The role of plants containing secondary compounds in sustainable deer farming – a review

S. O. HOSKIN, T. N. BARRY and P. R. WILSON
College of Sciences, Massey University, PN 452, Private Bag 11222, Palmerston North
S.O.Hoskin@massey.ac.nz

Abstract

The productivity and health of farmed deer is improved by substituting perennial ryegrass-based pasture with forages containing condensed tannins (CT) and/or sesquiterpene lactones. Benefits have included improved lactation, growth, trace element status, resilience to internal parasites and reductions in parasite larval development. Forages evaluated for deer include the forage legumes sulla and birdsfoot trefoil, which contain CT, and the herb chicory, which contains both CT and sesquiterpene lactones. Autumn grazing of weaner deer on chicory has shown growth can be increased whilst anthelmintic requirement reduced compared to grazing of perennial ryegrass/ white clover pasture. The importance of secondary compounds relative to other nutritive characteristics of alternative forage species, such as low fibre and highly digestible carbohydrate concentrations, have not been fully characterised, but they are likely to contribute to improved deer health. Unlike sheep and cattle, deer produce salivary proteins that bind CT, allowing them to consume plants containing higher CT concentrations than sheep and cattle. The effect of CT upon the digestion and absorption of protein, which has been determined for other domestic ruminants, needs to be measured in deer fed forage diets, to establish if beneficial effects exist. *In vitro* work has shown direct inhibitory effects of CT and sesquiterpene lactones extracted from forages on deer internal parasite larvae. The faeces, rumen and abomasal fluid of deer grazing chicory also contained substances reducing the viability of parasite larvae. Alternative plant species such as chicory, birdsfoot trefoil and forage willows containing secondary compounds will play an important role in low chemical sustainable deer farming.

Keywords: anthelmintic, *Cichorium intybus*, condensed tannins, forage, *Hedysarum coronarium*, internal parasites, protein, red deer

Introduction

The role of forages for deer production other than perennial ryegrass based pastures, many of which contain secondary plant compounds, has been the subject of two recent reviews by the authors (Barry *et al.* 2002; Wilson *et al.* 2002).

It is important for economic viability and market access that deer farmers continually improve both the level of production and the quality of products produced, with minimal chemical or drug input. A key aspect of sustainability is the relationship between animal health, welfare, production and product quality. In particular, widespread control of internal parasites using synthetic chemicals may be unsustainable in the long term, due to the increasing risk of anthelmintic resistance and the risk or perception of chemical residues in deer products. There is a growing consumer awareness of, and demand for, low-chemical input or 'naturally produced' deer products (Loza 2001). The focus on natural, rather than manufactured dietary supplements to provide essential trace elements and vitamins for farmed animals is increasing.

There is also a growing understanding of "*the complexity of food resources and heterogeneity of natural environments*" (Hanley 1997) from which our farmed deer species originated, both overseas and from within the wilds of New Zealand (NZ). This contrasts with the simple, homogenous ryegrass/ white clover pasture-based farming system. Deer farming in NZ is based largely on conventional pastoral sheep and beef production systems utilising perennial ryegrass (*Lolium perenne*)/ white clover (*Trifolium repens*) (PRG/WC) pastures. Although deer farmed in this system out-perform feral deer (Moore *et al.* 1988), the mismatch between pasture growth patterns and deer feed demands and seasonal changes in pasture quality spurred research into alternative forage species, originally for venison production (Barry & Wilson 1994). These studies have led to increasing awareness of, and slowly, research into, their influence on deer health, welfare and production, and potentially, environmental enrichment.

Chicory (*Cichorium intybus*) appears to be the forage species most suitable for deer production on a range of soils types across NZ given its relative persistence, ease of establishment and high deer feeding value (Kusmartono 1996). Birdsfoot trefoil (*Lotus corniculatus*) has shown potential for use as a pure species forage crop in drier, east-coast regions with free-draining soils (T.N. Barry pers. comm.) and narrow-leaved plantain (*Plantago lanceolata*) has potential as a means of introducing a persistent CT-containing species as part of permanent pasture (Moorhead *et al.* 2002). Sainfoin (*Onobrychus viciifolia*), sulla (*Hedysarum coronarium*) and lotus major (*Lotus pedunculatus*) have limited potential for use in deer grazing systems due to agronomic limitations such as poor persistence

(P.D. Kemp pers. comm.). Willow species (*Salix* spp.) are likely to be successful forage trees due to ease of planting poles and selection of cultivars for high yield and persistence, however the potential for use of native species as forage trees for deer should not be overlooked.

This paper reviews current and potential roles of plants containing secondary compounds in sustainable deer production systems. In particular, it reviews legumes containing condensed tannins (CT) and herbs containing sesquiterpene lactones that have been evaluated, or have the potential to be used, for *in-situ* forage grazing or supplementary browse feeding of farmed deer in NZ. The focus will be on current research and areas needing further research. Since most research conducted in this area involved red deer (*Cervus elaphus*), this review refers to red deer unless specified otherwise.

Nutritional role of secondary plant compounds

Plant secondary compounds or their metabolites, sometimes referred to as allelochemicals, are prevalent in the plant kingdom. They have effects on ruminants ranging from improved nutrition and health to interference with feed intake, digestion or metabolism of energy or nutrients and acute toxicity and death (Rosenthal & Janzen 1979). Secondary compounds are produced as natural defence mechanisms against pathogenic micro organisms, insects and grazing by herbivores (Swain 1979). The group of secondary compounds best understood for deer is the phenolics, particularly CT (proanthocyanidins) in NZ. Additionally, knowledge about sesquiterpene lactones present in forage chicory is emerging. Many other secondary compounds isolated from forage and browse species are frequently detrimental to ruminant health and production and will not be discussed.

The concentration of the major known secondary compounds in temperate forages suitable for deer and NZ growing conditions are shown in Table 1. Some trees, shrubs and forage legumes such as sulla and lotus major contain concentrations of CT that are considered too high or only marginally acceptable for sheep and cattle. Perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), red clover (*Trifolium pratense*) and lucerne (*Medicago sativa*) contain only traces of CT that are too low to have a nutritional benefit.

Condensed tannins, in contrast to most other phenolics, are beneficial to ruminant animal production at low to medium concentrations, especially in NZ where pastures have high soluble protein concentrations. Condensed tannins bind strongly to protein in a pH-dependant manner (Asquith & Butler 1986). Condensed tannins are not absorbed from the digestive tract (Terrill *et al*. 1994). Medium CT concentrations in birdsfoot trefoil reduce rumen degradability of protein and increase amino acid absorption from the small intestine (Bermingham *et al*. 2001; Waghorn *et al*. 1994). In field experiments this increased reproductive rate (Min *et al*. 1999, 2001), wool growth, milk secretion and liveweight gain of sheep (Wang *et al*. 1996a,b). However, CT chemical structure and molecular mass, which vary between plant species,

Table 1 The concentration of secondary compounds (g/kg DM) in forages grown in New Zealand (adapted from Barry *et al.* 2002 and unpublished).

Plant	Total condensed tannins	Other major secondary compounds
Grasses		
Perennial ryegrass* (*Lolium perenne*)	Trace	Endophyte alkaloids
Annual ryegrass* (*Lolium multiflorum*)	3-4	
Yorkshire fog (*Holcus lanatus*)	4-5	
Legumes		
Sulla* (*Hedysarum coronarium*)	30-100	
Birdsfoot trefoil* (*Lotus corniculatus*)	15-25	
Lotus major (*Lotus pedunculatus*)	50-70	
Lucerne* (*Medicago sativa*)	Trace	Coumestans
Red clover* (*Trifolium pratense)*	Trace	Iso-flavones
Herbs		
Chicory* (*Cichorium intybus*)	4-5	Sesquiterpene lactones (3.6)
Sheep's burnet (*Sanguisorba minor*)	3-4	
Plantain (*Plantago lanceolata*)	12-16	Iridoid glycosides
Trees & shrubs		
Tree willow* (*Salix matsudana x alba*)	29	Phenolic glycosides
Osier willow* (*Salix viminalis*)	66	Phenolic glycosides
Kinuyanagi willow (*S. kinuyanagi*)	274	Phenolic glycosides
Dorycnium rectum (leaf)	200	
Veronese poplar (*Populus deltoids x nigra*)	10	Phenolic glycosides

*Evaluated for deer feeding

also appear to influence astringency (and hence feed intake) and the effectiveness of CT in precipitating protein in the rumen and increasing absorption of essential amino acids from the small intestine in sheep (Aerts *et al.* 1999; Barry & McNabb 1999; Waghorn *et al.* 1994). Similar research has not been conducted in deer.

For sheep, CT concentrations above about 35-40 g/kg DM (depending on plant species and type of CT) have resulted in reduced voluntary feed intake and reduced dry matter digestibility (Barry & Duncan 1984; Barry & McNabb 1999). Deer have evolved production of CT-binding proline-rich salivary proteins, as a means of counteracting plant defence mechanisms against herbivory and the anti-nutritional effects of high CT concentrations, probably due to their browsing habits and may tolerate higher concentrations or more astringent CT than sheep or cattle. No such proteins have been found in the saliva of domesticated sheep and cattle (Austin *et al.* 1989).

In NZ, sambar deer (*Cervus unicolor*) were shown to have a higher CT binding capacity of salivary proteins than red deer, corresponding to a greater dietary preference for browse species containing high concentrations of CT for sambar compared with red deer (Semiadi *et al.* 1995). These salivary proteins can have a high specificity for binding to CT only present in the normal diet (Hagerman & Robbins 1993). However, the extent to which the production of these binding proteins might change, for example, as dietary CT concentrations or structure in the diet selected change with season is not known.

Barry & McNabb (1999) suggest that the beneficial nutritional effects of dietary CT could only occur if the ruminant species concerned does not produce salivary CT-binding proteins. They also suggest that the opportunity for manipulation of nitrogen digestion in deer may be less than in sheep and cattle that don't produce CT-binding salivary proteins. This might be the case for forages with low CT concentrations, where most of the free CT is more likely to be bound up by salivary proteins. It is less likely for plant species with medium to high CT concentrations, when the concentration of CT in the diet exceeds the capacity of the salivary proteins for binding. This relationship may also vary according to the CT-binding capacity of the saliva produced by the deer species concerned, with sambar deer likely to need a diet higher in CT than red deer for nutritional benefits of CT to be seen. Also, given the specificity of CT-protein bonds, not all CT present in forages are likely to be bound to the same extent by salivary proteins. Therefore it is clear that the effect of CT upon the digestion and absorption of protein needs to be determined for deer fed forage diets. The significance of salivary binding of dietary CT on rumen degradation of protein and absorption in the small intestine also needs to be determined in deer.

The ability of CT in forage legumes to bind to soluble protein in the rumen reduces the incidence of frothy bloat, an important role of CT in diets of sheep and cattle. However, the high rumen outflow rate of liquid in deer (Domingue *et al.* 1991) means deer appear not to be susceptible to bloat.

Recent research showed feeding forages containing CT reduced methane emissions from dairy cows without compromising milk solids production (Woodward *et al.* 2002) and reduced methane production by sheep (Waghorn *et al.* 2002). Therefore another potential, unexplored role of CT-containing forages in sustainable deer production may be to reduce methane emissions.

The role of alternative forage and browse species in deer production systems

Research into forages for deer has centred on species with high nutritive value that produce more dry matter during the late spring, summer and autumn periods. This coincides with peak nutrient demand for lactation which is after peak pasture production in most environments. Deer production from perennial ryegrass-based swards is limited during late spring to autumn, due to slow growth in dry conditions and/or lower nutritive value (Barry & Wilson 1994).

Most alternative forages evaluated for deer coincidentally contain significant levels of secondary compounds. Condensed tannin levels in some plants fed successfully to deer (e.g. sulla 84 g/kg DM CT, Hoskin *et al.* 1999b) can be deleterious to other ruminant livestock (Barry & McNabb 1999). Grasslands Puna chicory has received most attention, but, red clover, birdsfoot trefoil and sulla have increased growth of young deer in comparison with that on PRG/WC pasture (Adu *et al.* 1998; Hoskin *et al.* 1999a,b; 2000; Kusmartono *et al.* 1996; Min *et al.* 1997; Niezen *et al.* 1993; Semiadi *et al.* 1993; Soetrisno *et al.* 1994). Their increased feeding value is largely attributed to increased voluntary feed intake and digestibility (Barry *et al.* 1998a).

Red deer prefer legumes (many containing CT) and chicory (containing CT and lactones) over PRG/WC pastures (Hunt & Hay 1990; Scott 1989). Sambar deer prefer browse species such as willow (Semiadi *et al.* 1995). Red deer are classified as intermediate feeders, adapting well to browse and to forage grazing (Kay & Staines 1981; Hoffman 1985). Fallow deer (*Dama dama*) are classified as intermediate feeders tending to bulk feeders, with grasses the predominant food source. They appear to be more selective grazers than red deer (Putman 1986; Kerridge & Bullock 1991).

Genotype x nutrition interactions have been shown with different forage diets, with growth of young ¼ wapiti (*Cervus elaphus canadensis*): ¾ red deer exceeding growth of pure red deer to a greater extent whilst grazing chicory compared with PRG/WC pasture (Kusmartono *et al.* 1996). The increased nutrient supply from chicory allowed the greater growth potential of the crossbred deer to be expressed. Therefore, when evaluating different plant species, it is important to consider the species of deer, their foraging habits and preferences, and the likely magnitude of response.

A significant deer health advantage contributing to sustainability of the system may be through higher essential trace elements in alternative forages. Chicory contains a higher concentration of most minerals than PRG/WC pasture (Barry *et al.* 2001). After autumn grazing of Grasslands Puna chicory, deer liver copper and vitamin B12, and blood selenium concentrations were significantly higher than those grazing conventional pasture (Barry *et al.* 2001; Wilson & Grace 2002; Wilson unpublished). In addition, after winter when all deer were combined on pasture, despite no significant difference in mean liver copper levels of deer having grazed either chicory or pasture during autumn, significantly fewer deer having grazed chicory in autumn were at risk of copper deficiency (Grace *et al.* 2003). This aspect of forages and deer health is currently under further investigation. Studies to date highlight the largely unexplored potential of natural dietary components in meeting deer health requirements in a sustainable manner, using reduced or zero chemical inputs. The added benefit of reducing trace element supplementation also contributes to the cost-effectiveness of alternative plant species.

Feeding value of forage legumes and herbs containing secondary plant compounds for farmed deer

Other than studies of diet selection of red (Hunt & Hay 1990; Scott 1989) and red versus sambar deer (Semiadi *et al.* 1995), little research has been conducted into the feeding value of forages or browse containing CT, or significant quantities of other known beneficial secondary compounds, specifically for NZ farmed deer. Furthermore, most research has taken place on a single property at Massey University, Palmerston North. Grasslands Puna chicory has been evaluated in a number of trials over several years, but red clover, birdsfoot

Table 2 Feeding value (indicated by seasonal liveweight gains, carcass weights and proportion of stags reaching 50kg carcass weight at 12 months of age) of forage species for red deer determined from studies conducted at Massey University, Palmerston North (Barry *et al.* 1998b).

Perennial Ryegrass/White Clover Pasture 10cm (9 studies)	Chicory (5 studies)	Red Clover (4 studies)	Sulla (1 study)	Birdsfoot Trefoil (2 studies)
Growth of stag and hind calves from birth to weaning in late February (g/d)*				
333		433 (30)		
331	385 (16)	410 (24)		
351	404 (16)			
399				485 (22)
Growth of stags during autumn (g/d)*				
178	246 (38)			
152	235 (55)			
176				248 (41)
192		263 (37)		
207		237 (14)		
224	154 (-45)		315 (41)	
Growth of stags during spring (g/d)*				
260	255 (-2)			
285	335 (18)			
292				279 (-5)
341		354 (4)		
281		346 (23)		
289	344 (20)		333 (15)	
Mean carcass weight of stags at 12 months (kg)*				
53.8	56.4 (5)	59.6 (11)	63.1 (17)	
Mean % (*range*) of stags reaching 50kg carcass at 12 months				
78 (*25-100*)	87 (*80-100*)	100	100	

*Values in brackets are % increases compared with grazing perennial ryegrass / white clover pasture.

trefoil and sulla have been evaluated in 1-2 grazing seasons. A summary of the relative feeding value of forages containing secondary compounds evaluated for deer on the Massey University Deer Research Unit is presented in Table 2. It is not known what the contribution of the secondary compound *per se* is to the feeding value observed.

Secondary plant compounds and internal parasitism in deer

A range of known plant secondary compounds are present in plant species currently fed, or suitable for feeding to, farmed deer in NZ. In addition to knowing little about the majority of the known compounds, other than generalised antioxidant (Duke 1992), anti-bacterial and -fungal roles (Barry & Blaney 1987), there are many compounds as yet unidentified. Internal parasites, particularly lungworm and abomasal nematodes, are significant contributors to production loss and risk of mortality in young farmed deer in NZ (Charleston 2001). A summary of work with forages containing CT and sesquiterpene lactones is presented here.

There are direct and indirect mechanisms by which forages containing secondary compounds may potentially reduce infection or ameliorate internal parasitism in ruminants. Plant chemicals may have direct inhibitory effects by binding to the parasites themselves in the digestive tract or faeces of the animal. The indirect effects of CT improving protein status of the host could increase the animal's tolerance of worm burdens. Further, plant morphology and sward structure may also influence the free-living stages of the parasites. The relative contribution of direct and indirect mechanisms has not been investigated.

Effects of grazing and feeding forages containing secondary compounds on internal parasitism

Most forage evaluations for grazing deer have employed routine 3 or 4–weekly anthelmintic treatment to eliminate the potentially confounding effect of internal parasites. When anthelmintic was given in response to pre-determined levels of faecal egg or larvae counts or clinical signs were observed (trigger treatment), weaner deer grazing chicory did not require treatment during autumn, whereas clinical signs of lungworm, reduced voluntary feed intake and liveweight gains were observed in pasture-grazed weaners (Table 3; Hoskin *et al.* 1999a). This work is being repeated, with treatment criteria based on individual animal, rather than the group basis employed previously. A sub-sample of weaners were slaughtered for nematode counts at the end of the autumn grazing season in late May 2002, and preliminary results are presented in Table 4. This confirmed that grazing chicory in autumn negates the reductions in weaner liveweight gain attributable to sub-clinical parasitism. It prevented clinical parasitism seen in untreated pasture-grazed weaners. Mean adult lungworm numbers in pasture-grazed weaners in late May were twice that of chicory-grazed weaners.

Indoor study of weaner deer artificially infected with lungworm and gastrointestinal parasites and fed either fresh harvested lucerne (negligible or trace CT), birdsfoot trefoil (19 g/kg DM CT) or sulla (35 g/kgDM CT) (Table 5) showed a negative linear relationship between dietary CT concentration and abomasal nematode numbers (Hoskin *et al.* 2000; Equation 1).

Table 3 Voluntary food intake (VFI), liveweight gain (LWG) and carcass weight of weaner deer grazing perennial ryegrass/white clover pasture and Grasslands Puna chicory and treated 3-weekly with anthelmintic* or treated on a group basis of production loss of clinical signs of parasitism (Hoskin *et al.* 1999).

	Pasture		Chicory		SE
	Treated[1] 3-weekly	Trigger[2] Treated	Treated[1] 3-weekly	Trigger[2] Treated	
VFI (kgOM/d)					
Autumn	1920a	835[#]b	1015a	1150[#]a	127.3
Spring	1539	1739	1765	1631	55.2
LWG (g/d)					
Autumn	217a	125b	184a	212a	8.7
Winter	133	138	115	95	7.4
Spring	249a	238a	288b	291b	12.4
Carcass weight (kg)					
12 months of age	57.9a	51.3b	57.1a	57.0a	1.37

*Oral ivermectin was the anthelmintic used.
a, b: different letters denote significant differences ($P < 0.05$) within rows.
[#]VFI was measured prior to anthelmintic treatment being given to these groups.
[1] Anthelmintic treated at 3 weekly intervals.
[2] Anthelmintic withdrawn until trigger criteria were reached.

Table 4 Preliminary data (not statistically validated) on the proportion of deer requiring anthelmintic treatment, average liveweight gain and number of adult lungworm recovered from weaner deer grazing perennial ryegrass/ white clover pasture or Grasslands Puna chicory during the autumn and either treated 4-weekly with anthelmintic* or individually treated on the basis of production loss or clinical signs of parasitism (trigger-treated) (Hoskin *et al.* 2002 unpublished).

	Pasture (n=34)	Chicory (n=34)
	% requiring anthelmintic treatment	
Trigger-treated	35	0
	Average liveweight gain (g/d ± SD; 18 Mar-20 May)	
Treated 4-weekly	136 (±65.0)	207 (±75.1)
Trigger-treated	67 (±63.5)	181 (±67.8)
	No adult lungworm at slaughter on 20 May (range)	
Treated 4-weekly	1 (0-4)	0 (0)
Trigger-treated	643 (142-1276)	311 (52-536)

*Topical moxidectin was the anthelmintic used for deer treated 4-weekly. Combination oral ivermectin and oxfendazole were the anthelmintics used for trigger treated deer.

Equation 1 $AN = 3309 - 315CT$

$SE = \pm 181.9; \pm 79.2$

$r^2 = 0.914$, $P=0.002$

AN = group mean abomasal nematode count

CT = dietary condensed tannin concentration, % DM

If this relationship applied to higher CT concentrations than used in that study, then the ability of deer to cope with very high tannin diets due to salivary binding of CT might mean the potential use of forage CT to control internal parasites by direct rather than nutritional effects in deer may be much greater than in other ruminants.

One mechanism by which CT may enhance the tolerance of deer to internal parasitism by improving amino acid supply to the small intestine (Coop & Kyriazakis 1999). This could counteract protein losses caused by gut parasitism (Kimambo *et al.* 1988) that lead to reduced nitrogen retention (Bown *et al.* 1991) and also better meet the amino acid demands of the immune system. Increased resilience and immunogenic responses of sheep to internal parasitism whilst fed sulla compared with lucerne has been demonstrated (Niezen *et al.* 1995; 2002).

Moss & Vlassoff (1993) seeded different herbage species with strongylate eggs from sheep and recovered fewer nematode larvae in the grazing zone from chicory than from grass. Forage herbs and legumes have a taller growth habit compared with grasses, and hence fewer infective larvae appear to migrate to the stratum consumed by grazing animals. However, effect of plant morphology and sward conditions on development and intake of infective larvae in grazing deer needs to be investigated in deer.

Table 5 Mean voluntary food intake (VFI) and liveweight gain (LWG), number of nematodes recovered at slaughter, and faecal lungworm larval and gastrointestinal egg counts of parasite-naïve deer fed lucerne (0.1% CT), birdsfoot trefoil (1.9% CT) and sulla (3.5% CT) and trickle infected 3-weekly with internal parasite larvae for 5 weeks, then slaughtered at 7 weeks (Hoskin *et al.* 2000).

	Lucerne	Birdsfoot trefoil	Sulla	SEM
VFI (kg OM/d)	1.15	1.08	1.22	0.05
LWG (g/d)	49.4a	62.0ab	99.2b	14.5
No. lungworm	280	254	211	47.7
Total abomasal nematodes	3347a	2555ab	2290b	312
Faecal larval count/g faeces	1039	462	242	328
Faecal egg count/g faeces	210	140	167	

a, b: different letters denote significant differences (P < 0.05)

Research into direct anthelmintic effects of secondary compounds

Quebracho extract (*Schinopsis* sp.; containing CT) fed to sheep directly inhibited gastrointestinal parasites (Athanasiadou *et al.* 2001). CT extracted from lotus major, birdsfoot trefoil, sulla and sainfoin also showed direct inhibitory effects on the developmental first (L1) and infective third (L3) stages of deer lungworm (*Dictyocaulus* sp.) and the infective third (L3) stage of mixed species of deer gastrointestinal nematode larvae cultured from deer faeces (Molan *et al.* 2000b). Relative ranking of apparent anthelmintic activity of CT extracted from the forage legumes against all larvae was sainfoin > lotus major > sulla > birdsfoot trefoil. To the authors' knowledge, sainfoin and lotus major have never been evaluated with grazing deer, probably due to agronomic limitations, but this result suggests their use as specialist feed supplements for deer parasite control should be evaluated.

The effects of CT extracted from seven plant species on egg hatching and larval development of *Trichostrongylus colubriformis* from sheep, also found in deer, was determined *in-vitro* (Molan *et al.* 2002). The CT from dock (*Rumex obtusifolius*) had the greatest inhibitory effect on egg development, followed by CT from *Dorycnium rectum*, sainfoin, *Dorycnium pentaphylum*, lotus major, sulla and birdsfoot trefoil. However deer tend to select against eating dock (S.Hoskin, personal observation).

There was no difference in the hatching of eggs from faeces of deer grazing chicory compared with perennial ryegrass-based pasture (Schreurs *et al.* 2002), but *in vitro* research using sesquiterpene lactones extracted from chicory has shown similar inhibitory properties against deer parasite larvae to CT (Molan *et al.* 2000a). Schreurs *et al.* (2002) showed that faeces, rumen and abomasal fluid of deer grazing chicory contained compounds that inhibited the motility of deer L1 lungworm larvae, while compounds from the same sources from deer grazing PRG/WC did not (Table 6).

and have poor persistence, and would provide an option for including CT in diets of deer on properties with limited flat land for growing crops. Other unexplored options include the use of native species such as broadleaf (*Griselinia* sp.) and mirror plant (*Coprosma* sp.) which are highly suitable for shelter and trimming and may contain desirable secondary compounds. They are highly preferred by wild red and fallow deer in NZ (Nugent 1990; Nugent *et al.* 2001).

However, caution must be advised as to the likely success of mixing dietary CT-containing and non-CT containing plants in a sward or harvested diet, with respect to improving protein supply to the small intestine. It is the free (rather than fibre- or protein-bound) fractions of CT that are most available for binding to dietary or rumen microbial proteins. These free CT react preferentially with proteins originating from the CT-containing temperate forages, rather than with proteins from other plants present in a mixed diet (Beever & Siddons 1986; Barry & McNabb 1999). It appears that beneficial effects of forage mixing would be more likely if the CT content is very high and the protein content relatively low in the CT-containing supplement, allowing release of free CT to bind with proteins from the basal non CT-containing diet. This is likely to occur with legume shrubs like *D. rectum,* but may not occur if low CT-containing willows like osier willow (see below) are used. These nutrition-related processes may be further complicated by binding of free CT in the supplement by deer salivary proteins.

Table 6 The effect of source of faeces (chicory or pasture), source of fluid (chicory or pasture) and type of fluid (rumen or abomasal) upon the viability of deer L1 lungworm larvae as measured *in vitro* by the Larval Migration Inhibition Assay (Schreurs *et al.* 2002).

Forage type deer grazed on to obtain:		**% larvae not passing through sieves**	
Faeces (larvae)	Fluid	Rumen Fluid	Abomasal Fluid
Pasture	Pasture	28a	21a
Pasture	Chicory	40b	30b
Chicory	Pasture	44b	39b
Chicory	Chicory	49b	40b
SEM		2.0	2.0

a, b: different letters denote significant differences between columns (P < 0.01)

The potential of browse feeding for farmed deer

The presence of tannin-binding proteins in deer saliva means there may be greater potential to use browse species containing high CT concentrations for farmed deer than other domestic ruminants.

Evaluation of poplars (*Populus* spp) and willows (*Salix* spp) for supplementary feeding of cattle (Moore *et al.* 2002) and sheep (McWilliam *et al.* 2002 & unpublished) during drought conditions has highlighted a nutritional use for plants used as shelter on farms. This might provide an alternative to stands of specialist CT containing legumes, such as sulla, which are difficult to establish

Investigation into the chemistry of tannin-plant protein and tannin-salivary protein bonds is required when mixed versus single species diets are fed.

Limited data exists on feeding of browse or tree species to farmed deer. McCabe & Barry (1988) fed tree willow (*Salix matsudana* x *alba* 'Wairakei'; 29 g/kgDM CT) and osier willow (*Salix viminalis* 'Gigantea'; 66 g/kgDM CT) as a sole diet to sheep, goats and red deer. Osier willow had a lower nutritive value for sheep and goats than tree willow based on voluntary feed intake, apparent DM digestibility and CT content. Red deer consumed more osier willow than tree willow despite the higher

CT concentration of osier willow, which contradicts the data from sheep and goats (Table 7). This is yet another indication that red deer are able to cope better with higher CT concentrations than sheep and goats.

Current research (Hoskin & Waghorn unpublished) is evaluating supplementary feeding of *D. rectum* to red deer, with deer readily accepting a diet consisting of 20% *D.rectum* (200 g/kg DM CT) and 80% PRG/WC pasture, giving a dietary average CT content of 40 g/kg DM. From an agronomic perspective, Oppong *et al.* (2001) found osier (*S. matsudana x alba*) and kinuyanagi (*S.kinuyanagi*) willows to have greater potential as browse species than *D. rectum* due to their higher yield. However, Douglas & Foote (1994) found *D. rectum* (20t DM/ha) could produce yields exceeding that of lucerne (14t DM/ha).

Table 7 Voluntary feed intake and CT concentration of tree (*Salix matsudana x alba*) and osier (*Salix viminalis*) willow by sheep, goats and red deer, expressed relative to that of lucerne hay (McCabe & Barry 1988).

	Tree willow	Osier willow
CT (g/kg DM)	29	66
Voluntary feed intake relative to lucerne hay		
Sheep	0.71	0.6
Goats	1.34	1.18
Deer	0.85	1.00

Conclusions and future challenges

Research into effects of forages containing CT and sesquiterpene lactones, on internal parasites has highlighted an important potential role in sustainable deer production systems. Improved health and productivity, and reduced chemical input provide more ecologically sustainable and consumer-friendly deer management practices.

However, further research is needed to evaluate the following:

1. The effect of CT upon the digestion of protein and absorption of amino acids in deer fed forage and browse diets.
2. The salivary protein CT-binding capacity in farmed deer fed forage diets needs to be determined, including its variability with diet and whether this phenomenon is likely to limit the opportunities for manipulation of nitrogen digestion by CT or anthelmintic effects of CT, and whether it is likely to result in deer consuming higher CT-containing plants.
3. The relative contributions of secondary compound mediated direct anthelmintic effects, compared with indirect nutritional, plant morphological and sward structure effects on reduction of production losses attributable to internal parasitism in deer fed alternative forage species.
4. The feeding value and benefits to deer health of feeding lotus major, sainfoin, plantain and other potential new forages containing secondary compounds need to be determined.
5. The secondary compounds are present in poplar, willow and NZ native tree and shrub species potentially suitable for shelter / browse on deer farms needs to be measured and their effects upon deer health and productivity determined. If shown to be beneficial, their integration into deer farming systems would require evaluation.

Confirmation and validation of research centre findings in commercial farming environments, and their application to deer production systems are essential prerequisites to adoption by deer producers.

REFERENCES

Adu, E.K.; Barry, T.N.; Wilson, P.R.; Kemp, P.D. 1998. Evaluation of *Lotus corniculatus* for increasing pre-weaning growth of red and hybrid deer. *Journal of Agricultural Science, Cambridge 131*: 197-204.

Aerts, R.J.; McNabb, W.C.; Molan, A.L.; Brand, A.; Peters, J.S.; Barry, T.N. 1999. Condensed tannins from *Lotus corniculatus* and *Lotus pedunculatus* effect the degradation of ribulose 1,5-bisphosphate carboxylase (Rubisco) protein in the rumen differently. *Journal of the Science of Food and Agriculture 79*: 79-85.

Asquith, T.N.; Butler, L.G. 1986. Interactions of condensed tannins with selected proteins. *Phytochemistry 25*: 1591-1593.

Athanasiadou, S.; Kyriazakis, I.; Jackson, F.; Coop, R.L. 2001. Direct anthelmintic effects of condensed tannins towards different gastrointestinal nematodes of sheep: *in vitro* and *in vivo* studies. *Veterinary Parasitology 99*: 205-219.

Austin, P.J.; Suchar, L.A.; Robbins, C.T.; Hagerman, A.E. 1989. Tannin-binding proteins in the saliva of deer and their absence in saliva of sheep and cattle. *Journal of Chemical Ecology 15*: 1335-1347.

Barry, T.N.; Duncan, S.J. 1984. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. 1. Voluntary intake. *British Journal of Nutrition 51*: 485-491.

Barry, T.N.; Blaney, B.J. 1987. Secondary compounds of forages. pp. 91-119. *In*: Nutrition of Herbivores. Eds. Hacker, J.B.; Ternouth, J.H. Academic Press, Australia.

Barry, T.N.; McNabb, W.C. 1999. The implications of condensed tannins on the nutritive value of temperate forages fed to ruminants. *British Journal of Nutrition*

81: 263-272.

Barry, T.N.; Wilson, P.R. 1994. Review: Venison production from farmed deer. *Joumal of Agricultural Science, Cambridge 123*: 159-165.

Barry, T.N.; Wilson, P.R.; Semiadi, G. 1998a. Growth, voluntary feed intake and digestion in farmed temperate and tropical deer. *Acta Veterinaria Hungarica 46*: 369-380.

Barry, T.N.; Wilson, P.R.; Kemp, P.D. 1998b. Management of grazed pastures and forages for optimum deer production. *Proceedings of the 2nd World Deer Farming Congress, Limerick, Ireland* 141-160.

Barry, T.N.; Molan, A.L.; Wilson, P.R.; Lopez-Villalobos, N.; Schreurs, N.M.; Duncan, J.A. 2001. Chicory as an alternative forage for deer health. *Proceedings of a Deer Course for Veterinarians, Deer Branch of the New Zealand Veterinarians Association 18*: 122-127.

Barry, T.N.; Hoskin, S.O.; Wilson, P.R. 2002. Novel forages from growth and health in farmed deer. *New Zealand Veterinary Journal* (In Press).

Beever, D.E.; Siddons, R.C. 1986. Digestion and metabolism in the grazing ruminant. pp. 479-497. *In*: Control of Digestion and Metabolism in Ruminants. Eds. Milligan, L.P.; Grovum, W.L. and Dobson, A. Englewood Cliffs, NJ: Prentice Hall.

Bermingham, E.N.; Hutchinson, K.J.; Revell, D.K.; Brookes, I.M.; McNabb, W.C. 2001. The effects of condensed tannins in sainfoin and sulla on the digestion of amino acids in sheep. *Proceedings of the New Zealand Society of Animal Production 61*: 116-119.

Bown, M.D.; Poppi, D.P.; Sykes, A.R. 1991. The effect of post-ruminal infusion of protein or energy on the pathophysiology of *Trichostrongylus colubriformis* infection and body composition in lambs. *Australian Journal of Agricultural Research 42*: 253-267.

Charleston, W.A.G. 2001. Review of deer anthelmintics. *Proceedings of a Deer Course for Veterinarians, Deer Branch of the New Zealand Veterinarians Association 18*: 144-152.

Coop, R.L.; Kyriazakis, I. 1999. Nutrition – parasite interactions. *Veterinary Parasitology 84*:187-204.

Domingue, B.M.F.; Dellow, D.W.; Wilson, P.R.; Barry, T.N. 1991. Comparative digestion in deer, goats and sheep. *New Zealand Journal of Agricultural Research 34*: 45-53.

Douglas, G.B.; Foote, A.G. 1994. Establishment of perennial species useful for soil conservation. *Proceedings of the New Zealand Grassland Association 45*: 239-242.

Duke, J.A. 1992. Handbook of Biologically Active Phytochemicals and their Activities. CRC Press, Boca Raton, London, Tokyo.

Grace, N.D.; Wilson, P.R.; Nicol. A. 2003. The copper nutrition of grazing deer. *The nutrition and management of deer on grazing systems. Grassland Research and Practice Series 9:* 113-120.

Hagerman, A.E.; Robbins, C.T. 1993. Specificity of tannin-binding salivary proteins relative to diet selection in mammals. *Canadian Journal of Zoology 71*: 628-633.

Hanley, T.A. 1997. A nutritional view of understanding and complexity in the problem of diet selection by deer (Cervidae). *Oikos 79*: 209-218.

Hoffman, R.R. 1985. Digestive physiology of the deer – their morphophysiological specialisation and adaptation. pp 393-407. *In*: Biology of Deer Production. Eds. Fennessy P.F.; Drew K.R. The Royal Society of New Zealand Bulletin 22.

Hoskin, S.O.; Barry, T.N.; Wilson, P.R.; Charleston, W.A.G.; Hodgson, J. 1999a. Effect of reducing anthelmintic input upon growth and faecal egg and larvae counts in young farmed deer grazing chicory and perennial ryegrass/ white clover pasture. *Journal of Agricultural Science, Cambridge 132*: 335-345.

Hoskin, S.O.; Barry, T.N.; Wilson, P.R.; Charleston, W.A.G.; Kemp, P.D. 1999b. Growth and carcass production of young farmed deer grazing sulla, chicory or perennial ryegrass/white clover pasture in New Zealand. *New Zealand Journal of Agricultural Research 42*: 83-92.

Hoskin, S.O.; Wilson, P.R.; Barry, T.N.; Charleston, W.A.G.; Waghorn, G.C. 2000. Effect of forage legumes containing condensed tannins on lungworm and gastrointestinal parasitism in young red deer. *Research in Veterinary Science 68*: 223-230.

Hunt, W.F.; Hay, R.J.M. 1990. A photographic technique for assessing the pasture species preference of grazing animals. *Proceedings of the New Zealand Grassland Association 51*: 191-196.

Kay, R.N.B.; Staines, B.W. 1981. The nutrition of the red deer (*Cervus elaphus*). *Nutrition Abstracts and Reviews, Series B 51*: 601-622.

Kerridge, F.J.; Bullock, D.J. 1991. Diet and dietary quality of red deer and fallow deer in late summer. *Journal of Zoology, London 224*: 333-337.

Kimambo, A.E.; MacRae, J.C.; Walker, A.; Watt, C.F.; Coop, R.L. 1988. The effect of prolonged subclinical infection with *Trichostrongylus colubriformis* on the performance and nitrogen metabolism of growing lambs. *Veterinary Parasitology 28*: 191-203.

Kusmartono; Barry, T.N.; Wilson, P.R.; Kemp, P.D.; Stafford, K.J. 1996. Effects of grazing chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture upon the growth and voluntary feed intake of red and hybrid deer during lactation and post-weaning growth. *Journal of Agricultural Science, Cambridge 127*: 387-401.

Kusmartono. 1996. Nutritive value of chicory (*Cichorium intybus*) as a special purpose forage for deer production. PhD thesis, Massey University, New Zealand.

Loza, M.J. 2001. Sensitive issues for the deer industry. *Proceedings of a Deer Course for Veterinarians, Deer Branch of the New Zealand Veterinarians Association 18*: 73-78.

McCabe, S.M.; Barry, T.N. 1988. Nutritive value of willow (*Salix* sp.) for sheep, goats and deer. *Journal of Agricultural Science, Cambridge 111*: 1-9.

McWilliam, E.L.; Barry, T.N.; Kemp, P.D.; Lopez-Villalobos; Cameron, P.N. 2002. Responses to poplar supplementation in ewes grazing drought pasture during mating. *Proceedings of the New Zealand Society of Animal Production 62*: 174-176.

Min, B.R.; Barry, T.N.; Wilson, P.R.; Kemp, P.D. 1997. The effects of grazing chicory and birdsfoot trefoil on venison and velvet production by young red and hybrid deer. *New Zealand Journal of Agricultural Research 40*: 335-347.

Min, B.R.; McNabb, W.C.; Barry, T.N.; Kemp, P.D.; Waghorn, G.C.; McDonald, M.F. 1999. The effect of condensed tannins in *Lotus corniculatus* upon reproductive efficiency and wool production in sheep during late summer and autumn. *Journal of Agricultural Science, Cambridge 132*: 323-334.

Min, B.R.; Fernandez, J.M.; Barry, T.N.; McNabb, W.C.; Kemp, P.D. 2001. The effect of condensed tannins in *Lotus corniculatus* upon reproductive efficiency and wool production in ewes during autumn. *Animal Feed Science and Technology 92*:185-202.

Molan, A.L.; Duncan, A.; Barry, T.N.; McNabb, W.C. 2000a. Effect of condensed tannins and sesquiterpene lactones extracted from chicory on the viability of deer lungworm larvae. *Proceedings of the New Zealand Society of Animal Production 60*: 26-29.

Molan, A.L.; Hoskin, S.O.; Barry, T.N.; McNabb, W.C. 2000b. Effect of condensed tannins extracted from four forages on the viability of the larvae of deer lungworm and gastrointestinal nematodes. *The Veterinary Record 147*: 44-48.

Molan, A.L.; Waghorn, G.C.; McNabb, W.C. 2002. Effect of condensed tannins on egg hatching and larval development of *Trichostrongylus colubriformis* in vitro. *The Veterinary Record 150*: 65-69.

Moore, G.H.; Littlejohn, R.P.; Cowie, G.M. 1988. Liveweights, growth rates and mortality of farmed red deer at Invermay. *New Zealand Journal of Agricultural Research 31*: 293-300.

Moore, K.M.; Barry, T.N.; Cameron, P.N.; Lopez-Villalobos, N.; Cameron, D.J. 2002. Willow (*Salix* sp.) as a supplement for grazing cattle under drought conditions. *Animal Feed Science and Technology* (*In Press*).

Moorehead, A.J.E.; Judson, H.G.; Stewart, A.V. 2002. Liveweight gain of lambs grazing 'Ceres Tonic' plantain (*Plantago lanceolata*) or perennial rygrass (*Lolium perenne*). *Proceedings of the New Zealand Society of Animal Production 62*: 171-173.

Moss, R.A.; Vlassoff, A. 1993. Effect of herbage species on gastrointestinal roundworm populations and their distribution. *New Zealand Journal of Agricultural Research 36*: 371-375.

Niezen, J.H.; Barry, T.N.; Hodgson, J.; Wilson, P.R. Ataja, A.M.; Parker, W.J.; Holmes, C.W. 1993. Growth responses in red deer calves and hinds grazing red clover, chicory and perennial ryegrass/white clover swards during lactation. *Journal of Agricultural Science, Cambridge 121*: 255-263.

Niezen, J.H.; Waghorn, T.S.; Charleston, W.A.G.; Waghorn, G.C. 1995. Growth and gastrointestinal nematode parasitism in lambs grazing either lucerne or sulla which contains condensed tannins. *Journal of Agricultural Science, Cambridge 125*: 281-289.

Niezen, J.H.; Waghorn, T.S.; Charleston, W.A.G. 1998. Establishment and fecundity of *Ostertagia circumcincta* and *Trichostrongylus colubriformis* in lambs fed lotus (*Lotus pedunculatus*) or perennial ryegrass (*Lolium perenne*). *Veterinary Parasitology 78*: 13-21.

Niezen, J.H.; Charleston, W.A.G.; Robertson, H.A.; Shelton, D.; Waghorn, G.C.; Green, R. 2002. The effect of feeding sulla (*Hedysarum coronarium*) or lucerne (*Medicago sativa*) on lamb parasite burdens and development of immunity to gastrointestinal nematodes. *Veterinary Parasitology 105*: 229-245.

Nugent, G. 1990. Forage availability and the diet of fallow deer (*Dama dama*) in the Blue Mountains, Otago. *New Zealand Journal of Ecology 13*: 83-95.

Nugent, G, Fraser, K.W.; Asher, G.W.; Tustin, K.G. 2001. Advances in New Zealand mammalogy 1990-2000: Deer. *Journal of the Royal Society of New Zealand 31*: 263-298.

Oppong, S.K.; Kemp, P.D.; Douglas, G.B.; Foote, A.G. 2001. Browse yield and nutritive value of two *Salix* species and *Dorycnium rectum* in New Zealand. *Agroforestry Systems 51*: 11-21.

Putman, R.J. 1986. Grazing in temperate ecosystems: large herbivores and the ecology of the New Forest. London: Croom Helm.

Rosenthal, G.E.; Janzen, D.H. (Eds.) 1979. Herbivores: their interaction with secondary plant metabolites. Academic Press, New York.

Schreurs, N.M.; Molan, A.L.; Lopez-Villalobos, N.; Barry, T.N.; McNabb, W.C. 2002. Effect of grazing undrenched weaner deer on chicory or perennial ryegrass/ white clover pasture on gastrointestinal nematode and lungworm viability. *Proceedings of the*

New Zealand Society of Animal Production 62: 143-144.

Scott, I. 1989. Pasture preferences of deer. *Proceedings of a Deer Course for Veterinarians, Deer Branch of the New Zealand Veterinarians Association 6*: 176-180.

Semiadi, G.; Barry, T.N.; Wilson, P.R.; Hodgson, J.; Purchas, R.W. 1993. Growth and venison production from red deer (*Cervus elaphus*) grazing red clover (*Trifolium pratense*) or perennial ryegrass (*Lolium perenne*) white clover (*Trifolium repens*) pasture. *Journal of Agricultural Science, Cambridge 121*: 265-271.

Semiadi, G.; Barry, T.N.; Muir, P.D.; Hodgson, J. 1995. Dietary preferences of sambar (*Cervus unicolour*) and red deer (*Cervus elaphus*) offered browse, forage legume and grass species. *Journal of Agricultural Science, Cambridge 125*: 99-107.

Soetrisno, E.; Barry, T.N.; Wilson, P.R.; Hodgson, J.; Purchas, R.W. 1994. Effects of grazing red clover (*Trifolium pratense*) or perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pastures upon growth and venison production from weaner red deer (*Cervus elaphus*). *New Zealand Journal of Agricultural Research 37*: 19-27.

Swain, A. 1979. *In*: Herbivores; Their Interaction with Secondary Plant Metabolites. pp. 657-682. Eds. Rosenthal G.A.; Janzen, D.H. Academic Press, London & New York.

Terrill, T.H.; Waghorn, G.C.; Woolley, D.J.; McNabb, W.C.; Barry, T.N. 1994. Assay and digestion of ^{14}C-labelled condensed tannins in the gastrointestinal tract of sheep. *British Journal of Nutrition 72*: 467-477.

Waghorn, G.C.; Shelton, I.D.; McNabb, W.C.; McCutcheon, S.H. 1994. Effects of condensed tannins in *Lotus pedunculatus* on its nutritive value for sheep. 2. Nitrogenous aspects. *Journal of Agricultural Science, Cambridge 123*: 109-119.

Waghorn, G.C.; Tavendale, M.H.; Woodfield, D.R. 2002. Methanogenesis from forages fed to sheep. *Proceedings of the New Zealand Grassland Association 64*: 167-171.

Wang, Y.; Douglas, G. B.; Waghorn, G. C.; Barry, T. N.; Foote, A. G. 1996a. Effect of condensed tannins in *Lotus corniculatus* upon lactation performance in ewes. *Journal of Agricultural Science, Cambridge 126*: 353-362.

Wang, Y.; Douglas, G. B.; Waghorn, G. C.; Barry, T. N.; Foote, A. G.; Purchas, R. W. 1996b. Effect of condensed tannins upon the performance of lambs grazing *Lotus corniculatus* and lucerne (*Medicago sativa*). *Journal of Agricultural Science, Cambridge 126*: 87-98.

Wilson, P.R.; Grace, N.D. 2002. Practical considerations for diagnosis and management of copper status of deer. *Proceedings of the New Zealand Society of Animal Production 62*: 315-318.

Wilson, P.R.; Barry, T.N.; Hoskin, S.O. 2002. The role of alternative pasture species for farmed game health and productivity: observations from red deer. pp.143-152. *In*: Game Conservation and Sustainability: Biodiversity, Management, Ecotourism, Traditional Medicine and Health. *Proceedings of the 4th International Wildlife Ranching Symposium*. Ed. Renecker L.A. TA.

Woodward, S.L.; Waghorn, G.C.; Lassey, K.R.; Laboyrie, P.G. 2002. Does feeding sulla (*Hedysarum coronarium*) reduce methane emissions from dairy cows? *Proceedings of the New Zealand Society of Animal Production 62*: 227-230.