.2	Hathaway 1986a
	5	2.7	Hathaway 1986a
<i>Salix matsudana x alba</i>	1	1.2	Douglas <i>et al.</i> 1996
	3	2.9	In this study
	4	3.2	In this study
	5	5.7	Hathaway 1986a
<i>Salix kinuyanagi</i>	1	1.8	Douglas <i>et al.</i> 1996
	3	2.1	In this study
	4	2.7	In this study

Keoghan (1986) described three systems for integrating browse species into the New Zealand pastoral system and indicated that no single system may suit all livestock enterprises. Some suitable systems for browse integration into the pastoral system are;

- (1) Feed banks also referred to as fodder banks, are special purpose areas planted solely in browse species, for cut and carry feed and for browsing with back fencing to enable uninterrupted recovery of utilised plants.
- (2) Mixed browse and pasture plantations, where hedges of browse species are planted in strips as an integral part of conventional pasture fields, with multiple rows spaced at 10-15 m intervals.
- (3) Fence line hedges for shelter and emergency feed.

Other possible systems to integrate browse species into pastoral systems are;

- (4) Planting widely spaced trees within the pasture. These trees should be above browsing height and could serve as shade during dry summers and lopped when necessary to provide green feed.
- (5) Planting trees for stream bank protection. These can be pollarded to harvest browse during dry summers to provide fodder for stock.

The *Salix* spp. especially *S. matsudana* x *alba* clone 'Tangoio', could be established as feed banks, mixed browse and pasture plantations, and as fence line hedges for shelter and emergency feed. They could be planted as scattered trees in the pasture to provide shade and emergency feed during dry summers and along river banks and water courses to stabilise the river bed and protect it from scouring. As feed banks, a between row spacing of 2.0 m is recommended so that harvesting using a tractor-mounted saw would be possible in a cut and carry system, and trimming can be conducted after browsing. If the mixed browse and pasture plantation option is adopted, the strips should be made of alternating hedges of *S. matsudana* x *alba* and *S. kinuyanagi* so that *S. matsudana* x *alba* does not become over-browsed, though both species tend to have similar preference ratings in autumn. Growing *S. matsudana* x *alba* as a fence line hedge for shelter and emergency feed is appropriate since it was selected mainly for farm and horticultural shelter (Hathaway 1986c). The third option may also be suitable for

Populus spp. since they are amenable to lopping rather than short rotation coppice management (Hathaway 1986a).

Salix kinuyanagi may be more suitable for planting along river banks for river bed stabilisation and being a male species (Slui 1990), it will not cause any seedling problems in river channels (Hathaway 1986d) but *Salix matsudana* x *alba* is a female clone (Hathaway 1986c) and may cause seedling problems. However it could be planted as scattered trees in the pasture to provide shade and fodder during summer.

Analyses of the fodder contribution by some tree species under different browse production systems and that of pasture are given in Table 7.5. This approach could provide the basis for selecting the most appropriate production system for different species that serves the requirements of the pastoral system in operation. Estimates of edible DM yields in all browse systems except those of widely spaced trees were expressed as kg DM/tree using figures reported by Douglas *et al.* (1996) for trees aged one year. Those for widely spaced trees were based on data reported by Oppong *et al.* (1996) for three year old trees. It should be noted that the edible DM yield will increase as the trees age. These estimates are considered only as accumulated forage to supplement pasture during dry summers when pasture yields are low. Pasture yield for Maraekakaho, Hawke's Bay, a site with potential for low pasture yield during summer, is compared with the edible DM yields from the browse production systems. The browse yield was the accumulated DM over the entire growing period while pasture yield was for summer-autumn (January - April).

In New Zealand, the most acceptable browse systems are; feed banks, fodder from fence line hedges and trees planted for stream bank protection. This conclusion emanates from their potentially high browse yields compared to the others and the number of stock units that can be maintained, as estimated in Section 7.2 (paragraph 8). Lack of financial information on the browse production systems makes it extremely difficult to evaluate the profitability of these systems in monetary terms. Nonetheless, ecological benefits including their role in soil conservation are an immeasurable asset.

Table 7.5 Estimated annual fodder production under different browse production systems and pasture production over summer-autumn (January-April).

Fodder production systems/Species	Tree density/ha	Edible DM Yield (kg DM/ha)
FEED BANK*		
<i>Salix matsudana x alba</i>	5000	2000
<i>Salix kinuyanagi</i>	5000	3000
<i>Chamaecytisus palmensis</i>	5000	5500
MIXED BROWSE AND PASTURE*		
<i>Salix matsudana x alba</i>	1000	400
<i>Salix kinuyanagi</i>	1000	600
<i>Chamaecytisus palmensis</i>	1000	1100
FENCE LINE HEDGE*		
<i>Salix matsudana x alba</i>	5000	2000
<i>Chamaecytisus palmensis</i>	5000	5500
<i>Populus spp.</i>	5000	1000
WIDELY SPACED TREES**		
<i>Salix matsudana x alba</i>	100	110
<i>Salix kinuyanagi</i>	100	80
STREAM BANK PROTECTION*		
<i>Salix kinuyanagi</i>	5000	3000
Pasture [§]		975

Data derived from figures reported by Douglas *et al.* 1996* ; Oppong *et al.* 1996** ; Radcliffe (1975)[§]. Edible pasture yield estimated as 70% of total live pasture yield.

7.6 CONCLUSIONS

The experimental results indicated that the *Salix* spp. are potential multipurpose plants and cutting height has no major effect on edible DM yield of the species. A maximum of two harvests during the growing season had no effect on DM yield over a two-year period at a moist site. Unrooted stem cuttings were as productive as rooted cuttings and did not adversely affect browse quality. Therefore unrooted stem cuttings are recommended because they are easier to establish and less expensive.

Maintaining a low stump height will ensure that the regrowth of the species is within reach of the browsing animal and ease mechanised harvesting to reduce labour requirements. Pastoral farmers in New Zealand will find it more convenient to allow animals to browse young regrowth directly than having to cut and carry to feed housed animals. Direct browsing fits well into the existing management systems. *S. matsudana* x *alba* trees when cut initially in mid-spring outyielded those of *S. kinuyanagi* compared to when cut in late winter. The benefits for such management are (1) apart from improved yield, higher quality forage when needed in mid-summer and (2) regrowth within reach of the browsing animal, which is less woody.

S. matsudana x *alba*, *S. kinuyanagi* and *C. palmensis* had long-lived leaves of moderate to high quality which were retained beyond four months, although quality declined slightly at three months. The nitrogen concentration of leaves aged six months was higher than the recommended level in the diet for a lactating ewe rearing a single lamb and the leaves are of reasonable digestibility. Another advantage of browse species is that leaves last much longer than those of temperate grasses and other herbaceous species, without much loss in quality.

The *Salix* spp. and *C. palmensis* responded well to browsing by sheep and were not adversely influenced by heavy browsing. Browsing twice in the growing season increased regrowth in all species. *S. matsudana* x *alba* was the preferred species, but all the species were utilised to some extent and in different seasons. For the *Salix* spp., a mixed plantation of *S. matsudana* x *alba* and *S. kinuyanagi* is suggested and this could be in

feed banks or mixed browse and pasture systems. However *C. palmensis* must be cultivated in monocultures or with pasture to enhance its use, as it was less preferred when in association with the *Salix* spp.

S. matsudana x alba and *S. kinuyanagi* have potential as drought fodder and also serve as soil conservation plants. The *Salix* spp. have multiple uses and will fit in well with present pastoral farming systems. To achieve high DM yields, the *Salix* spp. must be established in relatively moist environments where *C. palmensis* cannot grow. *S. matsudana x alba*, especially the leaves, can constitute a maintenance feed for sheep during dry summers due to its satisfactory quality and edible forage yield and should be the preferred choice for fodder production in New Zealand pastoral systems. The potential role of *S. kinuyanagi* as a supplementary drought fodder is constrained by its higher CT concentration which may affect its acceptability. The relatively low yield from *Dorycnium rectum* and its decline with use limits its potential as fodder during dry summers in the lower North Island. The multipurpose nature of the *Salix* spp. should encourage their wider use by pastoral farmers and establish them as a viable option for overcoming dry summer pasture feed shortages.

7.7 RESEARCH NEEDS

This research has provided useful practical information on the growth, management and quality of the *Salix* species. However there are still numerous questions unanswered and six potential research areas have been identified:

- (1) *S. matsudana x alba* produced lower DM yields than *S. kinuyanagi* during the first two years of establishment. This may be related to differences in rooting characteristics and hence studies to determine root development and distribution of the species should be conducted.
- (2) The feeding value of the *Salix* species should be determined either as a sole diet or as a supplement to pasture feed.
- (3) Valuable information would be gained from determining the long-term persistence of the species under browsing.

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- (4) It is essential to determine the effect of tree density and cutting frequency on DM yield.
 - (5) The influence of stump height on the number and sites of potential growing buds should be determined and their contribution to regrowth assessed.
 - (6) The impact of *Salix* species in tree/pasture systems should be researched extensively.

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Appendix 3.1 Effect of harvesting times on dry matter (DM) yield of the *Salix* spp. and *Dorycnium rectum* at Aokautere over two years.

SPECIES	Harvest times	Dry matter yield (kg DM/tree)					
		Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM	Leaf : Stem ratio
<i>Salix matsudana x alba</i>	Summer	0.8	0.3	1.5	1.1	2.6	0.4
	Summer + autumn	0.9	0.3	1.7	1.3	3.0	0.5
<i>Salix kinuyanagi</i>	Summer	0.7	0.1	1.2	0.8	2.0	0.6
	Summer + autumn	0.9	0.1	1.4	1.0	2.3	0.6
<i>Dorycnium rectum</i>	Summer	0.2	0.2	0.2	0.4	0.7	0.6
	Summer + autumn	0.3	0.2	0.2	0.4	0.6	1.0
SEM		0.1	0.04	0.2	0.1	0.4	0.1
Significance		NS	NS	NS	NS	NS	NS

Sample size (n) = 36; SEM - standard error of the mean.

Appendix 3.2 Monthly wind run (km/hr) for AgResearch, Ballantrae and Palmerston North sites during 1995

Sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ballantrae	225	193	236	198	239	247	257	237	262	255	240	228
Palmerston North	197	179	236	-	131	149	193	195	118	207	176	209

Appendix 6.1 Procedure for calculating relative abundance (RAV) and browse preference indices (BPI) of the *Salix* spp. and *Chamaecytisus palmensis*

Block ^A	Species	Subplot	No. Plants	CD (m)	H (m)	FD	SFA	RAV	BPO	BPI
1	TAN	1	7	2.3	2.2	6.1	130.2	0.22	0.73	0.77
	KIN	1	8	3.4	2.2	5.9	314.3	0.53	0.04	0.02
	TAG	1	4	3.2	2.1	6.7	150.9	0.25	0.23	0.21
	TAN	2	8	3.0	2.4	6.1	276.1	0.20	0.77	0.88
	KIN	2	7	4.1	2.8	5.7	491.9	0.36	0.00	0.00
	TAG	2	7	4.1	2.7	7.3	607.4	0.44	0.23	0.12
2	TAN	1	8	2.5	2.6	6.6	224.7	0.21	0.71	0.83
	KIN	1	7	3.7	2.7	5.9	399.8	0.37	0.00	0.00
	TAG	1	7	3.7	2.7	6.9	467.6	0.43	0.29	0.17
	TAN	2	8	2.6	2.7	6.1	233.3	0.23	0.54	0.64
	KIN	2	8	3.6	2.7	5.9	432.6	0.42	0.00	0.00
	TAG	2	6	3.5	2.6	7.3	365.4	0.35	0.46	0.36
3	TAN	1	8	2.1	2.2	5.7	115.9	0.26	0.62	0.77
	KIN	1	6	2.4	2.0	4.8	86.9	0.20	0.00	0.00
	TAG	1	7	2.9	2.2	7.1	240.8	0.54	0.38	0.23
	TAN	2	5	2.5	2.2	6.4	115.2	0.22	0.75	0.82
	KIN	2	7	3.3	2.5	4.7	234.6	0.45	0.00	0.00
	TAG	2	4	3.3	2.2	6.8	170.7	0.33	0.25	0.18
4	TAN	1	4	1.5	1.6	4.9	18.5	0.03	0.36	0.92
	KIN	1	5	3.2	1.7	5.4	123.1	0.22	0.04	0.01
	TAG	1	7	3.6	2.3	7.7	420.8	0.75	0.60	0.06
	TAN	2	8	2.4	2.3	7.4	205.4	0.22	0.95	0.96
	KIN	2	7	3.0	2.2	6.2	225.1	0.25	0.03	0.03
	TAG	2	5	4.1	2.7	8.2	487.4	0.53	0.02	0.01

Appendix 6.1 Continued

Block ^B	Species	Subplot	No. Plants	CD (m)	H (m)	FD	SFA	RAV	BPO	BPI
1	TAN	1	7	2.4	1.2	3.5	44.3	0.14	0.08	0.12
	KIN	1	6	2.7	1.4	4.3	66.0	0.21	0.85	0.86
	TAG	1	4	4.0	1.8	6.8	198.9	0.64	0.07	0.02
	TAN	2	8	2.3	1.3	3.9	56.2	0.12	0.45	0.68
	KIN	2	7	3.1	1.5	5.1	135.5	0.30	0.51	0.31
	TAG	2	7	3.9	1.5	6.3	266.4	0.58	0.04	0.01
2	TAN	1	8	2.2	1.3	3.5	44.5	0.13	0.22	0.47
	KIN	1	8	2.9	1.4	5.4	131.4	0.37	0.47	0.36
	TAG	1	6	3.4	1.6	6.0	179.7	0.51	0.31	0.17
	TAN	2	8	2.3	1.3	3.7	52.2	0.14	0.54	0.25
	KIN	2	7	2.8	1.3	4.3	78.6	0.21	0.42	0.73
	TAG	2	7	3.5	1.7	6.6	239.1	0.65	0.04	0.02
3	TAN	1	8	1.7	1.2	2.3	16.4	0.06	0.05	0.22
	KIN	1	6	2.8	1.4	4.7	76.5	0.28	0.76	0.70
	TAG	1	7	3.2	1.3	7.1	179.7	0.66	0.19	0.08
	TAN	2	5	2.0	1.3	2.8	17.9	0.07	0.14	0.50
	KIN	2	7	2.7	1.4	4.9	93.0	0.38	0.49	0.33
	TAG	2	4	3.6	1.5	6.5	136.2	0.55	0.37	0.17
4	TAN	1	4	1.5	1.2	1.5	3.9	0.01	0.07	0.69
	KIN	1	5	3.1	1.4	4.8	83.0	0.22	0.58	0.26
	TAG	1	7	3.5	1.8	7.2	292.7	0.77	0.35	0.05
	TAN	2	8	2.1	1.3	3.9	43.3	0.10	0.29	0.65
	KIN	2	7	3.3	1.7	6.0	201.0	0.46	0.59	0.29
	TAG	2	5	3.5	1.5	8.0	188.8	0.44	0.12	0.06

Appendix 6.1 Continued

^A Summer data^B Autumn dataTAN - *Salix matsudana* x *alba* clone 'Tangoio'KIN - *Salix kinuyanagi*TAG - *Chamaecytisus palmensis*

BPO, proportion of browsing observations

Species foliage abundance (SFA) = foliage volume (FV) * foliage density score (FD) * number of trees (t)

Foliage volume is estimated on the assumption that the tree canopy is an inverted cone using the formula:

$$FV = \pi/3 * CD^2/4 * H$$

Where $\pi = 3.14$

CD, crown diameter

H, mean height of trees per row

Appendix 6.2: Interaction between pre- (16 months) and post-browsing biomass of the *Salix* spp. and *Chamaecytisus palmensis* between 6 February and 20 December 1996 (Experiment 1).

		BIOMASS (kg DM/tree)				
		Leaf DM	Edible stem DM	Woody stem DM	Total edible DM	Total DM
SPECIES	Browsing stage					
<i>Salix matsudana</i> x <i>alba</i>	Pre-browsing	0.4 ^c	0.1	0.3	0.5	0.8
	Post-browsing	0.6 ^c	0.2	0.8	0.8	1.6
<i>Salix kinuyanagi</i>	Pre-browsing	0.3 ^c	0.02	0.3	0.3	0.6
	Post-browsing	0.8 ^{ab}	0.1	1.1	0.9	2.0
<i>Chamaecytisus palmensis</i>	Pre-browsing	0.7 ^{ab}	0.2	0.7	0.9	1.6
	Post-browsing	1.0 ^a	0.3	0.8	1.2	2.0
SEM		0.1	0.03	0.1	0.1	0.2
Significance		*	NS	NS	NS	NS

Means in a column followed by the same letters are not significantly different at 5% significance level