SUMMER NUTRITION OF SHEEP BASED ON RESIDUES OF ANNUAL CROPS AND MEDIC PASTURES

by

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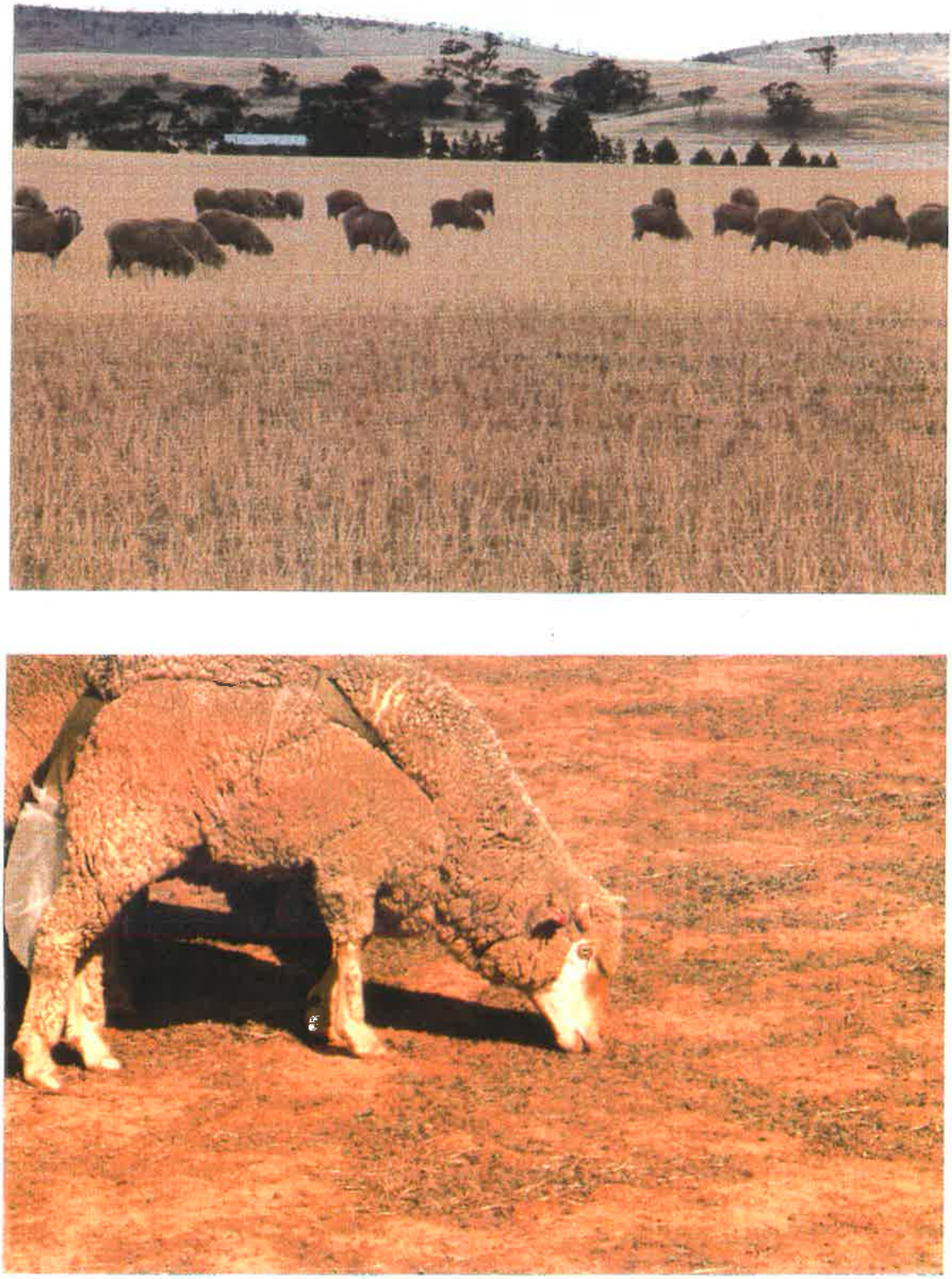

Cereal stubbles (above) and dry residues of medic pastures (below) are of major importance in the summer nutrition of sheep in southern Australia

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ABSTRACT

The investigations reported in this thesis are in the general area of summer nutrition of sheep in the cereal-livestock zones of southern Australia where summer grazing is associated with a decline in the quantity and quality of dry pasture residues, loss of pasture legume seeds and, frequently, soil erosion. Five main areas of research have been undertaken as follows:

- The effects of sheep stocking densities in autumn on annual medic pasture (Chapter 3)
- Estimation of the nutritive value of mature pods of annual medics (*Medicago* spp.) (Chapter 4)
- Studies on the variable intake of mature pods of *M. truncatula* cv. Paraggio (Chapter 5)
- Alkali treatment of crop and pasture residues (Chapter 6)
- Lot-feeding of sheep (Chapter 7)

Chapter 3 describes a grazing experiment at Korunye, 50 km north of Adelaide, South Australia involving continuous grazing of dry medic pasture residues at three stocking densities (Low = 12 sheep/ha, Medium = 24 sheep/ha and High = 36 sheep/ha) during April and May 1991. The main findings and conclusions were: stocking densities had a marked influence on availability of dry pasture components; the availability of total dry pasture residues after three weeks grazing was reduced by 15, 29 and 41 percent for low, medium and high stocking densities respectively; the disappearance of dry residues (without the pods) was faster than the mature pod components from the start of grazing when dry residues had similar dry matter digestibility (average 50.4%); both dry matter and organic matter digestibility of the dry residues (without pods) declined for all stocking densities with increasing grazing time.

The average pod weight, seeds per pod and seed weight decreased with grazing time. Sheep lost weight and condition as medic pod (and seed) reserves declined through ingestion, further losses in total seed reserves occurred because of decreased levels of hard-seededness through exposure of pods to higher surface temperatures on hard-grazed (bare) areas. This increased the emergence of medic seedlings.

Chapter 4 describes the *in vivo, in vitro* and *in sacco* experiments undertaken to estimate the nutritive value of mature pods of three medic cultivars, viz. Sava, Parabinga and Paraggio. The main conclusions were that whole medic pods had high content of both crude protein

(around 20%) and crude fibre (over 35%). The voluntary intake of Paraggio pods was significantly lower than the other cultivars (236 g/sheep/d vs 796 g/sheep/d for Parabinga and 685 g/sheep/d for Sava). Although the dry matter digestibility of pods of all cultivars was very low (27-37%) the digestibility of the crude protein fraction was high (over 62%). The digestible energy content of whole pods also was low (6.88, 6.57 and 5.65 MJ/kg for Sava, Parabinga and Paraggio respectively). The seed survival following ingestion of pods of each cultivar was less than 3%. It was evident from the *in vitro* study that although seeds comprised only about 30% of whole pods these are the most valuable nutrient component of mature medic pods. The results of *in sacco* studies showed that physical damage to mature medic pods and seed following ingestion (i.e. chewing and rumination) as well as level of hard-seededness are the most important factors in medic seed survival. Also, incubation of intact soft medic seeds in the rumen severely reduced their germination ability indicating susceptibility of soft seeds to digestion.

Chapter 5 considers experiments on voluntary intake of two lines of mature pods of *M. truncatula* cv. Paraggio. The results of *in vivo* and *in sacco* studies in this chapter showed that, in spite of similarity in chemical composition and degradation in the rumen, the voluntary intake of one line (G-Paraggio) was about 5.4 times greater than the intake of another line of Paraggio pods (P-Paraggio) fed to sheep in the previous *in vivo* experiment (1837 vs 343 g/sheep/d).

In the subsequent *in vivo* experiment described in this chapter various treatments except molasses not only did not overcome the intake problem of the P-Paraggio pods but also they had a synergistic effect in combination with the factor responsible for low intake. It was concluded that the very low intake of P-Paraggio pods may be related to presence of some anti-quality factors that influenced palatability.

Chapter 6 involves evaluation of the nutritive value of cereal straws, grain legume residues and mature medic pods following treatment with NaOH and $Ca(OH)_2$ applied by various techniques. The main conclusions were: crude protein content of grain legume residues was higher than that for cereal straws (7.5% vs 3.1%); the grain legume residues also showed higher values for *in vitro* digestibility (52% vs 49%); calcium hydroxide treatment of the residues especially with higher concentrations (12% (w/w) for cereals and 9% (w/w) for grain legumes) and the soaking method rather than spraying increased dry matter disappearance in the rumen. Generally, greater increases in digestibility were obtained following treatment of roughages of low initial digestibility (e.g. wheat straw). For both types of roughages NaOH was more effective than $Ca(OH)_2$ and the highest coefficients for the digestible fraction were obtained following treatment with 40 g NaOH per 100 g straw. 4·0

In spite of poor solubility of $Ca(OH)_2$, significant improvement in the disappearance of mature medic pods was obtained in these studies. Also, the efficiency of this chemical by the soaking method was much higher than by the spraying procedure. In terms of improving rumen degradation the best responses were obtained following treatment of medic pods with 4% NaOH and 9% $Ca(OH)_2$ (w/w).

Finally, **Chapter 7** relates to lot-feeding of Merino wethers during early autumn, a practice that is gaining popularity in the cereal-livestock zones of southern Australia. Four groups of 15 Merino wethers were handfed with differing straw-based rations for a period of 10 weeks. The overall daily intakes varied between 1.0 and 1.1 kg/sheep/day. Generally, voluntary intake of pea straw was lower than barley straw. In all treatments sheep rapidly lost body weight and fat score during the early weeks in the feedlot. Body weight fluctuations were much lower in the following weeks. The sheep recovered their lost body weight and condition after being released onto green pasture. The average wool growth for all groups of sheep was approximately six grams clean wool per head per day. Wool growth was not depressed or enhanced by body weight changes and dietary regimes. No shy feeders were detected and there were no deaths of sheep in this study. Supplementation of the diets with around 10-15% lucerne chaff or mature medic pods helped maintain/increase body weight of the sheep.

The results of experiments described in this thesis show that grazing the dry medic pasture residues over summer and autumn should be carefully monitored to avoid excessive consumption of seed. While lot-feeding of sheep during the dry summer-autumn period can be an economical and practical method of reducing intake of pods (and seed) and minimising loss of cover and consequent soil erosion, the regeneration of seedlings from sheep faecal pellets is unlikely to contribute significantly to the overall regeneration of the pasture. The results show that low-quality roughages can be successfully treated and fed to sheep in feedlots.

STATEMENT

I hereby declare that the thesis here presented contains no work which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

3 June, 1994

Reza Valizadeh

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1.0 GENERAL INTRODUCTION

Agriculture remains the largest and the most important industry in the Australian economy (Cribb 1986; Pestana 1993-94). The total gross value of agricultural products in 1991-92 amounted to nearly $20,623 million, and contributed $15,587 million in export earnings (about 75.6% of production) to the Australian economy (Australian Bureau of Statistics (ABS) 1993). Today, Australia is one of the world's leading producers of agricultural products. This importance and the unique agricultural systems are the results of the years of enterprise, resourcefulness and application by Australians from the early days of settlement in 1788 (Organisation for Economic Co-operation and Development (OECD) 1975) to the present time (Begg and Peacock 1990).

The major and largest enterprise in this sector is the sheep industry. Australia and the sheep industry have been synonymous for more than 150 years (Bryant 1983). Australia has the largest sheep industry in the word. Sheep numbers reached a peak of 180 million in 1970. However, due to the effects of poor international markets the sheep number declined to 148 million in 1992 (ABS 1992a). The most important product in this sector has always been wool but in recent decades sheep meat has increased in importance. Wool is still Australia's dominant single product. Australia produces nearly 30 percent of the world's wool and it occupies first place in the world export trade in this product. According to the estimated figures by ABARE (1992) Australia supplies over 50 percent of the world wool exports among the main producing countries. This leading position has increased over the years. Wool export is therefore a major source of foreign exchange income for the farmers and the Australian economy.

The Australian sheep industry is spread over a wide range of ecological zones (Pratley 1991). The main sheep-grazing regions have been divided into three zones: (a) the pastoral zone; (b) the cereal-sheep zone and (c) the high-rainfall zone.

The pastoral zone is characterised by marginal cropping and extensive grazing of native pastures with low stocking rates. About 10-20% of the total sheep numbers are found in this zone (BAE 1984; AWC 1989). In the cereal-sheep zone regular cropping in addition to the grazing of mainly sheep on a more intensive basis than in the pastoral zone is practised. Although this zone occupies c. 11 percent of Australian land, because of its favourable conditions, such as a longer growing season, it supports nearly 45-55% of the total sheep population in Australia (BAE 1983). The third zone includes the coastal mainland with higher rainfall and hillier topography. This zone is suitable for intensive grazing rather than for grain production. Generally about 20-30% of the nation's Merino sheep are maintained in this zone.

The various agricultural zones mentioned above are found in the State of South Australia (Jefferies and Nash 1989). The cereal zone accounts for more than 65% of the annual gross value of agricultural production in the state. The cereal zone production is based on a cereal-livestock ley farming system. Most of the sheep population are grazed on annual legume-based pastures (South Aust. Dept. Agric. 1991).

A major characteristic of sheep husbandry in Australia is the dependence on pasture. Pastures are the main source of nutrients for sheep (Squires 1981). By world standards the grazing practice in Australia can be defined as extensive. The system of animal husbandry is very different from that practised in other counties with similar vegetation types. The major characteristic of the Australian livestock production system is its great dependence on year-round, low input and continuous grazing on large properties (Wheeler and Freer 1986; Squires 1991). Pastures are, therefore, the valuable national resource contributing over 60% of the value of all agricultural products to the national economy (Archer *et al.* 1993).

Historically, one of the most important features of Australian agricultural systems has been the evolution, development and expansion of sown pasture technologies (Donald 1982). The major contribution to Australian animal and cereal production in the cereal-livestock zone was the introduction of annual legume pastures (Halse and Wolfe 1985). The sowing of annual legumes as the basis of self-regenerating pastures in the cereal-livestock zone of southern Australia started with the widespread sowing of subterranean clover in the 1920's and annual medics in the 1930's (Carter 1978). Generally, these annual legumes are grown in rotation with cereal crops (Carter 1982, 1987; Reed and Cocks 1982; ICARDA 1986). These annual legumes, besides providing cheap and good quality feed for ruminants make a further contribution to the Australian agricultural industry through the nitrogen fixation process (Reed and Cocks 1982; Carter *et al.* 1992; Ladd and Butler 1992). The value of pasture legumes, basically annual, self-regenerating medics (*Medicago* spp.) and clovers (*Trifolium* spp.) has been estimated at US $2,500 million per year to the Australian crop and livestock industries (Carter 1982).

The persistency and sustainability of the pastures are therefore key factors in the whole Australian community, both rural and urban (Dear 1988; Archer *et al.* 1993). However, the sustainability of the temperate pastures in this environment depends on careful management of the complex soil-plant-animal interrelationships (Carter 1993).

In southern Australia it has been well documented that the annual pastures have declined in productivity and quality in recent years due to loss of legumes (Carter 1982; Gillespie 1983; Dear and Loveland 1985). Carter (1981b, 1993) listed some 15 factors causing the serious decline of medics in southern Australia. In the pasture/cereal rotation systems the key requirement for persistence of the annual pasture legumes is that appropriate amount of seeds must be produced and survive both under grazing and through the year of the cereal crop (ICARDA 1984; Jones and Carter 1989). In the Mediterranean-type environment of southern Australia the pastures available to the grazing animals during the summer months are the dry residues from the previous growing season. Livestock production is often limited by the quality and quantity of the dry feed on offer (Brown 1976b).

Research carried out by Carter and his group at the University of Adelaide over the past 20 years has highlighted that generally about 80-90% of farms have insufficient legume seed reserves following the cropping sequence to regenerate a reasonable legume-based pasture.

It has been demonstrated that one of the major causes of pasture legume deterioration in the cereal belt is excessive consumption of legume seed by sheep during the dry and hot period of late summer and early autumn (Carter 1981a; de Koning and Carter 1989; Squella 1992). They have shown that sheep first selected the largest medic pods and clover burrs containing the most and largest seeds and progressively ate smaller pods and burrs. In such situations the surviving pasture legume seed reserves are too low to guarantee a dense and productive pasture following the cropping year. Soil erosion, declining sheep body weight and wool production and high death rates are other consequences of this excessive grazing. However, these sorts of difficulties can be minimised or completely removed by undertaking appropriate management.

Pasture management for efficient utilisation is a complex process which can be affected by many interacting factors. Stocking density is the most powerful tool and the key factor to profitable pasture utilisation (Archer 1989). Most available information on stocking rates with sheep has been derived from experiments conducted during the growing season. However, most of the above-mentioned problems concerning the maintenance of dense and productive pastures are related to the grazing of mature and dry residues, including pods. Therefore, the challenge is to find the correct balance between grazing pressure and stocking intensities without significant damage to the soil and seed reserves. Little data are available on this livestock-pasture interface during the dry period of year. Although the optimum stocking density is difficult to determine on a year-long basis, studies on the relationship between stocking density and the pattern of disappearance of individual dry pasture components can provide valuable information on efficient use of the dry clover or medic pasture residues (Carter 1977; Carter *et al.* 1993).

To reduce the dramatic effects of sheep grazing during the dry season on the annual medic pod or seed reserves it may be possible to select some medic cultivars that produce mature pods which are less palatable or unpalatable to grazing animals. Although no data on this subject was found in the literature, wide variation in resistance to pests was found between the under-utilised medic cultivars (Dear 1988), it is possible that the mature pods of some cultivars could be rejected by sheep. In such circumstances sheep may prefer to graze other dry residues rather than pods, thus damage to the annual legume seed bank would be much lower than the cultivars producing more-palatable, mature pods.

Lot-feeding is another effective method for saving both pastures and sheep during the dry season in the Mediterranean-type environment of southern Australia (Carter *et al.* 1993). This management practice can be used for a number of purposes, i.e. lot-feeding of sheep for maintenance during a period of feed shortage or where there is the erosion risk in running sheep in paddocks, lot-feeding for production or finishing and lot-feeding after the break of the season in order to save the newly emerged annual legume seeds (Rehn 1988; Ashton 1989).

In comparison with lot-feeding of beef cattle, lot-feeding of sheep is a new practice for most sheep farmers because they are used to an extensive livestock production system based on pastures. However, lot-feeding of sheep during late summer and early autumn is gaining popularity in the cereal-livestock zones. Since the 1982 drought in southern Australia many farmers have successfully lot-fed their sheep (Morbey and Ashton 1990; Rodda 1992). Although sheep lot-feeding is now a part of the farming system in South Australia, lack of scientific research in this area is apparent. For satisfactory lot-feeding of sheep, farmers need more information about simple, easy and cost-effective designs, management methods and feeding value of available feedstuffs.

In sheep lot-feeding practices nutrition represents the most important factor in sheep performance and profitability. The lot-fed sheep should be handfed with the available feedstuffs such as cereal grain, hay, crop residues and agro-industrial by-products. If this management practice is to be acceptable and profitable, crop residues must be used. Every year enormous amounts of crop residues are produced in Australia. Collecting these residues could be more efficient than grazing. Harvesting these residues reduces weather effects, avoids trampling, allows their use in the period of feed shortage and provides opportunity for treatment in order to upgrade their nutritive value (Burns 1981).

As it has been widely pointed out, the intake, digestibility and protein content of fibrous crop residues are very low (Dixon 1987). These limitations can be significantly reduced by various treatments (Ibrahim 1983). In the extensive livestock industry of Australia application of these treatments even for the feedlot situations may not show good returns. However, the increasing demand for food and agricultural products in the world (Oram 1993) may, in future, make this option more cost-effective.

The major component of mature medic pastures is the pods. Although, in some districts of South Australia these pods are harvested and pelleted with other feed ingredients, their nutritive value is largely unknown. Medic pods are rich in crude protein and can balance the complete rations for the sheep in feedlots mainly when large amounts of crop residues with lower content of protein are fed (Hunter 1988). However, mature pods have a high fibre content which is likely to limit their feeding value. Nevertheless, following chemical treatment, a considerable improvement in the availability of this feed resource could be expected.

This thesis aims to improve and add to the body of available knowledge in the area of pasture-livestock interface and feed resource from the mature annual pasture legumes and the animal/feed resource interface, concentrating on the annual legumes and more specifically dry medic pods. Understanding the importance of grazing pressure on availability of dry pasture components, the nutritive value of different crop and pasture residues, the potential improvement and use in sheep lot-feeding, were the most important objectives in this context.

The experimental component of the thesis is divided into five broad parts. In the first part the effects of different stocking densities on the dry medic pasture residues was studied in a grazing experiment during the dry season. In the second part the feeding value of mature medic pods was studied using *in vivo*, *in vitro* and *in sacco* methods. In the third and fourth parts some chemical treatments were applied to the mature medic pods and several crop residues in order to improve their feeding value. The fifth part describes the lot-feeding of Merino sheep fed with low-cost, balanced rations at the maintenance level based on a range of feedstuffs including medic pods, cereal crop residues and grain.

2.0 REVIEW OF LITERATURE

2.1 The role of annual *Medicago* species in agricultural systems

2.1.1 Historical background and distribution

The annual species of *Medicago* (commonly called medics) are native to the northern hemisphere, mainly the lands around the Mediterranean sea and western Asia (Heyn 1963; Reed *et al.* 1989; Reeve 1990). Many of the medic species have been distributed over wide areas in many countries of the world, particularly those regions with Mediterranean-type climates (Heyn 1963; Cocks and Carter 1978). The annual *Medicago* species were originally introduced to Australia from the Mediterranean basin (Carter 1975, 1978; Carter *et al.* 1982). Andrew and Hely (1960) noted that medics first entered Australia about 130 years ago and became naturalised after about 50 years. Andrew (1962) indicated that within Australia *Medicago spp.* can be found where the environments are suitable for growth, although these are not necessarily the most desirable species. Webber *et al.* (1976) mentioned that medic species were introduced into South Australia fortuitously and spread naturally throughout much of the cereal zone. Following settlement there were thousands of hectares of medics long before any were deliberately sown (Carter 1975; Ababneneh 1991). Carter *et al.* (1982) found that in the 1920's there was a rapid spread of the annual species of *Medicago* following the widespread use of superphosphate on wheat crops. Trumble (1937) and Trumble and Donald (1938) noted that seed from the annual species of *Medicago* was first harvested in South Australia (Noarlunga) in the mid-1930's.

2.1.2 Importance of annual medics

The annual species of *Medicago* increase soil fertility through fixation of atmospheric nitrogen, which becomes immediately available for host plant growth (Scott and Brownlee 1970; Langer 1972) and this is imperative for maximizing grain yields from cereals in pasture-cereal crop rotation systems (Carter *et al.* 1982; Reeves 1987; Quigley 1988). Annual medics also supply high-quality herbage for grazing livestock (Carter 1986). Generally, legumes have a high content of crude protein and minerals, especially magnesium and calcium, which are frequently implicated in metabolic disturbances of livestock grazing grasses (Day and Michelmore 1952; Lazenby and Swain 1969; Langer 1972). Quigley (1988) noted that in a sward with a substantial component of legumes, the total dry matter and feeding value of pasture herbage increased. Scott and Brownlee (1970) stated that in the same environment medic pastures carry more livestock than volunteer natural pastures. Annual medic pastures are easily established on a wide variety of soils and persist over diverse seasonal conditions (Scott and Brownlee 1970). Medics reduce soil erosion by improving year-round ground cover and lessen ground water contamination, especially by nitrates (Marten *et al.* 1989). The self-regenerating legumes are unique plants in ley farming systems because they can produce seed under limited moisture conditions (Downes 1969). Integration of legume-based pasture-cereal crop rotations and livestock production in addition to increasing cereal grain yields, enabled higher stocking and stock growth rates and stabilized farm incomes (Carter 1975; Quigley 1988). Generally there is a negative correlation between protein content of green forages and their age, but the reduction in protein level of forage legumes is much slower than in grasses around the flowering stage (Langer 1972). The herbage production of annual medics is more rapid than other temperate legumes (Bowdler and Lowe 1980).

2.1.3 Nutritive value of dry residues of mature annual medic pasture

In southern Australia, pasture legumes have an established role in providing high quality forage during their vegetative stage. The dry residues of pastures are also grazed during the summer and early autumn months (Wilson and Hindley 1968; Radcliffe and Cochrane 1970). Mature annual legumes are important feed sources for ruminants during the dry period in southern Australia (Li *et al.* 1992), although during this period under continuous grazing a large proportion of dry plant residues tend to shatter and waste (Amor 1965). The cell wall content of legume residues is lower and nitrogen content higher than cereal straws (Hartley and Jones 1977). These are important advantages of the dry legume pasture materials in comparison with *Graminae* roughages, particularly when they have to be upgraded (Adebowale *et al.* 1989).

The annual medics produce considerable amounts of seed pods (Franklin *et al.* 1964). These pods are potentially a large source of nutrients, mainly crude protein for ruminants over summer and autumn (Denney *et al.* 1979). Franklin and Powning (1942) demonstrated that the crude protein content of the whole pods and their seeds ranged from 13 to 25 and 28 to 50 percent respectively. The seed:hull ratio in their experiment was 34:66 while Denney *et al.* (1978) reported that pods of *M. truncatula* were 30% seed and 70% hull.

In an *in vivo* study measuring the intake and digestibility of a sole ration of mature barrel medic pods by penned mature Corriedale wethers, Vercoe and Pearce (1960) observed a dry matter intake of 940 grams per day per sheep, a dry matter digestibility of 30% and a crude protein digestibility of 68%. The crude protein contents of the whole pod, seed and hull were 18, 45 and 6 percent respectively. Denney *et al.* (1979) reported that organic matter digestibility of barrel medic pod was 24%, chiefly because of low digestibility of crude fibre as its major component. In a pen-feeding experiment with pure mature medic pods Carter (1980) reported daily intake of 757, 755 and 555 grams per day per sheep for *M. truncatula* (cv. Jemalong), *M. scutellata* (Commercial) and *M. littoralis* (cv. Harbinger) respectively. Brand *et al.* (1991) reported that dry matter intake of mature burrs of *Medicago truncatula* cv. Jemalong was 1996 grams per day per sheep, with an organic matter digestibility of 44%. However, in spite of the low digestibility of medic pods (because of a high indigestible crude fibre content) their high content of crude protein would be used more efficiently when pods form part of a ration consisting mainly of mature low protein forage (Denney *et al.* 1979). Medic seeds are highly digestible (Cocks 1988); Carter (1980) demonstrated that between 90 and 99% of the medic seeds were digested by sheep. Therefore the main source of nutrients is seeds and the feeding value of whole pods depends on their content of seed (Denney *et al.* 1979). In some districts of South Australia harvested medic pods are sold commercially for establishing pasture and also feeding: some pods are hammer-milled for making pellets, mainly for feeding to live sheep including those exported to international markets.

In the integrated crop-livestock farming systems of South Australia ruminants graze the pastures throughout the year. In these systems, seed of pasture should survive in adequate amounts (particularly for annual species) to ensure continuation. Carter (1980) reported that the medic seed survival was less than 2% on average. Vercoe and Pearce (1960) recovered a total 1.9% of *M. truncatula* seeds in sheep faeces, while Thomson *et al.* (1987) observed seed survival percentage as low as 2.2 percent for *M. constricta* and as high as 23.4 percent for *M. polymorpha* using the digestibility method. They concluded that chewing and rumination could be the major determinants of seed survival. Undamaged seeds are highly resistant to microbial fermentation. Probably those seeds whose coats are slightly damaged during the rumination process are completely digested even if they escape from the rumen. Carter *et al.* (1989)

mentioned that small hard-seeded pasture legumes have higher percentage of survival following ingestion by sheep. The effects of seed size and hard seededness on seed survival of pasture plants after ingestion by grazing animals have been examined by other workers (Suckling 1950; Simao Neto *et al.* 1987; Thomson *et al.* 1987; Squella 1992). It is reasonable to conclude that selecting medic species with small seeds which are resistant to digestion could increase seed survival and reduce the damage of overgrazing in dry periods particularly in drought years (Carter 1980, 1981a, 1987, 1989; Thomson *et al.* 1987).

2.1.4 Problems of maintaining annual medic pastures in southern Australia

In the Mediterranean-type environment of southern Australia the pasture available to grazing animals is dead for several months of the year and livestock production is limited by the quality and quantity of dry feed on offer (Brown 1976a; de Koning and Carter 1987, 1989). Carter (1987) pointed out that many annual pastures throughout southern Australia are in a very poor condition because of neglect of good pasture management practices. Carter *et al.* (1982, 1993) listed 15 major causes of deterioration of medic pastures in the cereal-livestock zone of South Australia. Deterioration of annual legume pastures in southern Australia has also been emphasized by other workers (Gillespie 1983; Dear and Loveland 1985). In particular, it has been suggested that inadequate seed reserves of pasture legumes in the soil, leads to poor pasture regeneration (Carter 1980, 1981a, 1981b, 1982, 1990a, 1990b, 1990c). Carter (1990d) concluded that common reasons for an inadequate pasture legume seed bank in the soil can be summarised as: (a) Selecting unsuitable legume species and cultivars; (b) Poor grazing management mainly during the dry period of the year; (c) Insufficient insect pest control.

The adverse impact of overgrazing of dry legume pastures by sheep in summer-autumn on seed reserves and pasture regeneration is well recognized (Carter 1981a; de Koning and Carter 1989). They concluded from their detailed studies that in the late summer and early autumn with continuous grazing sheep firstly select the largest medic pods or clover burrs which normally contain more and larger seeds and then progressively ingest smaller pods and burrs with fewer and smaller seeds. Gramshaw *et al.* (1989) stated that annual medics with larger pods such as snail and gamma medics are more disadvantaged by over-grazing because of greater pod accessibility. Carter (1981a) demonstrated that in eight weeks of summer grazing sheep can consume about one tonne/ha of medic seed at normal grazing pressures. Therefore, careful summer-autumn livestock grazing management is necessary, especially after poor pasture years, to ensure that there are adequate seed reserves (Webber *et al.* 1976).

Soil erosion is an important problem which is associated with livestock grazing during the dry period (Rehn 1988). At this time of the year paddock feed is scarce and continuous grazing, particularly with high stocking rates and in drought years, makes the annual pastures bare and soil is lost through wind erosion.

However, to minimise damage to soil by grazing bare paddocks and to protect seed reserves there is sometimes a need to practise lot-feeding, mainly at maintenance levels, to ease these pressures on the pasture (Rehn 1988; Ashton 1989; Carter 1990d, 1992; Carter *et al.* 1993).

2.1.5 Grazing management

Pastures are the most important Australian resource so these grazing areas need to be properly managed (Kemp 1993). Pasture management is a complex process affected by many interacting factors (Archer 1989). Traditionally, grazing management has been defined as maximising the production of grazing animals consistent with long-term pasture sustainability (Whalley 1980; Kemp and Michalk 1993).

The most important factor which influences economic returns from grazed pastures is grazing intensity (Rossiter 1966; Bransby and Conrad 1985). Stocking rate has been defined as "the number of animals or equivalents per unit area of pasture"(Carter, pers. comm.; Humphreys 1974). Equivalents are used when adult and young animals or cattle and sheep graze together on the same pasture. Stocking rate is a major determinant affecting the structure, botanical composition of pastures, nutritional value of available forage and consequently the productivity of grazed pasture systems (Rossiter 1966; Carter and Day 1970; Evans 1981). Therefore, determination of the desirable stocking pressure should have first priority in pasture studies rather than the system of grazing (Humphreys 1974). The term "stocking density" may be synonymous with stocking rate, but generally it is applied to short-term grazing situations (Carter, pers. comm.).

In a five-year grazing experiment in the Mediterranean-type climate of South Australia on an annual pasture with five stocking rates from 7.4 to 22.2 sheep per hectare, Carter (1977) concluded that wool value and production increased almost linearly with stocking rate up to the level of 17.3 sheep/ha. In another experiment under a similar climate and for a similar period with Merino wethers, Brown (1976a) pointed out that on annual pastures at stocking rates up to 22.2 sheep/ha animals can be continuously grazed with little or no hand feeding. Lloyd Davies (1968) and Lloyd Davies and Southey (1985) observed that ewe and lamb body-weight was affected by stocking rate. Dunlop *et al.* (1984) found that total annual pasture production declined from 7.5 to 4.0 ton/ha with increasing stocking rates from 5.6 to 16.3 sheep/ha. McMeekan (1956) noted that the conversion efficiency of pasture to animal products can be affected by three major factors: grazing methods, kind of stock and stocking rate. However, it seems that the effects of different stocking rates on dry medic pastures and the interrelationship between pasture components and the physiological status of grazing animals is inadequately understood.

Two basic grazing methods are normally considered in grazing systems: (a) continuous grazing and (b) intermittent grazing. Continuous grazing is synonymous with set stocking, while intermittent grazing has been divided into: (i) rotational grazing, (ii) strip grazing and (iii) mob grazing (Smetham 1967). Continuous grazing involves keeping livestock on a certain part of pasture continuously for an indefinite period, usually a full year or more. Continuous grazing of ewes and lambs or cows and calves is normal in southern Australia but after weaning of lambs and calves the adults are moved for strategic grazing of weedy pastures or to allow hay making, etc.(Carter, pers. comm.). Similar grazing management is used elsewhere where livestock depend on pastures for the main feed supply (Clark 1993). Smetham (1967) mentioned that continuous grazing is the normal method of grazing ewes and cattle from the end of lambing or calving until weaning in the North Island of New Zealand. He also reported that when stocking rate is too low and the herbage offering is excess of requirements, grazing animals will select the palatable plants and leave less-palatable ones. In these situations flat weeds can invade the heavily-grazed areas, but this can be prevented by increasing stocking density and adjusting the stocking rate continually during grazing. The impact of grazing pressure by sheep on yield and botanical composition of annual pastures has been shown clearly by Lloyd Davies (1962); Carter (1965) and others (Sharkey *et al.* 1962, 1964; Dunlop *et al.* 1984).

Rotational grazing methods concentrate livestock and restrict the forage availability in short pre-determined grazing periods (Stuth *et al.* 1985). Little evidence can be found to justify choice of rotational grazing over set-stocking for livestock performance. Although sub-division of pasture is necessary for pasture establishment, livestock separation and so on, this management can adversly affect animal performance because of the restrictions applied. The most intensive form of grazing is strip grazing which involves grazing small areas of pasture with much higher stocking densities for short periods (12 hours or less). This management method was undertaken in Western Australia for sheep grazing annual pastures with the objective of producing high-quality wool and carrying more stock in winter (Doyle *et al.* 1992). Nevertheless, Doyle *et al.* (1993) concluded that in relation to the application of this management tactic (strip grazing) for annual pastures key aspects have to be studied. In another form of rotational grazing which is called mob grazing, large numbers of animals are concentrated during grazing and are moved from paddock to paddock. This method of grazing has been used in New Zealand for ewes between weaning and tupping (Smetham 1967): however, it is not favoured in ewe-lamb flocks in southern Australia because it frequently causes digestive upsets in lambs. Therefore, such systems should be carefully appraised before being introduced and recommended for this area (Archer 1989).

In a grazing experiment with sheep on a subterranean clover pasture in Western Australia, Lloyd Davies and Southey (1985) observed no large differences in animal production with deferred or continuous grazing. Evans (1981) pointed out that according to the evidence from temperature pastures, there is no advantage in using rotational grazing in increasing production per head. However, control over the level of pasture production and utilisation, by varying grazing intensity is an important tool for optimising the total financial return from pasture-livestock enterprises in various circumstances (Mc Meekan 1956; Morley *et al.* 1969).

Deferred grazing has been used as a method for reserving pasture forage for later use or to allow annual species to emerge and develop and perennials to make appropriate vegetative growth before grazing (Carter, pers comm.; Christian 1987). Deferment of grazing of pastures during autumn involves removing ruminants from pastures soon after the opening rain or seed germination and feeding with alternative feed sources while pasture reestablishes (Bishop and Kentish 1966; Brown 1977). In a series of deferred autumn grazing experiments with Merino sheep in the Mediterranean-environment of South Australia carried out by Brown (1976a, 1976b, 1977) it was shown that with this method of grazing extra pasture production can be obtained during the winter months. Consequently, sheep body-weight and wool growth rate increased during the months of June to September. However, he suggested that with autumn deferment grazing the yearly stocking rates cannot be increased.

Doyle *et al.* (1993) emphasized that in the annual pasture zone of southern Australia grazing management on annual pastures has to be flexible to cope with seasonal variability in feed on offer from the pasture. Annual pasture production is more influenced by season and management than by introducing new cultivars of pasture plants.

In Mediterranean-type climates of Australia, grazing animals are kept at pasture throughout the year (Allden 1981). Over most of Australia, the pasture available to livestock is dry and fibrous and of relatively low nutritional value for several months. Under this nutritional stress sheep may lose weight and wool growth rate is reduced (Pearce *et al.* 1987). Providing supplementary feeds for grazing animals during the periods of nutrient inadequacy is recommended (Siebert and Hunter 1981; Rowe *et al.* 1989). Supplementary feeds may be supplied in the form of processed or unprocessed hays, grains and crop residues. Rowe *et al.* (1989) noted that in Western Australia supplementation of young grazing animals and pregnant ewes is necessary every summer on most sheep farms. Siebert and Hunter (1981) stated that deficiencies may range from trace minerals to energy limitation in the different physiological status of animals.

Supplementary feeding may be considered for survival or production purposes, depending on the costs and objectives of the systems. Nevertheless, in the areas that crop residues are available they should be grazed by animals as a supplement to pastures (Burns 1981). Rowe *et al.* (1989) mentioned that from late November to the first rain in April or May dry pasture and cereal stubbles are the only available feeds in Western Australia. Frequently sheep in dry annual pastures have been fed with lupin grain as a supplement to the low-quality feed on offer (Arnold and Charlick 1976; Arnold *et al.* 1977). However, the final analysis of increased animal survival or increased productivity per unit of supplement input determines the success of supplementary feeding to grazing animals on pastures (Siebert and Hunter 1981).

2.2 Nutritional evaluation of feedstuffs

2.2.1 Introduction

Nutritional evaluation of animal feeds is undertaken for different purposes. The main ones could be summarised as follows: (a) to measure the extent to which one feed can replace another (Oldham and Emmans 1990) or which feed is the most economical to be fed (Flatt 1988); (b) to relate feed attributes to animal requirements (Oldham and Emmans 1990); (c) to control the performance of farm animals through nutrition (Van der Honing and Steg 1990); (d) feedstuff evaluation systems enable livestock feeders to calculate suitable diets for animals and plan for adequate feed supplies (Flatt 1988).

Chemical analysis of feedstuffs provides a practical means of feed evaluation in the laboratory and helps the investigators to assess available feeds and nutritional phenomena. The proximate analysis of feeds was originally introduced by German scientists, Henneberg and Stohmann in the 19th century (Van Soest 1969). However, the procedure has been severely criticised and partially replaced by other analytical procedures e.g. Van Soest fractionation of carbohydrates in feed (1967). Modified procedures continue to be used, because of their simplicity and difficulties involved in the application of new procedures.

2.2.2 Voluntary intake

The amount of feed that an animal consumes in a given time is an important aspect of feed evaluation. The most important factor controlling animal production and the utilisation of roughages by ruminants is the voluntary intake of the material by animals (Hovell *et al.* 1986; Minson 1987; Garnsworthy and Cole 1990). The amount of feed which ruminants voluntarily consume is the first step in the process of conversion of feed into valuable products (Ketelaars and Tolkamp 1992). Our understanding of the mechanisms which control feed intake in ruminants is still poor, because the mechanisms are extremely complex (Grovum 1988). However, it has been suggested that voluntary intake of roughages is determined largely by rumen load, which is influenced by rate of digestion and passage (Balch and Campling 1962; Donefer *et al.* 1963; Montgomery and Baumgardt 1965; Thomas and Chamberlain 1990). Perhaps in diets consisting entirely or mainly of concentrates, voluntary intake is controlled by thermostatic or chemostatic regulatory mechanisms rather than the rate of passage (Balch and Campling 1962; Weston 1985; Grovum 1988).

Voluntary intake of roughages, concentrates and mixed feeds is influenced by different factors. These factors can be cited in three categories : (a) animal factors (Weston 1966, 1979, 1981; Freer 1981; Dulphy and Demarquilly 1983). (b) dietary factors (Elliott 1967a, 1967b; Weston 1967; Hegarty 1981; Barry and Duncan 1984; Howarth 1988; Pritchard *et al.*1988; SCA 1990; Ketelaars and Tolkamp 1992) and (c) other factors (CAB 1980; Grovum 1988; Ketelaars and Tolkamp 1992).

Animal factors such as species, genotype, age, sex, weight, body composition and physiological status affect the voluntary intake of feedstuffs in ruminants. Blaxter and Wilson (1962) reported that the voluntary intake of roughages by cattle and sheep is similar per unit metabolic body weight ($kgW^{0.75}$). Probably due to this similarity, equations have been proposed for prediction of intake by cattle from measuments made on the standard sheep (Dulphy and Demarquilly 1983). Domesticated ruminant species have different sizes (Ketelaur and Tolkamp 1992), therefore different results with regard to the effect of size on intake will be seen in the literature. Even between ruminants of the same mature size and condition a considerable variability in voluntary intake can be found (Freer 1981). The physiological status of ruminants substantially affects feed intake. Generally, intake is higher if the physiological status is associated with enhanced nutrient demand. Therefore, voluntary intake is usually high in young animals, in lactating and pregnant animals and when body tissue stores are depleted (Weston 1979). Ruminants achieve their highest voluntary intake during lactation. During this period animals spend more time both eating and ruminating and the rate of eating is increased (Dulphy *et al.* 1980; Weston 1981). Allden (1979) reported that, in Merino sheep, voluntary intake increased progressively until about 30-40% of mature body weight was achieved, after which it remained steady or decreased slightly. However, Ketelaars and Tolkamp (1992) concluded that changes in intake following changes in physiological status (maturity, pregnancy and lactation) are poorly explained by current concepts.

It has been shown that the main characteristics of fibrous feedstuffs that determine intake by ruminants are those which limit the rate at which these can pass through the digestive tract

(Balch and Campling 1962; Freer 1981). In ruminants, when a roughage is chopped or ground its voluntary intake increases due to the faster rate of passage of material from the rumen. On the other hand this physical treatment can result in a slight decrease in digestibility because the feed is subjected to the microbial digestion for a shorter period of time (Garnsworthy and Cole 1990). Minson (1981) concluded that the quantity and composition of the fibre and availability of the essential nutrients for microbial population of the rumen are the most important factors that influence intake of pastures. Weston (1979) reported that inadequate levels of essential nutrients depress feed intake. Moir *et al.* (1975) and Freer (1981) stated that generally roughage intake is inversely related to the cell-wall content and its rate of fermentation.

Taste, smell, odour, flavour and texture of feeds that have been regarded as palatability (Arnold 1981; Grovum 1988) may affect feed intake. Palatability is clearly a major factor in feed selection by ruminants when they are grazing or fed hay of different quality (Doyle and Egan 1987; Minson 1990). Some materials such as molasses, often make the diet or feed mixtures more acceptable to livestock because of their taste or their effect in controlling dust (Grovum 1988). Sometimes, in spite of the rumen being nearly empty, intake of some feeds is very low. This may be attributed to some roughage characteristics that influence taste and odour (Weston 1979; Dulphy and Demarquilly 1983).

Many minor antiquality constituents such as phenolic compounds, tannins, saponins, alkaloids and allergenic compounds can be found in various species of pasture and forage plants and crop residues (Hegarty 1981; Howarth 1988; Liener 1990). Their concentrations are influenced by factors such as plant maturity and climate (Weston 1979) and could be reduced by plant breeding, crop and animal management, or by secondary processing of the crop (Howarth 1988). These constituents could reduce feed intake and animal appetite by adversely affecting the metabolism of the ruminant and the rumen microorganisms (Weston 1979; Minson 1981).

Diseases and parasitic infections reduce the potential feed intake (Weston 1979, 1981; SCA 1990). Climatic factors such as rain, wind, ambient temperature and humidity leading to thermal stress in the animal also have varying effects on feed intake (SCA 1990). For example, feed intake is increased when the ambient temperature falls beyond the thermo-neutral zone of the particular animal (SCA 1990).

It is important to understand feed intake in ruminants, but it must be noted that measurements of intake should serve to constitute the data-bank necessary for predicting feed intake. Recently it has been concluded that the degradation characteristics of roughages in the rumen have useful application in predicting voluntary intake (Hovel *et al.* 1986; Ørskov *et al.* 1988).

2.2.3 Digestibility

The potential value of a feed for farm animals can be determined by chemical analysis, but its actual value can only be arrived at after making allowances for the inevitable losses that occur during digestion, absorption and metabolism. Perhaps the most useful measurement of the nutritional value of livestock feeds is their digestibility (Corbett 1969). Its coefficients refer to that part of a given feed or ration which disappears during passage through the digestive tract (Merchen 1988). A vast number of digestibility determinations have been made upon a great variety of animal feeds and the results have been used as the basis for computing the relative values of livestock feeds.

The conventional method of measuring digestibility is substantially that originated by Henneberg and Stohmann (Armsby 1917). In these trials the test feeds were given to the experimental animals in known amounts and the output of faeces measured. Generally, more than one animal is used (Schneider and Flatt 1975; McDonald *et al.*1988; Merchen 1988). In this method, because faeces contain quantities of material of non-dietary origin the coefficients are known as apparent digestibilities. The digestibility of some feeds such as grain or protein supplements which are seldom fed as the sole ingredient in a ration can be measured by difference (Merchen 1988).

In some circumstances it may be difficult or impractical to measure directly either feed intake or faeces output or both. In such instances use of inert and completely indigestible substances, known as indicators, or markers can be employed. If the concentrations of these markers in the feed and in small samples of the faeces are determined, the ratio between these concentrations give an estimate of digestibility. The indicators can be grouped into internal markers such as lignin acid-detergent fibre and acid-insoluble ash and external markers such as chromic oxide (Maynard and Loosli 1956; McDonald *et al.* 1988; Merchen 1988).

Digestion coefficients of animal feeds are not constant in all situations. They are influenced by a number of factors (Sheehy 1955; Maynard and Loosli 1956; Tyler 1966; McDonald *et al.* 1988; Merchen 1988). The chemical composition of a feed chiefly affects its digestibility. The fibre fraction has the greatest influence on the digestibility of a given feed. Crude fibre tends to exert a protective influence against the digestibility of all nutrients. For this reason the digestibility of highly-lignified materials such as straws is very low. The digestibility of a feed can be influenced by the composition of other ration components and normally associative effects occur. In this situation the digestibility of a mixture of feedstuffs does not equal the sum of the separately-determined digestibilities of its components and most of the time these effects are non-additive (Mould 1988). With increasing levels of intake generally the rate of passage of digesta is increased, therefore feed leaves the reticulo-rumen at a faster rate and less digestion occurs (Joanning *et al.* 1981; Moe 1981). In roughages, particle size reduction also reduces the appearance time of the particles in the rumen before being reduced to a size small enough to exit through the reticulo-omasal orifice. Some feed processing such as chopping, crushing, grinding and pelleting of roughages decreases feed digestibility, but others such as heat treatment improves digestibility. Animal species, their physiological status, age, activity and environmental conditions are the other factors which may influence feed digestion (Sheehy 1955; Corbett 1969; McDonald *et al.* 1988).

Although the coventional method for measuring the digestibility of livestock feeds dates back to the 19th century, it is still the most precise technique for ruminants (Navaratne *et al.*1987). However, because of some limitations with this method such as laboriousness, cost, using large numbers of animals and quantities of feeds and the long time involved, there have been numerous alternative systems used to predict *in vivo* digestibility. Some are laboratory procedures such, as the Weende system of analysis (McDonald *et al.* 1988) *in vitro* digestion (Tilley and Terry 1963) and detergent fibre fractionation methods (Van Soest 1967). Some of these techniques have a highly significant correlation with *in vivo* digestibility (Deinum and Van Soest 1969; Oddy *et al.* 1983). However, the accuracy of predictions is influenced by different factors and the techniques must be modified for local conditions.

The most common *in vitro* procedure is the so-called "two-stage *in vitro* technique" which was described by Tilley and Terry (1963). In the first stage of this method the finely-ground samples of the test feeds are incubated with buffered rumen liquor in glass tubes under anaerobic conditions for 48 hours. In the second stage protein solubilisation is continued by Pepsin-HCl solution. Total dry matter disappearance of the samples is considered to be digestible dry matter or organic matter. Digestibility determined by the *in vitro* technique is generally slightly lower than that measured *in vivo* and corrective equations may be required (McDonald 1988).

In spite of the two-stage technique for *in vitro* digestion being the most accurate laboratory method for predicting digestibility of animal feeds, its requirement for fistulated animals is an important disadvantage of this method. Thus recently many attempts have been made to predict digestive values using enzymatic preparations (De Boever *et al.* 1988).

One measure of nutritional value is the rate of digestion of roughages in the reticulo-rumen of ruminants. This rate can be measured using a useful, simple, fast and cheap technique, the so-called nylon bag *in sacco* or *in situ* technique (Chenson *et al.* 1970; Mehrez and and Orskov 1977; Playne *et al.* 1978; Uden and Van Soest 1984; Kandylis and Nikokyris 1991). The use of the nylon bag technique was first reported by Quin *et al* (1938) and since then numerous reports have been presented using this technique (Balch and Johanson 1950; Erwin and Ellison 1959; Van Keuren and Heinemann 1962; Ørskov and Deb Hovel 1978; Mapoon 1980; Nakashima and Ørskov 1992).

In this technique small amounts of feed samples are placed in the nylon (Dacron) bags and incubated in the rumen of fistulated ruminants for pre-defined periods of time. The differences in weight of samples before and after incubation are considered as dry matter or organic matter disappearance. Rumen degradation of feedstuffs is best correlated with *in vivo* digestibility (Uden and Van Soest 1984).

Factors affecting the accuracy of the *in sacco* technique can be divided into three categories: (a) bag specifications; (b) sample preparation and (c) experimental animals. Bags for the *in sacco* technique are generally constructed from single pieces of nylon (Dacron or Polyester) cloth (Ørskov *et al.* 1980; Weakley *et al.* 1983; Vik-Mo and Lindberg 1985; Susmel *et al.* 1990). The pore size of the bag cloth regulates the passage of solid particles from and rumen microorganisms into the bags (Ørskov *et al* 1980; Lindberg and Knutsson 1981; Lindberg

1985). Small pore size restricts the flow of rumen liquor and large microorganisms (protozoa) may not be able to enter the bags and also there is a risk of gas formation in this kind of bag (SCA 1990). Uden *et al.* (1974) found dry matter disappearance of Guinea grass from nylon bags with a 53 micron pore size was higher than those with 20 or 35 micron porosity bags. Lindberg (1985) noted that degradability of feed proteins in the rumen was underestimated when pore size was 10 micron and overestimated when it was 36 microns, but Setälä (1985) for the same materials proposed the bag pore size of 40 microns. Nocek (1985) reported that disappearance of soybean meal was higher for bags with porosities of 80 and 102 microns compared with 6, 20, 40,or 59 microns. Ibrahim *et al.* (1988) and Gomez Cabrera and Van der Meer (1988) considered bag pore size of 41 microns for estimating the degradability of rice straw and barley straw.

Different sizes of nylon bags have been used: for example, dimensions of 3.5 x 5.5 cm (De Boer *et al.* 1987), 5 x 8 cm (Mehrez and Ørskov 1977), 10 x 11 cm (Michalet-Doreau and Cerneau 1991), 7 x 10 (Flachowsky *et al.* 1991), 8 x 10 (Ørskov and DeB-Hovel 1978), 10 x 12 (Weakley *et al.* 1983), 9 x 17 (Chapman and Norton 1982) and 19 x 10 cm (Gomez Cabrera and Vander Meer 1988). However, SCA (1990) concluded that a suitable size for the bags is 12.5 x 8.0 cm, which after tying will have an effective surface area of around 150 cm^2. Nylon bags with double-stitch sewing and rounded bottom corners are recommended (Ørskov *et al.* 1980).

Preparation of the samples for this technique is critical: samples should represent the materials which are consumed by the animals. The bulk density of feeds probably is the main factor that determines the size of samples. Ørskov *et al.* (1980) reported that 2 g air-dry ground straw, 3 g good quality hay, 5 g of concentrate and 10-15 g of fresh herbage are suitable sizes. Susmel *et al.* (1990), Ibrahim *et al.* (1988) and Van der Koelen *et al.* (1992) incubated 5 g of air-dried forages, rice straw and a mixed ration per bag respectively. Lindberg (1985) noted the relationship between amount of sample per unit bag area gave a better estimation of sample size and with this result he concluded that for bags with a pore size of 20 to 40 microns sample size could be 10-15 mg dry matter/cm^2 bag surface area. Setälä (1985) demonstrated that the size of the sample in the bag with internal dimensions of 6x12 cm, should be 25-30 mg dry matter per cm^2 for feed protein. The best particle size of samples would ideally seem to be those which are masticated and presented to the rumen, but little information is available to compare particle size of fibrous materials for *in sacco* experimentation (Nocek 1988).

The *in sacco* technique has been used in several animal species including permanently fistulated sheep (Ford *et al.* 1987; Pienaar *et al.* 1989), cattle (Van der Koelen *et al.* 1992), steers (Von Keyserlingk and Mathison 1989), heifers (Uden and Van Soest 1984), buffalo (Jelan and Kabul 1988) and goats (Uden and Van Soest 1984). Fistulated animals should be fed at maintenance level or slightly higher, and their basal diet should have the same characteristics in common with the materials under investigation (SCA 1990).

A maximum of six nylon bags may be placed in the rumen of sheep at any time, but more can be incubated in larger animals. Bags should be suspended in the rumen freely and the recommended length of cord from the cannuala is about 20-25 cm (Kempton 1980) in sheep. A minimum of three animals or three replications must be used (SCA1990). The time required for complete degradation varies with the feeds being incubated. As a rough guide, the time for reaching the potential degradation is 12-36 hours for concentrates, 24-60 hours for good-quality hay and 48-72 for low-quality roughages (Ørskov *et al.* 1980; Adebowale *et al.* 1989).

It can be concluded that the *in sacco* technique is a rapid and simple method for obtaining basic information about potential digestibility and nutritive value of livestock feedstuffs. Its value for assessing the extent and rate of degradation of low-quality roughages should be investigated further.

2.3 Utilisation of low-quality roughages by ruminants

2.3.1 Definition

In general, roughages have been defined as rough, coarse and bulky feedstuffs of low nutritive value, containing high levels of crude fibre, which stimulate intestinal muscular movements (Allen 1984; Dalal-Clayton 1985; Budget Books 1988; Macquarie Library 1990). Roughages usually indicate vegetative parts of the plants which are more fibrous, often highly lignified and therefore less digestible (Evans 1979; Castillo 1983; Ellis *et al.* 1988; Hunter 1988). These fibrous feeds are derived from many types of plants, both pasture and crop, in response to mainly environmental factors. In addition to crop residues, mature pasture plants are classed as low-quality roughages (Hunter 1988).

Owen (1976) has divided fibrous materials into four broad categories: (a) crop waste produced in the field. These can be further divided into materials with a high dry matter content such as cereals, legumes and grass straws and materials with a high moisture content such as sugar beet and sugar cane leaves (tops) and horticultural by-products; (b) crop wastes produced in industrial processing such as sugar cane bagasse, oilseed husks, sugar beet and citrus pulp; (c) fibrous wood waste such as sawdust, bark, waste wood, pulp and paper-making residues and (d) fibrous animal waste consisting of undigested parts of the feed and bedding materials.

2.3.2 Characteristics and availability

The cell wall of mature plants is made chiefly of cellulose, hemicellulose and lignin (Han 1978; Bacon 1988). Lignin, which is not a carbohydrate, is closely associated with cellulose and hemicellulose in the plant cell wall, confers chemical and biological resistance to this wall and mechanical strength to the plant (Barton 1988; McDonald *et al.* 1988). Cell wall can account for up to 90% of the plant dry matter (Aman and Graham 1990) but there is a considerable variation in its composition mainly in relation to different stages of growth and maturity (Hogan and Weston 1969; Hogan *et al.* 1969). A high percentage of lignin in sawdust and bark and the very high content of silica in paddy straw and hulls are examples of variation (Jackson 1977). Bacon (1988) has concluded that the amount of cellulose in the total plant cell wall dry matter ranges broadly from 35 to 60%.

The cellulose molecule is a linear polymer of ß (1-4) glucose units. Hemicelluloses are made up of relatively short chains of a mixture of glucose and mannose linked in ß (1-4) form to the cellulose (Hogan and Leche 1983). The lignin molecule is made up of many phenyl propanoid units associated in a complex cross-linked structure (McDonald *et al.* 1988).

The chemical composition of poor-quality roughages varies with type and variety, stage of maturity, location, climatic conditions and cultural practices (Jackson 1977; Hogan and Leche 1983). Mature roughages such as cereal straws have been known for their high level of fibre and low amount of crude protein (Dixon 1987). The crude protein contents of legume straws and oilseed hulls are relatively higher, but still their crude fibre contents are as high as cereal straws. Fibrous residues seem to be better sources of the major minerals such as calcium, magnesium, potassium and in some cases sodium (Coombe 1980).

Approximately 40% of biomass produced by photosynthesis every year finishes up as by-products (Boda 1990). The fibrous roughages are the major classes of this biomass. One method for estimating the quantity of some of them is from crop production. In almost all cases the quantity of residues or by-products is equal to or greater than the quantity of products used directly as human food (Kiflewahid 1983). The estimated quantity of cereal straw, sugar cane and sugar beet residues produced in 1990 is shown in Table 2.1.

Grain legume and grass crops produce some residues but compared with cereal straws these are quantitatively unimportant (Owen 1976). For example, in the ICARDA region, the overall contribution of grain legume residues to the diets of ruminants is about 1 percent, whereas for cereal straws this value is approximately 30 percent (Capper 1988). The nutritional studies carried out by Allden (1978-1979) in South Australia indicated that grain legume crops and residues are superior to cereals but quantitatively are unimportant.

Besides the materials in Table 2.1, industrial fruit processing produces localised amounts of residues such as citrus pulp. The quantity of wood wastes which is not shown in table 2.1 is also large and probably about half that of cereal straw (Owen 1976).

The value of the energy which could be made available from Australian fibrous roughages (Table 2.1) each year could support about 48 million sheep for one year at about maintenance levels. If these roughages were treated by chemical, physical and other methods (next section) their potential could be much higher. Theoretically, on a world scale also, large number of ruminant livestocks can survive on these materials each year. However, more than 3/4 of these by-products are left on the land (mainly in developed countries) and not harvested (Spedding 1971).

Table 2.1 Estimated quantity of fibrous roughages generated from world crop sources

Type of roughage	S.A.	Australia	Africa	Asia	Europe	N. America	Oceania	S. America	USSR	World
Cereal straws:						Dry matter in millions of tonnes				
Barley	1.5	4.0	5.1	18.4	71.3	23.1	4.4	1.0	57.0	180.3
Maize	-	0.4	67.6	246.5	86.8	453.0	0.7	64.2	32.0	950.8
Millet and Sorghum	-	1.9	38.7	33.5	1.1	29.4	1.9	20.9	7.6	133.1
Oats	-	1.6	0.2	1.0	12.1	8.8	1.7	1.2	18.8	43.8
Rice, paddy	-	0.9	11.5	478.7	2.4	9.0	1.0	13.5	2.5	518.6
Rye	-	-	-	1.3	13.5	1.2	-	0.1	21.0	37.1
Wheat	2.0	15.7	14.0	198.7	131.3	110.3	15.9	16.9	108.0	595.1
Cereals total	3.5	24.5	137.1	978.1	318.5	634.8	25.6	117.8	246.9	2458.8
Sugar cane by-products:										
Bagasse	-	5.2	14.6	82.5	0.1	34.7	6.1	66.4	0.1	204.5
Tops	-	6.6	18.2	106.5	0.1	43.3	7.6	83.0	0.1	258.8
Sugar beet tops	-	-	1.8	16.0	67.5	11.3	-	1.1	35.3	133.0
Sugar cane & beet Total	-	1.8	34.6	205.0	67.7	89.3	13.7	150.5	35.5	596.3

Source: FAO (1990) and Australian Bureau of Statistics (1992b)
Assumptions: (a) Straw/grain ratio, 1:1 for wheat, rye, barley, oats and rice; 2:1 for maize, sorghum and millet with straw DM of 85%. (b) Sugar cane tops/cane ratio 1:4, sugar cane bagasse/cane ratio, 1:5; sugar cane tops DM 30%, sugar cane bagasse DM 50%. (c) Total DM production top:root ratio 1:2.3; root DM 24%, top DM 15% (Owen 1976).

2.3.3 Importance of using low-quality roughages as animal feeds

The total world population was about 2,400 million at the middle of this century. It reached 5,300 million forty years later (FAO 1990). The world population is still increasing. The present increase is around 250,000 per day (90 million per year). The United Nations has predicted that by the year 2050 the world population will reach 10,000 million people (Langer and Hill 1991). This high world population creates enormous pressures and demands for food and other resources. At present, hunger and under-nutrition is the main problem for an increasing proportion of the world's human population (Boda 1990). The problems of feeding the world's livestock is equally great and both food and feed must be produced against declining resources of soil and vegetation.

Protein deficiency is a serious problem for developing countries. The average daily consumption of animal protein is 24 g per capita in the world, but there are big differences between the advanced and the less-developed countries. For example, this figure is more than 65 for Australia and for Africa and Asia it is about 11 g per capita (Boda 1990). To meet human food requirements and to overcome this deficiency (Kapasiotis 1976) man has developed a range of crop plants, techniques, tools and facilities. However, the main factor hindering the expansion of animal production in the developing countries is the inadequate supply of good-quality roughage (Promma 1988).

Huge amounts of low-quality roughages are produced every year as a result of production, processing and utilisation of food (Tannenbaum and Pace 1976). These can be converted into useful products by feeding them to ruminants (Coombe 1980). In many regions of most countries of South East Asia, West Asia and North Africa feeding systems for ruminant animals for at least part of the year are based on by-products such as fibrous crop residues or dried mature plants which have few alternative uses (Jayasuriya 1983; Kiflewahid 1983). Traditionally, farmers have accepted that crop residues constitute the principal supply of roughage for their livestock during the dry period (Promma 1988). Australia and many of the developing tropical countries suffer from a prolonged seasonal drought period which imposes a severe limitation on successful animal production systems. Fibrous crop residues such as cereal straws can be used during the dry season to supplement poor-quality grazing (Coombe 1980).

Many countries are trying to become self-sufficient in food production. Therefore it is logical to utilise as much as possible of the animal feed resources available. Utilisation of low-quality roughages has an important role in this context (Sundstøl 1984). Modern methods of cereal cropping tends to produce large quantities of fibrous residues (Burrows *et al* 1979). Generally, the disposal of these ligno-cellulosic residues is a big problem for farmers. Burning is regarded as wasteful (it also causes pollution) so a more positive approach is encouraged.

The current utilisation of fibrous materials has been classified by Castillo (1983) as follows: (a) ruminant feed; (b) fertiliser or soil improver; (c) fuel; (d) source of building/construction, kitchen utensils, handicrafts; (f) source of herbal medicines, biologics or chemicals and (g) miscellaneous uses.

In India, it has been estimated that dry roughages (mainly cereal straws) provide over 50% of the annual feed supply (Coombe 1980). In some advanced countries such as England straw has been used for paper making (Owen1976). Dixon and Egan (1988) reported that in South East Asia ruminants are usually dependent on diets based on crop residues at least for part of the year. Many attempts have been made to maximise the use of fibrous crop residues as animal feeds through supplementation or applying different treatments. In Africa, some proportion of cellulosic materials is traditionally used in livestock feed, fuel or bedding but large quantities are still wasted (Kiflewahid 1983). In North America a great number of trials have been conducted to use wood waste as animal feeds (Boda 1990).

2.3.4 Limitations to using roughages as animal feeds

Various factors influence the quality of animal feeds (Van Soest 1981). Fibrous residues are those feed resources that are low in digestibility, intake and efficiency. The factors which affect the quality of fibrous feeds may be separated into two classes i.e. chemical factors and physical factors (Evans 1979).

It is generally known that low animal productivity on poor-quality residues is due to low palatability and low intakes of digestible energy and protein which are, in turn, due to changes in the chemical composition of the plant as it matures (Han 1978; Coombe 1980). As plant cell walls mature the fibre contents (basically lignin) increase, but with a disproportionate decrease in soluble nutrients and fermentability. Lignin is the major factor causing decline in the digestibility of plant cell walls with maturity (Harkin 1973). It protects the structural polysaccharides, which are combined with it, from microbial breakdown (Boda 1990). The physical factors are related to the morphology of cellulose in the cell wall structure (Van Soest 1981).

The limitation to using the poor-quality roughages, or crop residues, as ruminant feeds can be summarised as follows: (a) low palatability, intake and digestibility (Han 1978; Dixon and Egan 1988; Hunter 1988); (b) low concentrations of nitrogen, sulphur and essential minerals for optimal rumen fermentation (Coombe 1980; Dixon and Egan 1988; Hunter 1988); (c) seasonal availability and bulky nature that restrict storage and transportation (Dixon and Egan 1988; Ellis *et al.* 1988) and (d) some fibrous residues contain anti-nutritive factors (Van Soest 1981; Dixon and Egan 1988).

In conclusion, when feeding ruminants a diet based on these materials it is generally impossible to sustain them even at maintenance levels. In such circumstances appropriate treatment and nutrient supplements are required. Improving the feeding value of low-quality roughages will be discussed in the following section.

2.4 Improving feeding value of low-quality roughages

It has been shown that the nutritive value of many lignocellulosic materials can be improved by using various processing methods (Han 1978; Kiflewahid 1983; Sundstøl 1988). Treatment processes can improve the voluntary feed intake, digestible energy content or a combination of these effects (Doyle *et al.* 1986; Sundstøl 1988). The processing methods used could be divided into four categories: (a) physical treatments; (b) chemical treatments; (c) physico-chemical treatments; (d) biological treatments. In addition, methods involving supplementation can also improve the utilisation of these materials.

2.4.1 Physical treatments

Many physical treatments have been employed to increase the feeding value of low-quality roughages. Some of these methods such as chopping and grinding, increase voluntary intake but are unlikely to affect chemical composition. However, others such as soaking, irradiation or steaming under pressure probably have effects on the chemical composition of fibrous feeds.

Long fodders such as hay and straws are sometimes chopped to reduce wastage and to facilitate feeding. Nevertheless, cutting of long straws and other low-quality roughages into short pieces does not alter the cell structure (Doyle *et al.* 1986) and hence does not increase its digestibility for cattle or sheep (Sheehy 1955).

Grinding low-quality roughages increases the surface area accessible for microbial attack in the rumen (Smith and Broster 1977; Doyle *et al.* 1986). The extent of any increase in cellulosic surface area probably depends on the fineness of grinding. It has been established that the major effect of grinding is increasing voluntary intake (Kiflewahid 1983; Sundstøl 1988) and lowering fibre digestibility (Minson 1963; Wilkins 1981; Seoane *et al.* 1982; Davis 1983). Reduced digestibility following grinding of low-quality feeds can be attributed to increasing the rate of passage from the rumen, without any effect on delignification.

Johanson *et al.* (1964) reported that retention time in the rumen and nutrient digestibilities of ground or pelleted hay were significantly lower than long or chopped hay: however, Greenhalgh and Wainman (1972) concluded that milling roughages increased their voluntary intake. Millett *et al.* (1970) noted that *in vitro* digestibilities can be increased by extreme reduction in particle size and vibratory ball milling was very effective for some wood species. The *in vitro* digestibility of Aspen and Oak wood increased greatly by ball milling about 30 minutes, but a longer period was not more effective.

In an experiment reported by Walsh (1974) straw ground to the size of 3/8" (9mm) gave optimum animal performance when fed at the rate of 30 percent in a complete diet. Despite the increased rate of passage due to grinding, digestible dry matter intake usually increased and this occurred to a greater extent for low-quality roughages than for better quality feeds (Minson 1981). However, the net effect should be assessed in terms of digestible organic matter intake.

Pelleting feed first became popular for poultry and rabbit feeds, because pelleting provides a better edible form for finely ground roughage (Dobie 1959). The pelletised feeds are less dusty, more convenient and pleasant to handle and are not subject to wasting or sorting by the consuming livestock. The feed pellets require storage space about 1/5 of that required for chopped or long hay (Bruhn 1955, 1957; Butler and McColly 1959).

Numerous research reports have shown that grinding and pelleting roughages increases the voluntary intake and performance of livestock consuming these feeds (Wallace *et al.* 1961; Johnson *et al.* 1964; Campling and Freer 1966; Greenhalgh and Wainman 1972; Greenhalgh and Reid 1973, 1974; Van Niekerk *et al.* 1973). This has been particularly true for low-quality roughages (Minson 1981) and when roughages constituted most of the diet (Johanson *et al.* 1964; Greenhalgh and Reid 1973). Generally, *in vivo* digestibility of pelleted roughages is low, but increased intakes more than compensate for this, thus the overall effect is increasing the intake of digestible nutrients (Reynolds and Lindahl 1960) and body weight gain (Cate *et al.* 1954; Weir *et al.* 1959; Wallace *et al.* 1961).

Greenhalgh and Reid (1973) observed that the increase in intake in response to grinding and pelleting was greater in young animals (38%) than older animals (18%) and for mature than for immature herbage. In another experiment (1974) they found that the effect of pelleting on intake was much greater in the short-term (61%) than in the long-term (40%) feeding trials. Campling and Freer (1966) showed the voluntary intake of ground, pelleted oat straw was about 26% greater than that of long straw. The simple explanation for the increasing intake, could be that pelleted feeds are more palatable and spend less time in the rumen (Meyer *et al.* 1959; Pearce and Moir 1964; Campling *et al.* 1963). However, economic constraints such as the cost of processing and transportation can restrict the use of this treatment in some countries and regions.

Soaking and wetting livestock feeds has been practised since early times, mainly on peasant farms as a traditional method. The water treatment has been applied for different diets, such as high-concentrate or high-roughage rations (Dalton *et al.* 1953; Hupp and Lewis 1958; Holzer *et al.* 1975; 1976; King 1982). Dalton *et al.* (1953) and Hupp and Lewis (1958) reported that moistening concentrate feeds for dairy cattle significantly increased rate of ingestion. Meyer *et al.* (1959) found that when ground alfalfa was moistened, feed intake and body weight gain of experimental sheep were increased to almost the same extent as by pelleting. Holzer *et al.* (1976) demonstrated that the performance of animals fed moist diets improved. They concluded that it may be attributed to the effects of three factors: (a) increased feed intake (b) improvement in digestibility and (c) increased concentration of propionic acid in the rumen. Similar results in zebu and buffalo calves were reported by Chaturvedi *et al.* (1973). Koes and

Pfanden (1974) observed a significant increase in digestibility of cellulosic components when water was sprayed over hay prior to feeding to lambs.

Roxas *et al.* (1987) noted that despite this fact, nutrient digestibility and composition of soaked and unsoaked rice straw did not differ significantly, but daily feed intake and body-weight gain resulting from wetted straw was higher than untreated straw. However, there are two disadvantages in using this treatment; firstly, limiting the intake of other nutrients because of consumption of large amount of unnecessary water and, secondly, soaked feeds are liable to turn sour when kept for a period more than a few days especially in warm conditions (King 1982). Therefore, this method of treatment does not appear as suitable as grinding or pelleting.

Irradiation by gamma rays or by high-velocity electrons has been reported to degrade the cell wall structure so that some insoluble carbohydrate components become available for rumen fermentation. This treatment may destroy the natural bonds between lignin and other structural components and reduce the resistance of fibrous feeds to physical degradation without the necessity for fine grinding (Lowton *et al.* 1951; Pritchard *et al.* 1962; McManus *et al.* 1972). Huffman *et al.* (1971) showed that four species of wood, that were exposed to 1×10^8 or 2×10^8 rads of gamma irradiation, had lower cellulose, ADF and ADL content than the un-irradiated samples or those exposed to 1×10^6 and 1×10^7 rads. Although this treatment appears to provide an effective means of enhancing the carbohydrate digestibility of certain roughages (McManus *et al.* 1972), the high costs of the process prohibits its commercial and practical application.

Steam processing and high temperature pressure of low-grade roughages has been reported to increase feeding value by freeing digestible nutrients from indigestible materials such as lignin or silica (Guggolz *et al.* 1971; Klopfenstein and Bolsen 1971; Oji and Mowat 1978; Rangnekar *et al.* 1982). Under laboratory conditions the effects of steam under pressure on fibrous feeds have been very successful. Hart *et al.* (1981) treated ground rice straw, sugar cane bagasse and sugar cane field trash with steam under pressures ranging from 7 to 42.2 kg/cm^2. The *in vitro* enzymatic digestibility of rice straw and sugar cane bagasse was increased from 26 to 47% and from 17 to 41% respectively after 90 sec. at a pressure of 21.1 kg/cm^2. At this pressure crop residues lost between 5 to 8% dry matter due to volatilization.

In an *in vivo* experiment Oji and Mowat (1978) treated ground (1.6 cm screen) corn stover at a pressure of 16.2 kg/cm^2 and 205°C for 15 minutes and fed it to wether lambs. This treatment increased dry matter intake (55%) and apparent organic matter digestibility (4 units). However, Garrett *et al.* (1981) showed that steam pressure treatments of rice straw at a pressure of 28 kg/cm^2 for either 20 or 90 sec. did not improve straw digestibility and lamb performance, but they pointed out that there were no animal health problems with steam pressure treated straws other than body-weight loss that was not likely to be associated with reduced intake of over-pressured straw.

Heat damage, dry matter losses and the generation of deleterious materials are associative problems with this method, also it has no scope in small-scale farming systems due to the cost.

2.4.2 Chemical treatments

Since 1900, chemical treatments have been used for low-quality roughages with the objective of improving the accessibility of cell wall carbohydrates to microbial enzymes in the rumen. A wide variety of chemical treatments has been tested for their potential to improve the nutritive value of these materials (Jones and Klopfenstein 1967; Klopfenstein *et al.* 1972; Jackson 1977; Smith and Broster 1977; Arnason 1979; Hartley 1981; Wilkins 1981; Ibrahim 1983; Kiflewahid 1983; Ben-Ghedalla and Miron 1984; Bunting *et al.* 1984; Lewis *et al.* 1987; Cottyn and DeBoever 1988; Solomon *et al.* 1992;). Although most attention has been given to treatment with alkalis, feeding value of poor-quality feeds may also be increased by treatment with oxidizing agents and acids. Therefore, the chemicals which have been most extensively studied can be classified into three categories: (a) alkalis, (b) oxidative reagents and (c) acids. Alkali treatments usually solubilise hemicellulose and increase the extent and rate of cellulose and hemicellulose digestion. Lignin contents of treated feeds are generally not reduced by alkali treatments (Feist *et al.*1970; Klopfenstein 1978; McManus 1978; Nikolic 1982). Increased digestion is generally attributed to the breaking of bonds between structural carbohydrates and lignin rather than the removal of lignin (Bunting *et al.* 1984).

Many alkalis have been used in laboratory tests to assess potential to increase digestibility of low-quality feeds. Nevertheless, only four alkalis are being routinely used in experimentation with animals. These are sodium hydroxide, ammonium hydroxide, calcium hydroxide and potassium hydroxide (Gadden 1920; Beckman 1922; Siebert 1974; Klopfenstein 1978; Sundstøl *et al.* 1979; Lesoing and Klopfenstein 1981; Djajnegara *et al.* 1985).

In 1895, Lehmann reported that dry matter digestibility of oat straw was increased from 37% to 63% and that of wheat husks from 26% to 56% when boiled in a 2% NaOH-solution. Since the beginning of this century many attempts were made to improve the feeding value of fibrous feeds by chemical treatment and the most prominent among these has been sodium hydroxide treatment. Beckmann (1922) described a practical and on-farm procedure for treating straw with NaOH-solution. In his method chopped straw was soaked for at least 4 h. with 8-fold its weight of 1.5% NaOH-solution at the ambient temperature and pressure. Subsequently, treated straw was washed free of NaOH. The wet-treated straw was fed directly. This treatment increased the organic matter digestibility of straw from 45 to 68%, but resulted in a loss of about 20% of dry matter. Furthermore, the procedure required large amounts of water to wash NaOH-treated straw and this washing removed soluble nutrients. On a large scale it caused a pollution problem (Wilson and Pigden 1964; Hartley 1981; Kristensen 1982; Sundstøl 1988). It has been estimated that about 15-20% of Norway's annual straw production is treated on-farm by the Beckmann technique (Owen 1978).

To eliminate the problems associated with the Beckmann method, since the 1960's several dry caustic techniques have been developed. Wilson and Pigden (1964) described a new method the so-called "dry NaOH treatment" based on the use of a much smaller amount of more concentrated alkaline solution. The moist product is fed to animals without being washed (Jackson 1977). Chandra and Jackson (1971) showed rumen dry matter digestibility of ground maize cobs was increased by more than 100% after using a spray method proposed by Wilson and Pigden (1964) at a rate of 10 g per 100 g of roughage (10%). In a feeding experiment with male calves conducted by Singh and Jackson (1971) digestible organic matter intakes of sodium hydroxide spray-treated straw increased with increased concentrations of sodium hydroxide up to 3.3% . Higher concentrations of alkali were less effective.

The appropriate level of NaOH for dry methods has been the subject of much research. Wilson and Pigden (1964) found that processing wheat straw with up to 9% NaOH caused marked increases in *in vitro* digestibility. Higher NaOH levels gave no further increases. Feist *et al.*

(1970) reported maximum digestibilities of Aspen and red Oak woods was obtained at 5 to 6% alkali with no further increases observed at higher levels. Mowat and Ololade (1970), in a sheep feeding trial, observed that dry matter digestibility of barley straw increased by treatment with 4% of sodium hydroxide but NaOH treatment at higher concentrations was less effective. In general, it is concluded that the best animal performance has been obtained using 3 to 5% alkali.

Sundstøl (1988) has divided the treatment methods of NaOH into three categories: (a) wet treatment, a modified method of the Beckmann procedure which has been used by Norwegian farmers for more than four decades and is still in use; (b) semi-wet treatment, in this method fibrous materials are mixed with 3-5% NaOH at a moisture content of 40-70% ensiled in an air-tight condition for a minimum period of one week and (c) dry treatment, a technique which was proposed by Wilson and Pigden (1964). In this treatment a certain amount of disolved alkali is sprayed on the low quality roughages, mixed and fed to ruminants without washing or ensiling.

However, in spite of the high cost of NaOH processing and the high cost of transportation of fibrous feeds nowadays, in most countries feed prices are steadily increasing and therefore effective methods for treatment of poor-quality roughages can be economically employed in many circumstances even on a large scale.

The upgrading of low-grade roughages by ammoniation has been known for a long time (Nikolaeva 1938; Chomyszyn *et al.* 1961; Kernan *et al.* 1981). Ammonia is used in three forms: (a) pure form (anhydrous or gaseous); (b) water solutions (aqueous ammonia or ammonium hydroxide) and (c) solid compounds e.g. urea (Kiangi and Kategile 1981; Davis 1983; Sundstøl 1984; Doyle *et al.* 1986; Cottyn and De Boever 1988).

A simple method for treating straws with anhydrous ammonia has been developed by Norwegian workers. According to their method anhydrous ammonia is injected into wrapped straw with polyethylene sheets at the rate of 30 kg per tonne. Gaseous ammonia penetrates into the stack after evaporating from the liquid. The recommended treatment time is about 8 weeks in northern Europe. Waiss *et al.* (1972) observed that when rice straw was treated with 5% ammonia the optimum moisture content was 30% at ambient temperature.

Generally, ammonia treatment increases digestibility and nitrogen content of treated straws (Ibrahim 1983; Kiflewahid 1983; Promma *et al.* 1985; Cottyn and De Boever 1988). However, two-thirds of the applied ammonia probably remains unattached and therefore the treated materials must be aerated prior to feeding to improve their palatability and intake (Promma *et al.* 1985). In spite of the several advantages of the ammonia treatment such as simplicity in application on farms and no residual alkali after treatment (Hartly 1981), it can be a dangerous chemical to handle. The boiling point of anhydrous ammonia is low at atmospheric pressure (-33.4°C) and it must be kept pressurized (Sundstøl 1988).

Aqueous ammonia is a slow-reacting chemical and a closed reaction vessel is necessary to obtain maximum effectiveness (Waiss *et al.* 1972; Ibrahim 1983). The important advantage of ammonium hydroxide is that it does not need to be pressurised (Kiangi and Kategile 1981). Sundstøl *et al.* (1978) concluded that after mixing the roughages with this alkali a reaction time of about 4-6 weeks is needed, but this can be reduced by increasing the temperature.

Urea is a more widely available source of ammonia to farmers and more pleasant chemical to handle than the other forms (Cloete *et al.* 1983; Wongsrikeao and Wanapat *et al.* 1985; Sahnoune *et al.* 1991). Generally, treatment of roughages with fertilizer-grade urea involves spraying these materials with 4-5% urea dissolved in equal amounts of water and storing the treated roughages after mixing for sufficient time (3-4 weeks) for the urea to be hydrolysed (Ibrahim 1985; Dixon and Egan 1988; Sundstøl 1988).

However, in some cases the intake of ammoniated straw has been reduced less than for untreated material and this might be due to the residue of ammonia. It is recommended that urea-treated roughages should be aerated for a few hours before feeding to animals (Ibrahim 1983).

Calcium hydroxide is a weaker alkali than NaOH because its solubility is low and, therefore, a longer period of time is needed for a desirable reaction (Ibrahim 1983; Verma 1983; Doyle *et al.* 1986; Kristensen 1982). To compensate for the low solubility of $Ca(OH)_2$, higher concentrations than those used for NaOH and the use of soaking methods are recommended (Djajanegara *et al.* 1985).

Gharib *et al.* (1975) observed that using a longer period (150 days of treatment) $Ca(OH)_2$ treatment was as effective as NaOH in improving the digestibility of poplar bark. Asadpour and Klopfenstein (1979) mixed and ensiled wheat straw with 4 and 5% $Ca(OH)_2$ for 3 weeks prior to feeding to wether lambs. They found the daily gain of experimental lambs was increased from 9 g for a control group to 60 and 80 g per day for straw-treated with 4 and 5% $Ca(OH)_2$ respectively. Djajanegara *et al.* (1985) treated hammer-milled (30 mm screen) wheat straw by soaking in a suspension containing 9 g $Ca(OH)_2$/100 g straw. At the end of soaking time treated straw was pressed and dried at 55°C for 24 hours and then mixed with other ration ingredients and fed to sheep. Their data showed that organic matter intake increased from 398 g/d for untreated to 685 g/d for $Ca(OH)_2$ treated straw and digestibility increased from 54% to 62%, without any adverse effects of the high calcium intake.

Using the spray method, $Ca(OH)_2$ has been found to be inferior to sodium hydroxide (Gharib *et al.* 1975). $Ca(OH)_2$ has also been combined with other alkalis to produce better results (Waller and Klopfenstein 1975; Asdpour and Klopfenstein 1979; Kiflewahid 1983). For example, Kiflewahid *et al.* (1983) reported that the best results were obtained with 4% NaOH plus 2% $Ca(OH)_2$, when the treated straws were supplemented with 5% molasses and 2% urea.

However, $Ca(OH)_2$ is a cheaper and safer alkali than the other alkalis. It supplies calcium to the ration without adverse effects, hence it can be applied to farm and village situations, mainly in developing countries. More experiments with $Ca(OH)_2$ are needed.

Potassium hydroxide (KOH) has been as effective as NaOH in treating low-grade roughages by the spray method (Rounds *et al.* 1976; Wilkinson and Gonzalez Santillana 1978; Sundstøl 1988). Generally , KOH is more expensive than NaOH , hence it has not been commonly used in an attempt to upgrade the feeding value of low-quality feeds (Doyle *et al.* 1986; Sundstøl 1988).

The polyhydric structure of cellulose and aromatic nuclei of the lignin molecule are susceptible to oxidative attack: therefore, the lignin-cellulose complex may be disrupted by treating the poor-quality roughages with oxidative reagents (Han 1978; Lewis *et al.* 1987).

Gaseous sulphur dioxide (SO_2) has been used to improve the nutritional value of poor-quality feeds (Ben-Ghedalia and Miron 1983; 1984; O'Shea and Baldwin 1986; Ben-Ghedalia *et al.* 1988). In an *in vitro* experiment Ben-Ghedalia and Miron (1983) found that the major and general effect of SO_2 was solubilising the matrix polysaccharides. In another experiment (1984) they showed that SO_2 treatment of wheat straw at the level of 40 g/kg decreased cell wall content from 79 to 56%. The same pattern was observed in organic matter digestibility.

In the third report from Ben-Ghedalia *et al.* (1988) it was concluded that SO_2-treated straw plus poultry litter can replace up to 60% of the concentrate in lamb-growing rations.

It has been shown that ozonation with O_3 gas is an effective treatment for improving the nutritive value of fibrous materials (Weakley and Owens 1975; Ben-Ghedalia and Miron 1981; Ben-Ghedalia *et al.* 1982; Ben-Ghedalia and Rubinstein 1986). In addition to solubilisation of the cell wall matrix, O_3 gas oxidises about half of the lignin fraction into organic acids (Solomon *et al.* 1992). In an *in vitro* study Ben-Ghedalia *et al.* (1980) reported organic matter digestibility of cotton straw was increased more than 100% by the ozone treatment (from 30% to 61%). In spite of this method being an effective and rapid treatment, the cost is high, mainly because O_3 generation needs sophisticated facilities (Alexander *et al.* 1987).

The effectiveness of some chlorine compounds in improving the nutritive value of straw on a laboratory scale (Yu *et al.* 1971, 1975; Cross *et al.* 1974; Ford 1983) and in *in vivo* studies (Miller *et al.* 1979; Ford *et al.* 1987) has been examined. These compounds generally oxidise the aromatic structures of the cell wall matrix. Ford (1978) reported that sodium chloride treatment reduced lignin concentrations of Pangola grass by between 52 and 87%. Similar results were reported by Goering *et al.* (1973) in applying sodium chloride treatment to several straws. However, the accumulation of some chemicals e.g. NaCl could cause environmental problems.

An alkaline solution of hydrogen peroxide (H_2O_2) reacts with lignin and similar compounds in plant cell walls. Low molecular weight, water-soluble oxidation products are the result of this reaction. About 50% of lignin is solubilised by this treatment and the derived products are not toxic (Gould 1985). Lewis *et al.* (1987) in a series of *in sacco* studies concluded that this reagent was effective in improving dry matter digestibility over that of NaOH treatment alone.

Some of the lignin-carbohydrate bonds of the plant cell wall are very acid labile (Crosthwaite *et al.* 1984). Acid treatment of coarse roughages hydrolyses mainly the hemicellulose portion of the cell wall (Doyle *et al.* 1986). In the experiments which were reported by Han (1978) acid hydrolysis of fibrous agricultural residues was used as a preliminary step. Dilute sulphuric acid has been tested for improving the nutritive value of woody materials (Boda 1990). Balasubramanya and Bhatawekar (1980) found that the maximum amount of sugar (about 30-34%) was released from rice and wheat straws when heated with 0.5 N H_2SO_4 at 121°C and water:substrate ratio of 3:1.

In a series of experiments for improving the feeding value of some fibrous materials with acids, which were carried out by Crosthwaite *et al.* (1984) cellulose digestion in bagasse was increased by about 87% after treatment with 1% sulphuric acid. The maximum effect with sulphuric acid was derived after about 10 weeks storage at 30°C. Cellulose digestibility of wheat straw was increased from 19% to 34% after treatment with 17% HCl using a storage time of 3-4 weeks at room temperature. Acid treatment of low-quality feed could be a low-cost and feasible method at the village level in under-developed countries. However, some disadvantages are involved such as the danger in handling and transporting acids, also the low pH of the treated materials. More in vitro and *in vivo* studies are needed in this area if this method is to be more widely used.

2.4.3 Physico-chemical treatments

The combination of physical and chemical treatments might be expected to be more effective in improving the feeding value of poor-quality roughages (Chandra and Jackson 1971; Guggolz *et al.* 1971; Fernandez Carmona and Greenhalgh 1972; Coombe *et al.* 1979). The surface area of roughages can be increased by reduction in the particle size and it is expected that chemical treatment of these smaller particles will give better results. In a feeding trial with beef steers conducted by Coombe *et al.* (1979) alkali treatment of either the chopped or pelleted straw increased the digestibility of these components by about 10 units compared with the respective untreated straw.

The effects of chemicals can be influenced by temperature. Ololade *et al.* (1970) reported that the *in vitro* digestibility of alkali-treated barley straw was increased as the temperature increased with the optimum temperature being about 80°C. Hart *et al.* (1981) found that digestibility of rice straw was improved from 26% to 47% without additives and 64% with NaOH under a pressure of 21.1 kg/cm^2. It is suggested that the combination of different processing methods has some benefits, but the additional costs this entails must be considered.

2.4.4 Biological treatments

The possibilities of improving feeding value of lignocellulose materials by biological treatments has been studied over many years (Leatherwood *et al.* 1960; Ralson *et al.* 1962; Baker *et al.* 1973; Hartley *et al.* 1974: Burrows *et al.* 1979; Latham 1979; Ramasamy and Veruchtert 1979; Zadrazil 1979; Wilkins 1981; Jung *et al.* 1992). The biological approaches can be grouped as follows: (a) ensilage; (b) fermentation and fungal growth; (c) enzymatic hydrolysis and (d) mushroom cultivation (Han 1978; Doyle *et al.* 1986). Ensilation of green fodder for improving and conserving their feeding quality through anaerobic fermentation has long been understood. In this treatment, anaerobic microorganisms, predominantly acidify *Lactobacilli,* rapidly repress the growth of undesirable microorganisms. The lactic acid resultant from this process also gives desirable odour and taste to the mass (Han 1978).

Nitrogen additives such as urea, biuret or ammonium polyphosphates and readily-fermentable carbohydrates, such as molasses, have been added to low-quality, roughage-based silage. As Kifelwahid (1983) reported, mixing urea, molasses, NaOH or even cattle excreta with agroindustrial by-products in many African countries produced good silages. Similar attempts have been made in Asia (Wanapat 1987; Cheva-Isarakul 1988).

Many efforts have been made to increase the protein content of cellulosic materials by aerobic microorganisms (Thomson and Poole 1979). Numerous microbes are capable of using cellulose for their growth, such as *Cellulomonas* (Han and Callihan 1974), *Pseudomonas* sp. (Ramasamy and Verachtert 1979). Most processes involving growing microorganisms have been aimed at production of protein of microbial origin which can be used as a feedstuff for non-ruminants (Han and Anderson 1975; Ibrahim 1983).

The main attempts in this area have been given to treatment of lignocellulosic materials with white-rot fungi which degrade lignin rather than structural carbohydrates (Han 1978; Latham 1979; Jung *et al.* 1992). But as Jung *et al.* (1992) reported, even though straw treatment with white-rot fungi can improve its quality, the loss of dry matter severely limits the practical benefit of this method.

There is interest in the addition of cell-wall-degrading enzymes to fibrous feeds as a means of improving feeding value. Supplementation with these enzymes gave variable and inconclusive results (Leathewood *et al.* 1960; Ralston *et al.* 1962; Willis *et al.* 1980). However, it seems that at present the cost of suitable enzymes is too high for the technique to be of commercial use.

Some fungi convert lignin and structural carbohydrates into fungal protein (e.g. mushroom) suitable for human food and animal feed (Han 1978). Some changes may occur in the chemical composition and nutritive value of spent lignocellulosic materials but it depends on the type of fungus, the nature of material and the growth conditions. It is still far from clear which type of mushroom cultivation can improve the feeding value of fibrous feeds.

2.4.5 Supplementation methods

The major limitations of fibrous feedstuffs are low digestibility, low intake and the deficiency of some essential nutrients. For efficient utilisation of fibrous materials by ruminants the shortage of specific nutrients such as N and S may be corrected by supplementation (Coombe and Tribe 1962; Ernst *et al.* 1975; Schiere *et al.* 1985, 1988; Dixon 1987; Cheva-Isarakul 1988; Aitchison *et al.* 1986; Doyle and Panday 1990; Paduano *et al.* 1990). Cereal grain and molasses are often used as energy supplements for ruminants consuming low-quality roughages. It can be generally concluded that supplementation of fibrous feeds with readily-available energy sources at about 10-15% may increase the intake of poor-quality roughage only when nitrogen and minerals are enough for microbial synthesis (Cheva-Isarakul and Kanjanaprutjipong 1987; Doyle *et al.* 1986). Molasses has been widely used with urea for feeding of ruminants at maintenance levels during the dry season. Entwistle and Baird (1976) and Niven and Entwistle (1983) reported that feed intake and productivity of sheep can be increased by molasses supplement as low as 50 g dry matter per day.

Ration supplementation with non-protein nitrogen (NPN) has been known for a long time. Nitrogen supplements only work when N is the primary limiting factor (Egan 1986). In most circumstances it is important to provide a source of readily-available energy such as molasses to ensure efficient use of NPN (mainly urea) due to its rapid degradation (Doyle 1983).

2.5 Lot-feeding

2.5.1 Introduction

Lot-feeding on a commercial scale originated in the 1950's in the United State of America, primarily for converting surplus grain into high-quality meat from beef cattle (Moore 1990). Although the first feedlots were established at the same time in Australia (Howard and Plasto 1991) it is generally considered that the feedlot industry began in the early 1960's in Australia (Tucker *et al.* 1991). At present, the total Australia beef cattle feedlot capacity is about 2.3% of the national herd of 22 million. The increasing demand from both domestic and overseas markets positively affects the feedlot industry in Australia (Callow1992). In South Australia, Clark (1985a) noted that commercial beef cattle feedlots were used: (a) for finishing stock that could not be finished on pastures; (b) in specialised feeding for a specific market; (c) as opportunity feedlots when store cattle are cheap or surplus grain could not be sold economically; (d) to take advantage of local industry by-products and finally (e) as an alternative to feeding at maintenance level in droughts.

Lot-feeding of sheep in Australia has became a more common practice recently (Hall and Mulholland 1982). In South Australia, sheep lot-feeding has been undertaken for various reasons. (a) In the Mediterranean-type environment of this State, generally there is a 3-5 month dry period during summer and early autumn (Allden 1959). In these seasons paddock feed may not support the flock so lot-feeding can maintain livestock numbers. The dramatic effects of heavy grazing on medic pastures as reported by Carter (1981a, 1982) and Carter *et al.* (1982) can be reduced by lot-feeding of sheep during the dry period of year. In other words, lot-feeding can be used to protect both the soil and the pasture legume seed supply (Carter *et al.* 1993). (b) In continuous sheep grazing over the summer months soil is at risk of wind erosion. Lot-feeding can be considered as an integral part of the "risk management program" on farms (Morbey and Ashton 1990). (c) In seasons where paddock feeds are inadequate and cheap supplies of energy sources are available, lot-feeding of sheep can be considered for producing marketable meat with high quality (Hack *et al.* 1988c). (d) When fodder or hay contains weed seeds, farmers could restrict the spreading of these weeds by lot-feeding where weeds can be monitored and controlled (Morbey and Ashton 1990; Ashton 1990). (e) Lot-feeding at the break of the season coupled with deferred grazing reduces the grazing pressure on the young pasture plants and improves pasture establishment (Ashton 1989). (f) The live sheep export from Australia to international markets has developed as a major trade over the past 20 years. These sheep are lot-fed before and during shipping (McDonald *et al.*1990).

2.5.2 Types of lot-feeding

Ashton (1989) has divided lot-feeding of sheep into three different classes as follows: (a) lot-feeding for maintenance purposes. This category involves removing the sheep from the paddocks before they become bare during the dry period. These sheep are kept in yards and fed at maintenance or survival levels. It can be a useful practice for maintaining sheep numbers during droughts. (b) Lot-feeding after the break of the season. This type of lot-feeding has to be done during wet and cold weather, hence the yards and feeds can become wet and boggy. Therefore, it is more difficult than lot-feeding during the dry weather. (c) Lot-feeding for finishing or production. The aim of this management is to produce marketable meat or live sheep. Therefore, sheep requirements, growth rate and feed conversion are the most important factors which must be considered. This type of lot-feeding is different from the other types and the animals should be fed by balanced least-cost complete rations with a high energy content. Computer programs are useful tools in this task for producing the maximum benefits.

2.5.3 Construction of feedlots

Many factors affect the selection of a site for a feedlot. Some are associated with economic considerations and others involved with animal health and environmental performances. Generally the chosen site for a feedlot should have a hard clay or stony base to reduce dust. Ideally, the site should be dry, well drained, sheltered from the wind and be away from sources of frequent disturbance (Ashton 1986, 1990; Bell *et al.* 1986; Hack *et al.* 1988a).

Different yard sizes can be considered, but generally 5 to 10 m^2 per sheep could be a good guide, although the yard size is not a critical point. In a larger area, sheep will tend to walk more and raise dust, cause soil erosion and waste energy. In very sandy conditions a reduced area of 1-2 m^2 per sheep can be used to minimise soil disturbance and consequent dust problems. In wet conditions a larger area e.g. 20 m^2 per sheep is preferred. Group sizes can also vary, but poor results have been experienced with large mob sizes in the feedlots (Bell *et al.* 1986). However, it is preferable to build a number of feedlots if more than 500 sheep are to be fed (Hack *et al.* 1988a).

A supply of fresh, cool and clean water is essential. Water should be available at all times with a daily allowance of 3 to 6 litres for an adult sheep and one metre of trough space for every 100 lambs. However, the speed at which a water trough fills is more important than its size. If the water troughs are located close to the feeding system these should be cleaned regularly to prevent fouling of the water by feed particles and dust (Ashton 1986; Bell *et al.* 1986; Hack *et al.* 1988a; Tucker *et al* 1991).

In feedlots, whole grain and other feeds with small particle size can be trailed on selected clay pans, hard bare ground or other suitable areas, or fed in troughs. In sandy, muddy or deeply cracked soils feeding animals in troughs is necessary. Feed troughs prevent feed wastage and some other problems such as sand impaction (Hack *et al.* 1988a; Ashton 1990). Sometimes self-feeders have been used instead of traditional feed troughs. Self-feeders are convenient and more flexible and by eliminating the need for daily feeding they can reduce labour requirements and the amount of trough space. Also, self-feeders can provide an *ad lib* feeding system (Bell *et al* 1986). However, Tucker *et al.* (1991) reported that self-feeders were an undesirable feeding system, because the accumulated grain and manure under these feeders creates a bad odour and attracts flies and is difficult to remove. Also, beside the higher cost, feeding grain in self-feeders increases the risk of grain poisoning. As a rough guide about 5 cm of trough space per sheep is needed when self-feeders are used (Bell *et al.* 1986).

Feed troughs should be easy to load and clean and designed to minimise spoilage and fouling by animals. Where sheep have access to both sides of the feed troughs a minimum of 12 cm per sheep is needed (Morbey and Ashton 1990). If sheep are fed *ad lib.* about 5 cm (Fels 1980) feed trough is required but on restricted rations more space around 30 cm per sheep is needed (Ashton 1986). Bell *et al.* (1986) noted that the width and depth of troughs for lot-feeding of lambs ideally should be 30 and 25 cm respectively. These types of troughs are suitable for feeding grain alone, grain/hammer milled roughage rations or a grain/whole hay mixture. Troughing should be 15 to 30 cm above ground level. Whole hay can be fed from hay racks. Hay racks can be simply made up from 10 cm square mesh held up by steel posts.

2.5.4 Nutritional principles

Generally sheep rations have two major ingredients, grains and roughages. Sheep in a feed-lot, or in the paddocks as with all ruminants, need roughage to ensure the efficient functioning of the digestive tract. Roughage should comprise about 20-40% of the ration for lambs in feedlots (Bell *et al.* 1991a). Cereal and grain legume straws are produced in abundant amounts in the crop-growing areas of Australia and can be used in place of hay for sheep in feedlots (Ashton 1990).

Rations comprising straw and cereal grain are suitable for maintenance feeding of adult sheep (Ashton 1990). However, many grains and straws have a low protein content for growing animals, and rations often need to be supplemented with small amount of materials with higher crude protein contents. For example, grain legume seeds such as lupins have been added or low-quality roughages sprayed with urea (Dunlop and McDonald 1986). Furthermore, the palatability of low-quality roughages is generally low. A small quantity of good quality lucerne hay or molasses is needed to ensure the initial acceptance (Bell *et al.* 1991a; Tucker *et al.* 1991). In feedlots, sheep should be introduced gradually to high levels of grain in the ration to reduce the risk of grain poisoning (Bell *et al.* 1991b).

Feed accounts for a large proportion of the variable costs of running a feedlot, hence ration quality and quantity and feeding management have the greatest effects on animal performance and the efficiency of the feedlot (FAU 1990). Therefore, it is necessary to provide a balanced and economical ration for animals in feedlots. Many methods have been proposed for ration formulation of farm animals (Crampton and Harris 1969).

Computer programs have been developed for calculating the least-cost ration for intensive livestock industries. Nevertheless, there has been little application in Australia of these programs for formulation of the optimum diets for feedlot animals (Shaw and Thornton 1974). Recently, the Department of Primary Industries in South Australia has produced a computer program (TAKE-AWAY) that calculates least-cost rations for sheep and cattle. This program can formulate suitable rations for different physiological conditions such as maintenance, growth, pregnancy or lactation feeding (Barber 1990).

2.5.5 Animal health in feedlots

In well-managed sheep feedlots health problems rarely occur and the death rate should be less than 1% over about 3 months (Ashton 1990; Langman *et al.* 1990). In a survey carried out by the South Australian Department of Primary Industries on Eyre Peninsula after the 1988 drought the average death rate in farm feedlots was 1.4% (Moreby and Ashton 1990). The main causes of death in these feedlots were: grain poisoning (19%), pregnancy toxaemia (13%), accidents (9%), enterotoxaemia (8%), shy feeders (6%), suffocation (6%) and fly strike (5%). Feedlot health problems can be grouped into nutritional and non-nutritional categories.

Grain poisoning and pregnancy toxaemia are the most serious health problems. Grain poisoning (lactic acidosis) probably is the main cause of death in feedlots. This illness results from a sudden increase in highly-digestible concentrates, such as cereal grains. The inclusion of a large proportion of readily-fermentable grain, reduces rumen pH and the population of potentially-pathogenic micro-organisms within the digestive tract. Some bacteria can migrate to the liver through the inflamed rumen wall and cause abscesses (Hack *et al.* 1988b; FAU 1990; Langman *et al.* 1990). Sheep should be slowly introduced to grain or concentrate and changes to the ration must be made over about two weeks. Adequate roughage must be provided and preferably fed before grain (FAU 1990; Langman *et al.* 1990).

Pregnancy toxaemia is a ewe disease caused by insufficient energy intake during the last 4-6 weeks of pregnancy. The ration should be increased in late pregnancy about eight weeks prior to the start of lambing. A full ration for pregnant ewes should be given 6 weeks prior to lambing (Langman *et al.* 1990). Urea poisoning and sand impaction resulting from feeding sheep on sandy soils are other feed-related illnesses (Clark 1985b; Hack *et al.* 1988b; Langman *et al.* 1990).

The main non-nutritional health problems are enterotoxaemia and pinkeye. Enterotoxaemia occurs when sheep are fed highly-digestible concentrates, although it is usually associated with grazing lush pasture and therefore a regular enterotoxaemia vaccination program must be employed.

Pinkeye can be caused by dust or sharp roughage particles and husks. Extra care is needed for severely-affected sheep. Preferably these sheep are placed in a separate yard in feedlots.

Fly strike, heat stress and accidental death are other non-nutritional health problems which often need attention (Lagman *et al.* 1990; Morbey and Ashton 1990).

2.5.6 Management practices in feedlots

A small proportion of sheep may not adapt to feedlot conditions or miss their share of feed and therefore perform poorly. These sheep known as "shy feeders" or "poor doers" may eventually die of starvation or become susceptible to stress-related illnesses. Up to 5 percent of shy feeders is common when feeding rations with high amounts of grain. These sheep must be managed separately. The proportion of shy feeders can often be reduced by using more feed troughs (greater length per sheep), self-feeders and giving detailed attention to other management aspects (Hack *et al.* 1988b; Langman *et al.* 1990).

Sheep must be vaccinated against enterotoxaemia. Two injections for sheep which have never been vaccinated with an interval of 4 to 6 weeks gives sufficient protection. Endo-parasites can cause significant feed, body weight and production losses (Langman 1988), therefore sheep must be drenched against these parasites before going into feedlots (Ashton 1984, 1990).

Daily checking of sheep can prevent problems before they occur. Feed must be given at the same time every day and detailed records kept. Any dirty section of troughs need to be cleaned. Sheep behaviour and general feedlot conditions are the other daily routine tasks that should be considered (Fels 1980).

At the end of lot-feeding, breeding sheep should be released to the paddock immediately after they have eaten their normal feed. It is recommended that sheep be fed hay for a few days in the paddock. Ewes in late pregnancy should be fed with good quality hay and grain for at least the first week in the paddock especially if the paddock feed is poor (Morbey and Ashton 1990).

However, for most farmers in South Australia sheep lot-feeding is still new and to make this practice profitable detailed attention must be given to all aspects.

3.0 THE EFFECTS OF SHEEP STOCKING DENSITIES IN AUTUMN ON ANNUAL MEDIC PASTURES

3.1 Introduction

In Australian ley-farming systems annual legume pastures are of special interest. These pastures provide low-input and nutritious grazing throughout the year, improve soil fertility (Carter 1987; Carter *et al.* 1989) and provide a break between cereal crops that helps control disease (Carter 1986; ICARDA 1986). The sowing of annual medics began in the 1930's in order to produce high quality livestock feed (Carter 1981b) and replace fallow in cereal/fallow rotations (Carter 1987). Commercialisation of barrel medic (*Medicago truncatula*) and snail medic (*Medicago scutellata*) occurred following seed harvesting of both of these species at Noarlunga, South Australia (Trumble 1937).

The main advantage of annual pasture legumes is that there is no need to re-sow them after the initial year. These species can regenerate following the cereal years mainly from the gradual softening of hard (impermeable) seeds in the surface soil. This natural regeneration of annual pasture legumes (especially medics) following a cropping sequence saves the expense of re-sowing and results in rapid establishment of pasture when adequate reserves of soft seed are available for germination and emergence. The key to medic pasture production is a high density at the break of the season and this depends on seed production, seed survival and adequate softening of hard seed reserves in the soil. Therefore, for the natural regeneration of dense, productive annual legume pastures, adequate survival of pod and seed reserves is essential (Carter, 1981a, 1982, 1987; de Koning and Carter 1989).

The success of this system has been threatened by several factors in recent years. It has been emphasised that many annual pastures are in a very poor state (Carter 1981b, 1982, 1987). Carter (1981b, 1982, 1993) listed 15 major causes of declining medic pastures in South Australia. One of the most important reasons for this deterioration of medic pastures is depletion of medic pods by sheep under heavy grazing of dry pasture residues in the summer-autumn period. This prompted detailed research at the Waite Institute to measure the effects of sheep grazing on annual medic-based pastures in the Mediterranean-type environment of South Australia (Carter 1981a).

From the extensive work carried out by Carter (1993) and his group at the University of Adelaide it has been concluded that the summer-autumn grazing pressure on pod and seed reserves of annual medic is critical to survival of a satisfactory pasture. Therefore, optimal levels of utilisation of dry residues of medic pastures are required to ensure an adequate seed bank of annual medic.

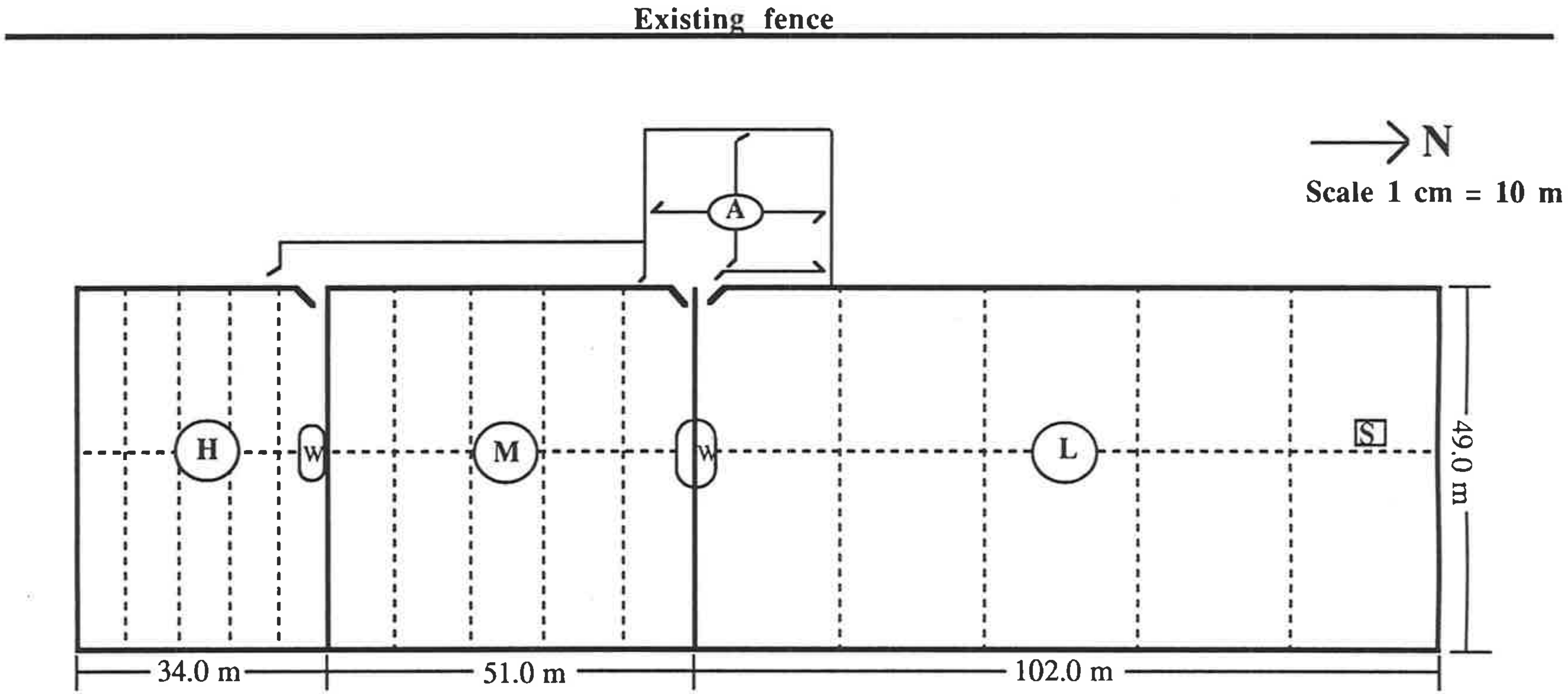
Grazing intensity is one of the most important factors which affects economic output from grazed pastures (Carter 1965, 1968a, 1968b, 1977; Carter and Day 1970; Bransby and Conrad 1985) and the pasture seed reserves. Nevertheless there is little detailed understanding of the interrelationship between different stocking densities, dry residues of medic pastures, pod reserve and seed survival following ingestion by sheep, probably because these kinds of relationships are complex, and considerable research effort is required to obtain the information.

The experiment described in this chapter was carried out to examine the influence of stocking density and grazing period on the disapperance of total dry medic residues, pod and seed reserves and to measure seed survival following ingestion by sheep under the field conditions.

3.2 Materials and methods

Experimental site: The experiment was conducted on a commercial medic seed-producing pasture of barrel medic (*Medicago truncatula*) cv. Paraggio at Korunye, South Australia, approximately 60 km north of Adelaide. The medic at the selected site was grown by the farmer under normal district practices, i.e. sown at c. 10 kg/ha with insect and weed control. The site was divided into three paddocks with dimensions shown in Diagram 3.1.

Stocking densities: Stocking densities were 12, 24 and 36 sheep/ha, referred to as Low, Medium and High stocking densities respectively. Stocking densities were attained by adjusting plot size to 0.5 ha for the low density, 0.25 ha for medium density and 0.17 ha for the high density.



A	Sheep holding and weighing area
L	Low stocking density (12 sheep/ha)
M	Medium stocking density (24 sheep/ha)
H	High stocking density (36 sheep/ha)
S	Stratum
W	Water trough

Diagram 3.1 The experimental areas used for the grazing experiment at Korunye, South Australia

Experimental animals: The experimental animals were 18 full-mouth Merino wethers (castrate males) from the Waite Institute wether flock. The wethers were stratified into body weight classes and randomly allocated to the three stocking densities (i.e. six sheep per paddock). Additionally, three spare wethers were kept in reserve. The sheep were introduced to the appropriate plots on 14 April 1991 and grazed continuously until 5 May 1991.

Animal measurements: Sheep were weighed immediately before introduction to the grazing areas and every seven days thereafter. They were fat scored at the time of weighing according to a standard procedure (see Chapter 7). Sheep from the three flocks were weighed in the same sequence starting at 0900 hr each week.

In order to estimate seed recovery from the digestive tract, the wethers were fitted with faecal-collection harnesses a few days after being introduced to the experimental areas. Total daily collections of faeces from all sheep were made on days 7, 8, 14, 15, 21 and 22 after they were introduced to the grazing areas. Sheep were penned in the morning at 0900 hr in order to remove and replace the faecal-collection bags (Plate 3.1). The total fresh faeces excreted by each sheep was weighed, well mixed and a representative, known, sub-sample of about 100 g taken to determine the dry matter content by drying in a forced-draught dehydrator at 100°C for 48 h. Another 100 g sub-sample was taken in order to measure seed recovery. The remaining faeces samples were dried in a forced-draught dehydrator at 40°C and held in reserve.

The 100 g sub-samples of fresh faeces taken for measuring seed recovery were washed under tap water through a 300 mm diameter square-holed 0.7 mm laboratory sieve. The materials remaining on the sieve (including undigested materials and seeds) were transferred to plastic Petri dishes with three pieces of Whatman No. 1 filter paper at the bottom and one at the top. Each Petri dish was moistened with about 10 ml distilled water containing 1.6 g/litre of the fungicide Thiram. The Petri dishes were placed in a humidified incubator at 19°C for 14 days. During the germination period the Petri dishes were re-moistened when necessary. The emerged seedlings were recorded every second day.

At the end of germination period the dishes containing undigested materials and the remaining seeds were oven-dried at low temperature to constant weight. The seeds were separated from the other residues by using an exhaust cupboard-fan unit. Total seed throughput and the percentages of soft (= permeable) seed that germinated and hard (= impermeable) seed that did not germinate were calculated.

Pasture measurements: The grazed paddock areas (experimental plots) were sampled at the beginning of the experiment and every seven days thereafter. For sampling the pasture, each small paddock was divided into 10 equal areas (strata), see Diagram 3.1. The dry pasture residues on the experimental plots were randomly sampled immediately before introducing the sheep. Thirty circular samples (one per stratum and 10 per grazing intensity) were taken at random using a galvanised steel cylinder of 28.5 cm in diameter. All of the above-ground dry matter was taken from the sampling points.

Concurrent with the sampling of dry pasture residues, 10 areas of about 50x50 cm of the plots (one per each stratum) near to the sampling points were protected against wind and sheep by using galvanised steel mesh and weldmesh cages. The flat steel mesh was pinned to the ground with steel pegs. Tent-like strong mesh was placed over the flat mesh to prevent grazing by sheep. All the protected areas were marked with wooden pegs as permanent markers.

During harvesting of the dry pasture residues, most of the samples were unavoidably contaminated with variable amounts of soil. In order to separate the soil from the samples, organic solvent of 1, 1, 1-trichloroethane, commonly named Genklene (registered trade mark of Imperial Chemical Industries Limited, London) was used because it had no influence on *in vitro* digestibility of the dry residues and germination of the seeds (Carter *et al.* 1977). The whole harvested samples were added to a container of the solvent under an exhaust fume hood, stirred and allowed to settle for a few minutes. The dry residues with other floated materials such as pods and seeds were skimmed from the solvent using a suitable sieve. The samples then were placed in paper bags, under the fume hood for a few hours and finally left on an open bench overnight to be dried at room temperature.

At the end of the 21-day grazing period sheep were weighed, fat scored and returned to the original wether flock.

Seven weeks after the end of the grazing period, counts of emerged seedlings were made (on 22 May 1991). The final harvests from the protected areas on the experiment were made immediately after counting the seedlings. All 240 harvested samples from the grazing areas were weighed and hand separated in two components, mature pods and dry residues without the pods. These components were weighed separately. The pods were processed to obtain mean pod weight, pods/m^2, seeds/ pod, seed weight, seed/hull ratio and hard-seededness.

The dry residues (without pods) were hammer-milled to pass a 1 mm screen. These samples were subjected to the modified two-stage method of *in vitro* digestibility proposed by Tilly and Terry (1963), see Chapter 4.

An estimate of the crude utilisation (CU) of dry pasture residues (Carter and Day 1970) was obtained from the differences between the pasture availabilities at the beginning and end of each grazing period (7 days). In fact, this value was a measure of the disappearance of dry residues rather than of the actual amount consumed by the grazing wether sheep. Some other factors such as wind, birds and insects can remove the dry residues from experimental plots. However the main part is consumed by sheep. This relationship as expressed by Carter and Day (1970) is as follows:

$$\text{Crude Utilisation (CU) \%} = \frac{\text{Amount of pasture DM eaten or otherwise disappearing}}{\text{Amount of pasture DM at the beginning}} \text{ X } 100$$

Germination tests were conducted using the method, detailed in Chapter 4. Briefly, the randomly-selected pods (from the 240 fully-processed samples) were placed in Petri dishes (i.e. 25 pods/dish). The dishes containing whole pods were transferred in a humidified incubator for a period of two weeks at 19°C to allow germination of the seeds in pods, which is the only true indication of the soft seed component.

Plate 3.1 General views of grazing experiment at Korunye showing areas grazed at low stocking density (L), medium stocking density (M) and high stocking density (H) after three weeks of continuous grazing, also sheep-handling pens.


L


M
H

3.3 Results

Pasture availability: The dry pasture residues on offer to sheep at each sampling throughout the experiment are given in Appendices 3.1, 3.2 and 3.3 and summarised in Figure 3.1. Dry pasture residues (without the pods), the available mature pods and the total dry residues (including mature pods) decreased linearly ($P<0.01$) with the grazing time (Table 3.1). Furthermore, there was a highly significant difference ($P<0.01$) between experimental stocking densities for these variables.

The availability of total dry pasture residues after three weeks grazing was reduced by 15, 29 and 41 percent for low, medium and high stocking densities respectively. With increasing stocking density sheep ate relatively more dry residues, compared with pods, so that the percentage of dry residues in the pasture at the end of the experiment was lower than at the begining and the percentage of pods was higher. For example, at the start of grazing at high density mature medic pods were 57% of the total available pasture, but after three weeks grazing, pods increased to 68% (Table 3.2).

The ratios of mature pods to dry residues (without the pods) at the beginning of grazing were 1.30, 1.32 and 1.33 for the plots allocated to the low, medium and high stocking densities, respectively. These ratios at the end of the first, second and third weeks of grazing were; 1.32, 1.32 and 1.34 for low stocking density; 1.38, 1.36 and 1.46 for medium stocking density and 1.42, 1.63 and 2.11 for the high stocking density respectively.

The changes in mature pod densities over the experiment are shown in Appendix 3.4 and Figure 3.2. Pod density (pod number/m^2) declined almost linearly with grazing time for all stocking densities. Differences between stocking densities were significant (Table 3.1).

The average pod weight, seeds per pod and mean seed weight decreased with time (Figures 3.3, 3.4 and 3.5) although this trend was not statistically significant for some of these comparisons Table 3.1). Regardless of stocking density, pod weight and number of seeds per pod declined significantly ($P<0.01$) with increasing the grazing period (Table 3.1).

The potential regeneration of the grazed pasture under natural conditions was measured 49 days after the end of grazing periods. These data are summarised in Figure 3.6. Approximately similar seedling numbers (377 ± 5/m^2) were counted in the experimental plots at the start of the grazing period. However, after grazing at different stocking densities the number of emerged seedlings in the areas grazed by medium and high densities for three weeks was 2.6 and 3.0 times more than the recorded seedlings for low stocking density (Figure 3.6); these differences were highly significant (Table 3.1). Accordingly, the percentage of bare ground increased linearly with advancing grazing time (Figure 3.7). By the end of three weeks the percentage bare ground was very high at the higher stocking density.

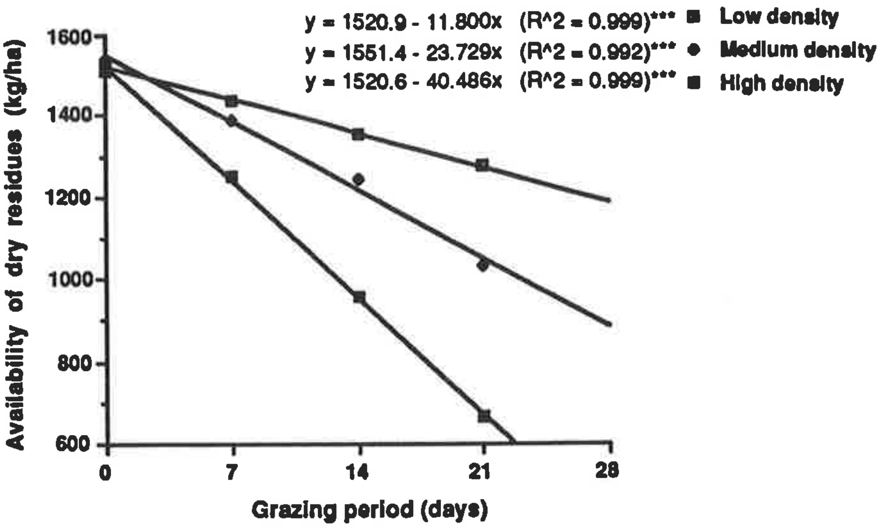
Table 3.1 Summary of analyses of variance on pasture availability data

Component	Comparisons		
	Stocking density	Grazing time	Stocking density x Grazing time
		Significance levels	
Total availability of dry pasture residues	**	**	**
Availability of dry residues without the mature pods	**	**	*
Availability of mature pods	*	*	NS
Pods density (#/m^2)	**	**	NS
Pod weight (mg)	NS	**	NS
Seeds (#/pod)	NS	**	NS
Hard-seededness (%)	NS	NS	NS
Seedlings emerged (#/m^2)	**	NS	NS
Mean seed weight (mg)	NS	NS	NS

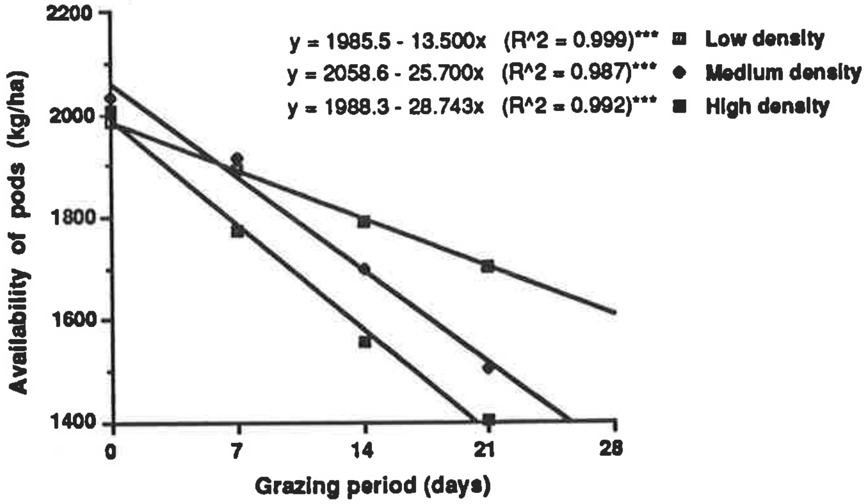
** = $P<0.01$; * = $P<0.05$; NS = Not significant

The percentage pasture crude utilisation (CU), increased significantly ($P<0.01$) with grazing time (Figure 3.8). However, the ratios of crude utilisation to the number of sheep per ha were similar for the different stocking densities and averaged 0.4 ± 0.03 at the end of first week, 0.8 ± 0.06 at the end of second week and 1.2 ± 0.06 at the end of third week grazing.

(A) Dry residues (without pods)



(B) Mature pods



Total dry residues (A+B)

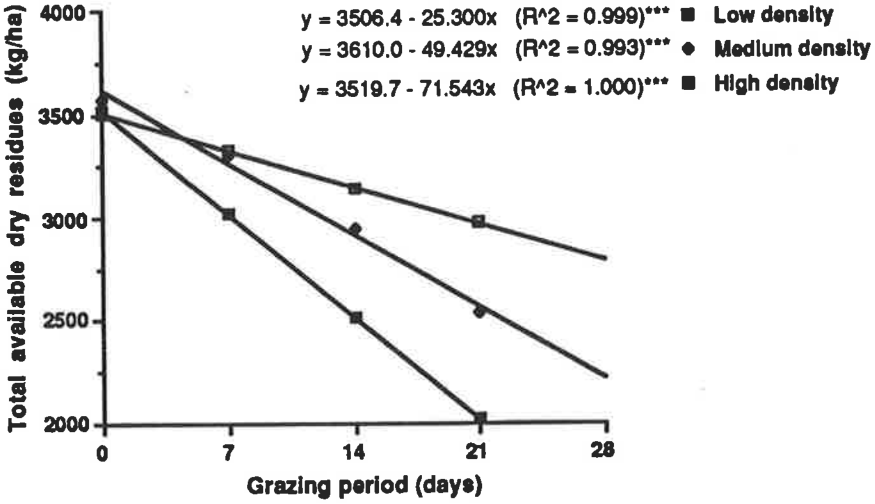


Figure 3.1 The changes in availability of dry pasture residues at three stocking densities

Table 3.2 **The percentage of pasture component in total dry residues during the grazing period and the protected areas harvested 49 days after the end of pasture grazing by sheep**

Component	Stocking density											
	Low				Medium				High			
	Grazing period (days)				Grazing period (days)				Grazing period (days)			
	0	7	14	21	0	7	14	21	0	7	14	21
Availability (%) (during grazing period):												
Total dry residues	100	95	90	85	100	92	82	71	100	86	72	59
Dry residues (without pods)	43	43	43	43	43	42	42	41	43	41	38	32
Mature pods	57	57	57	75	57	58	58	59	57	59	62	68
Availability (%) (in protected areas):												
Total dry residues	100	93	90	84	100	89	84	76	100	84	75	57
Dry residues (without pods)	41	42	39	40	42	43	43	40	44	40	39	30
Mature pods	59	58	61	60	58	57	57	60	56	60	61	70

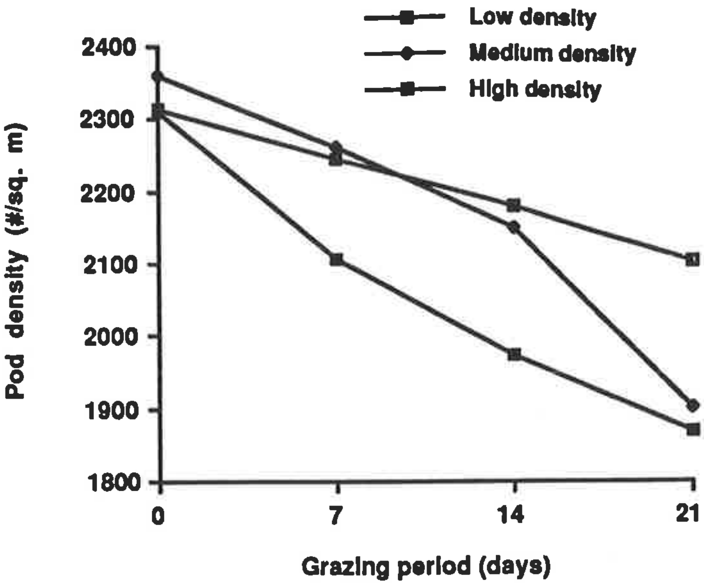


Figure 3.2 Changes in pod density of Paraggio barrel medic grazed by sheep

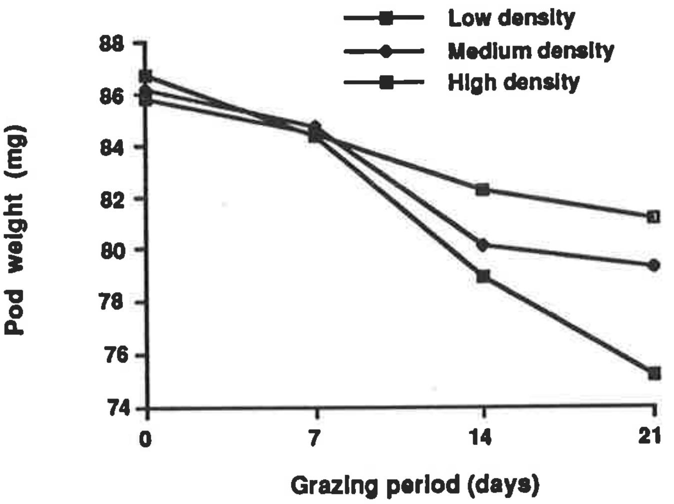


Figure 3.3 Mean pod weight of Paraggio barrel medic grazed by sheep

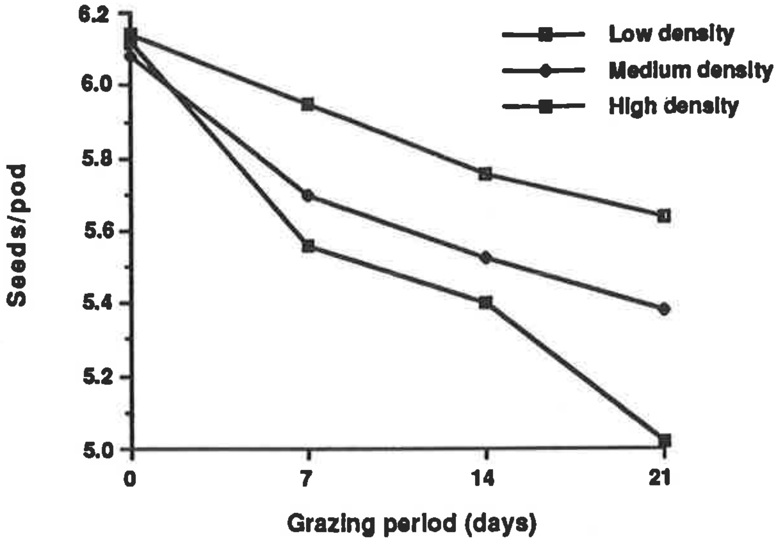


Figure 3.4 Mean seeds per pod of Paraggio barrel medic grazed by sheep

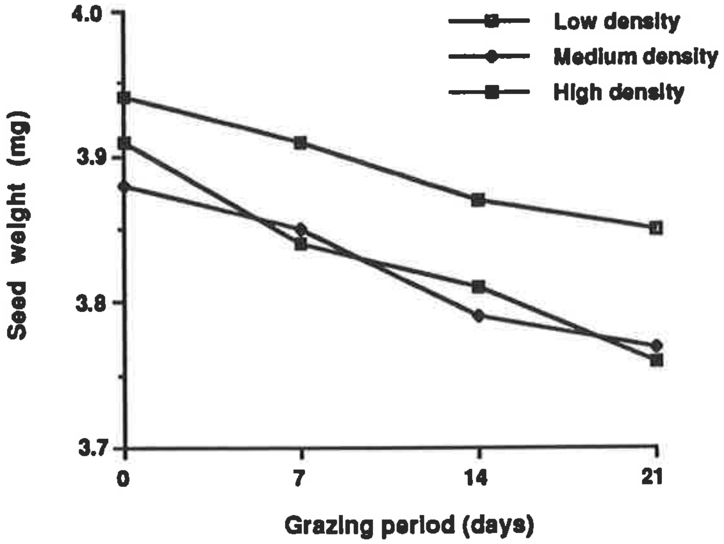


Figure 3.5 Trends in mean seed weight in pods of Paraggio barrel medic grazed by sheep

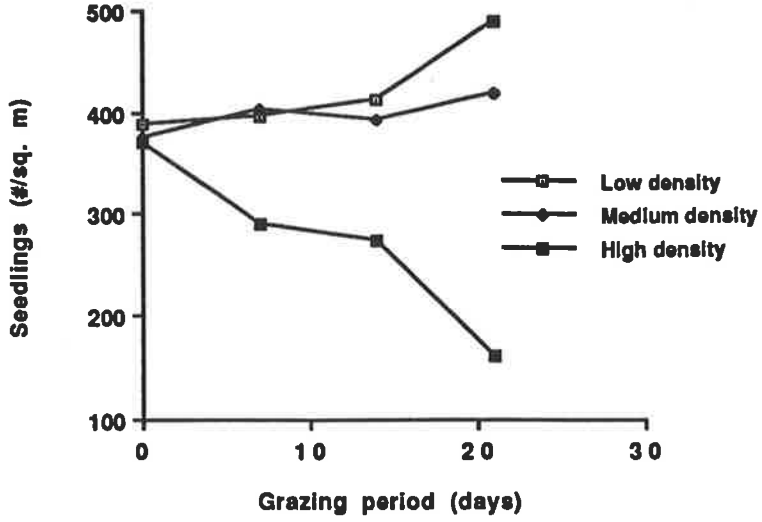


Figure 3.6 Mean seedling emergence from the protected areas 49 days after the end of grazing period

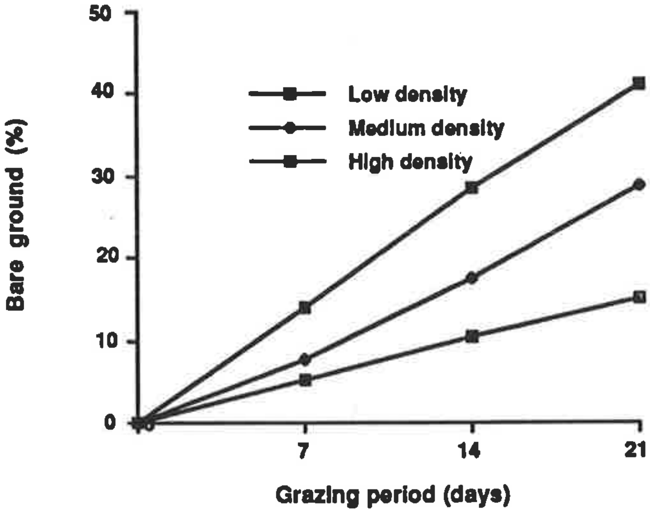


Figure 3.7 The average bare ground during the grazing period

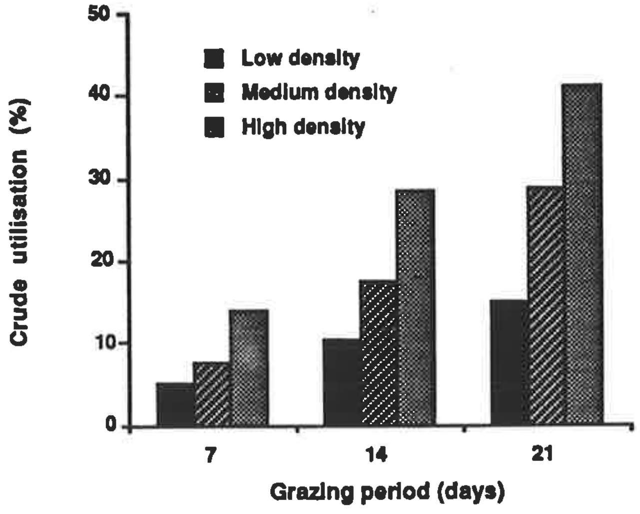


Figure 3.8 Crude utilisation of the total dry pasture residues during the grazing period

No significant changes in germination characteristics of seeds (from harvested intact pods) were observed. The hard seed percentages at the end of the first, second and third week of grazing were; 93, 92, 92 and 93 for low density, 95, 93 and 93 for medium density and 94, 91, 93 and 92 for the high density respectively.

Digestibility of dry pasture residues: The total dry pasture residues collected weekly were separated into two parts, mature pods and the dry residues without the pods. The pod components were processed for germination tests and physical characteristics. In some samples there were only as many pods as required for carrying out these tests and not enough for digestibility determinations as well. Because of this, only the *in vitro* digestibility of the dry residues without the pods was measured. The results are summarised in Table 3.3. At the start of grazing, the harvested dry residues from the allocated plots to the different stocking densities had similar dry matter and organic matter digestibilities (average 50.4 ± 0.2 DMD and 55.9 ± 0.2 OMD). The average organic matter digestibility was about 5 percentage units higher than the corresponding dry matter digestibility, indicating that there was contamination with soil.

Both dry matter and organic matter digestibilities of the dry residues declined for all densities with advancing grazing time. The rate of reduction was much higher for high and medium densities than that for low density. For instance, the dry matter digestibility of the dry residues harvested from the plot under low stocking density at the end of 21 days grazing was 46.1% whereas this coefficient for the samples from high stocking density was about 37.8%. In other words the reduction in dry matter digestibility of the dry residues from low and high densities was 4.8 and 12.3 percentage units respectively.

Sheep body weight and fat score: The average sheep body weight and fat score data are given in Table 3.4. Both body weight and fat score of the wether sheep declined with advancing grazing time for all the stocking densities. However, greater losses were observed for the higher stocking densities. These can be attributed to the low availability and digestibility of dry pasture residues in the plots grazed at higher stocking densities.

Medic seed survival following ingestion by the sheep: Data on the excreted faeces and seed throughput are summarised in Table 3.5. Generally, the average faeces output increased in the second week of grazing for all of the stocking densities, probably because of better sheep adaptation to the conditions and more feed eaten. Dry matter content of the faeces, mainly in the sheep grazing at the higher densities increased with the time, possibly due to increasing retention time of feed materials in the digestive tract.

The number of voided soft seeds significantly declined with advancing grazing period. For example, the number of soft seeds/sheep/day decreased from 302 to 87 for the high stocking density. The rates of this reduction were 40, 55 and 71 percent for the low, medium and high stocking densities respectively. A similar trend was observed for hard seed output. Total seed output also declined with time for all stocking densities. The reduction rates were 3, 22 and 56% for the low, medium and high densities respectively. Furthermore, the total seed output (soft + hard) for low stocking density was higher than that for the medium and high densities. For example, the average voided seeds (soft + hard)/sheep/day were 1171, 973 and 632 seeds for low, medium and high densities respectively.

Table 3.3 ***In vitro* digestibility of dry residues from the grazed pasture by wether sheep (moisture-free basis)**

Stocking density	Component	Grazing period (days)			
		0	7	14	21
Low					
(12/sheep/ha)	DMD	50.9	49.0	48.4	46.1
	OMD	55.7	53.7	53.3	50.0
Medium					
(24/sheep/ha)	DMD	50.2	49.8	46.3	45.0
	OMD	56.3	55.0	48.8	46.5
High					
(36 sheep/ha)	DMD	50.2	45.1	40.6	37.8
	OMD	55.8	50.1	41.5	39.7

DMD = Dry matter digestibility; OMD = Organic matter digestibility

Hard-seededness of the voided seeds increased as the experimental area was grazed longer (Table 3.5) but the mean hard seed weight decreased with time. Furthermore, the seeds obtained by dissection of representative pods harvested after any sampling time were significantly heavier ($P<0.01$) than the seeds found in the faeces on the same occasions.

Table 3.4 Sheep body weight and fat score during the grazing period
(Data show means ± SE)

Stocking density	Body weight (kg)				Fat score (scale 1-5)			
	Grazing period (days)				Grazing period (days)			
	0	7	14	21	0	7	14	21
Low	54.0	53.4	52.8	52.0	2.4	2.3	2.1	1.6
(12 sheep/ha)	±1.3	±1.3	±1.3	±1.2	± 0.1	± 0.1	± 0.2	± 0.1
Medium	53.8	53.0	52.5	51.3	2.4	2.3	2.1	1.3
(24 sheep/ha)	±2.1	±2.2	±2.2	±2.3	± 0.1	± 0.1	±0.2	±0.1
High	53.9	53.1	51.6	50.4	2.4	2.3	2.1	1.3
(36 sheep/ha)	±1.7	±1.4	±1.7	±1.8	± 0.1	± 0.1	± 0.0	± 0.2

If it can be assumed that medic pod disappearance (Appendix 3.3) is the same as pod consumption by sheep then the number of seeds consumed can be calculated as the product of the number of pods consumed divided by the average weight of each pod and multiplied by the mean seeds/pod. Using these figures and those for the number of whole seeds voided in faeces it was calculated that survival of seeds in this experiment was generally less than 2%, with seed survival for the higher stocking densities being lower than that for the low stocking density.

The mature medic pods in this experiment comprised about 28% seeds and 72% hull. These ratios did not differ significantly between the different stocking densities and grazing periods.

Within each of the three grazed paddocks the 40 small areas which were protected, marked and left for further data collection were sampled seven weeks after the completion of grazing. These samples were also processed to obtain information on the physical characteristics of the materials harvested. The results are summarised in Table 3.6.

Generally, the availability of total dry pasture residues, mature pods and dry residues (without pods) showed a decline after the end of grazing.

While the percentage of mature pods in total dry matter of the pasture increased with advancing grazing period, generally their density (#/m^2) declined. Opposite to this, availability (%) of the dry residues significantly ($P<0.01$) reduced with time (Table 3.6).

Table 3.5 **Summary of the data on average daily output of faeces and characteristics of the voided seeds (moisture-free basis; Data show means ± SE)**

Component	Stocking density								
	Low			Medium			High		
	Grazing period (days)			Grazing period (days)			Grazing period (days)		
	7	14	21	7	14	21	7	14	21
Faeces (g/sheep/day)	723 ± 56	810 ± 48	797 ± 41	748 ± 34	801 ± 71	774 ± 39	706 ± 44	805 ± 38	738 ± 36
DM content of faeces (%)	53.6 ±1.9	56.0±1.5	54.0 ±1.8	52.4 ±1.4	55.7 ±0.6	55.4 ±1.3	48.0 ±2.3	54.7 ±1.7	56.7 ±0.8
Soft seed output (#/sheep/day)	310 ± 69	141 ± 25	186 ± 39	332 ± 68	249±101	150 ± 38	302 ± 76	124 ± 25	87 ± 17
Hard seed output (#/sheep/day)	957 ± 83	875 ± 90	1044±87	747±135	755±101	687±183	635±134	432 ± 74	316 ± 64
Total seed output (#/sheep/day)	1267±139	1016±94	1230±123	1079±181	1004±188	837±219	937±203	556±87	403±81
Hard seed (%)	76 ± 3	86 ± 3	85 ± 2	69 ± 3	75 ± 7	82 ± 2	68 ± 3	78 ± 4	78 ± 1
Hard seed weight (mg)	3.10±0.08	3.05±0.07	3.03±0.05	3.10±0.02	3.07±0.04	2.97±0.02	3.04±0.05	2.95±0.06	2.87±0.05

Table 3.6 **Summary of the data on availability of the pasture components harvested from the protected areas 49 days after completing the grazing period**

Component	Stocking density											
	Low				Medium				High			
	Grazing period (days)				Grazing period (days)				Grazing period (days)			
	0	7	14	21	0	7	14	21	0	7	14	21
Total dry pasture residues (kg DM/ha)	3300	3079	2957	2787	3478	3099	2913	2630	3463	2915	2597	1976
Dry residues without pods (kg/ha)	1353	1293	1153	1115	1461	1320	1253	1052	1524	1166	1013	593
Mature pods (kg/ha)	1947	1786	1804	1672	2017	1779	1660	1578	1936	1749	1584	1383
Pods density (#/m^2)	2238	2067	2133	2007	2332	2116	2072	1978	2222	2061	2000	1808
Pod weight (mg)	87.0	86.4	84.6	83.3	86.5	84.1	80.1	79.8	87.1	84.9	79.2	76.5
Pod/dry residues (without the pods) ratio	1.4	1.4	1.6	1.5	1.4	1.3	1.3	1.5	1.3	1.5	1.6	2.3
Pod/total dry residues (%)	59	58	61	60	58	58	57	60	47	60	61	70
Crude utilisation (%)	-	6.7	10.4	15.5	-	11.04	16.2	24.2	-	15.82	25.0	42.9
Hard seeds (%)	98	97	99	99	99	99	99	99	100	100	99	100

In contrast, pod weight and crude utilisation of the grazed pasture increased as compared to the previously-reported data. The percentage of hard seeds in the seed bank considerably increased from about 94% to nearly 100%. This indicates that up to the time of final harvesting almost all of the soft seeds had germinated under the field conditions and the moisture provided by a few autumn rains.

3.4 Discussion

The results of this grazing experiment showed that stocking densities had a marked influence on availability of dry pasture components. In general, the rate of disappearance of total dry pasture residues was similar and approximately constant over the 21-day grazing period for all three stocking densities. However, the mature pod component at the higher stocking densities increased as the grazing period progressed, indicating that there was a greater disappearance of dry residues (without the pods) by comparison to the pod components. For example while the reduction in mature pods was 4.6, 9.5 and 11.2 percent for low, medium and high stocking densities respectively, the corresponding values for dry residues were 6.1, 12.7 and 23.8 percent.

The following explanations can be offered for the changes in the proportion of the dry pasture components.

(a) It may reflect the fact that in grazing situations sheep are selective grazers (Stobbs 1973; Leigh and Holgate 1978). It is clear that sheep select the more acceptable and accessible materials with appropriate taste and odour (Curll and Jones 1989). Because of this the upper part of the pasture canopy containing more leaves and the stems with higher digestibility have been taken. The results of *in vitro* digestibility of dry residues support this suggestion. Both dry matter and organic matter digestibilities of this component declined considerably over the grazing period. This is in agreement with the finding of de Koning (1990) for subterranean clover and Squella (1992) for balansa and cluster clovers. They both reported that burr selection by sheep at the start of summer-autumn grazing was slow because of the availability of the nutritious leaf and stem materials.

(b) The dry matter which disappeared from the experimental plots was not necessarily eaten by sheep. Displacement of the lighter residues such as leaves and the thin stems by wind in these situations is an unavoidable action and this is likely to be more pronounced at higher stocking densities. This is consistent with the greater increase in the ratio of pods at higher stocking densities in this study, because the mature pods are heavier than the dry residues without pods.

The changes in the proportion of dry pasture components calculated from the harvested samples 49 days after the end of grazing (Table 3.6) also reflect the effects of other factors such as displacement by wind or predation by insects as Squella (1992) reported for the other annual pasture legumes. Although the final samples (Table 3.6) were harvested from the protected areas and the same paddocks seven weeks after the end of the grazing period, availability of the pasture components and their ratios were different from those obtained concurrently with grazing periods. No doubt some part of this difference is because of the errors in sampling (may not be avoided) but most of it is likely to be related to other factors such as blowing up the residues, especially the lighter materials, by wind or otherwise disappearance because of insects, birds etc.

However, significant reduction in total availability of dry annual legume pasture residues under summer-autumn grazing by sheep has been reported by other workers (Carter 1981a; de Koning and Carter 1989; Squella 1992). Although Squella (1992) demonstrated that when the upper parts of balansa clover were severely reduced after the second week of grazing, the wether sheep showed intensive grazing on clover burrs, Carter (1981a) showed that the proportion of mature pods in the total available medic pasture reduced about 13.4 percentage units after a grazing period of 56 days with a stocking density of 56 sheep/ha. However, the stocking densities in this Korunye experiment were much lower (even for the highest density) than used by Carter (1981a) and the grazing period lasted only three weeks whereas Carter used eight weeks.

In the present study the high stocking densities not only reduced the availability of the dry pasture residues to a greater extent than the low stocking density, but also significantly increased the percentage emergence of seedlings. This pattern of seed softening in the field could have been influenced by the quantity of dry residues present on the different plots over the grazing period. Quinlivan (1965) showed that the soil surface temperature was markedly affected by the quantity of dry residues on the pasture. Such residues reduce the rate of seed softening through their insulation effect on the seeds during the dry and hot period of the year. Such an explanation could be applicable in the present study.

Over-grazing the medic pasture in this experiment not only led to a dramatic reduction in pod and seed reserves through the direct depletion of the pods by sheep, which findings are in agreement with the finding of Carter (1981a) for medic and de Koning and Carter (1989) for subterranean clover pasture, but also indirectly more losses in medic seed reserves resulted from increasing the soil surface temperature on hard-grazed areas with consequent decline in the percentage hard-seededness.

Seed dormancy over the dry period and the cereal year in the system of medic pasture-crop rotation is a desirable characteristic in any annual pasture species (Quinlivan 1962). It helps prevent seed loss through false germinations by summer rains which are not followed by the normal regular autumn rains. Also the surviving plants are unlikely to show the desirable performance during the coming growing season.

The digestibility of the pasture component or residues harvested from plots over the experiment declined as grazing time increased, but at different rates for different stocking densities. The declining rates in digestibility for the samples harvested from the areas under low, medium and high stocking densities averaged 0.23, 0.25 and 0.56 digestibility units per day respectively. Perhaps this happened because the tested samples had different proportions of cell contents and cell wall. However, it is likely, that the sheep selected the more digestible parts of the available residues and this led to the observed results.

It would be expected that there would be significant differences in animal performance at the different stocking densities due to these big variations in the changes in digestibility of dry pasture residues. Even at the lowest stocking densities sheep lost weight and condition and thus although the dry pasture residues may provide grazing for the sheep over the summer months in the Mediterranean-type climate of southern Australia, they frequently are inadequate to meet even sheep maintenance requirements. Therefore other pasture-livestock management, supplementary feeding or sheep feedlotting strategies are required.

The dry matter content of the sheep faeces increased as the grazing time progressed, probably because of lowering the digestibility of ingested materials. Generally, it is believed that the feeds with high fibre content and low digestibility remain for a longer time in the sheep digestive tract than the highly digestible feeds with a lower level of crude fibre. Similar trends in dry matter content of faeces from the sheep grazed on dry balansa and subterranean clover pasture was reported by Squella (1992). However, he suggested the high dry matter content of sheep faeces could be attributed to ingestion of inert soil particles with the dry pasture residues.

Less than 2% of the medic seeds survived following ingestion by sheep. The number of seeds voided in the faeces in this study were much lower than the numbers recorded by Carter (1980) and Carter and Lake (1985). Also, in contrast to the report of de Koning and Carter (1989) for subterranean clover, during the first week of grazing the number of seeds which survived after ingestion by sheep allocated to the high stocking densities was higher than that for the following weeks. For example, the total seed output of the high stocking density in the first week was 937 seeds/sheep/day, whereas it was reduced to 403 seeds/sheep/day in the third week of grazing. Medic seed throughput for the low stocking density in this experiment was approximately constant. However, the low seed output of the higher densities could be related to longer retention time of the ingested materials from the pasture in sheep digestive tract and more digestion. Consumption of the dry pasture residues with lower pod component or smaller pods by sheep is the other suggestion.

As recorded by Carter (1981a), de Koning and Carter (1989) and Squella (1992) most of the seeds found in sheep faeces were hard seeds. Carter (1981a) and Carter *et al.* (1989) demonstrated that the smaller hard seeds of annual pasture legume are the most likely to survive following ingestion by sheep. However, in this experiment the hard seed percentage of the voided seeds was much lower than the hard seed percentage obtained from germination of intact pods. It is quite clear that more than 98% of all seeds including soft and hard seeds have been destroyed following ingestion by sheep. Apparently, soft seeds are more susceptible to the rumen fermentation and digestion.

The lower hard seed percentage of the voided seeds indicates that, presumably, hardseededness of the ingested seeds has been reduced during the digestion process, i.e. besides physical damage by chewing, the digestive juices penetrated the seed coat of the hard seeds and made some of them permeable. For this reason the total hard seed percentage of the voided seed was lower in comparison with the hard seed percentage of the seeds before ingestion. Nevertheless the voided germinating soft seeds are unlikely to survive under the dry and hot conditions of the summer-autumn months in southern Australia which is the period of seed consumption.

The lower average weight of the voided hard seeds indicates that smaller seeds are more ecologically suitable to survive following ingestion, chewing or rumination by sheep. Such a conclusion has been reported by other workers (Carter 1980; Carter *et al.* 1989).

The results of this experiment indicate that excessive grazing of medic pasture over the summer-autumn period results in loss of pod and seed reserves and subsequently high mortality of seedlings and consequent poorer performance of the grazing animals.

However, from this study and the related knowledge it can be concluded that persistence of sustainable annual legume pastures is extremely important to the crop-livestock integrated system in the cereal-livestock zone of southern Australia. Efficient use of the available pastures, development of annual legumes that can cope with periods of heavy grazing and droughts, finding an optimal grazing pressure throughout the year, in particular during the dry period, and practising the newer livestock management strategies such as sheep lot-feeding during this summer-autumn period are most important factors.

4.0 ESTIMATION OF THE NUTRITIVE VALUE OF MATURE ANNUAL MEDIC PODS THROUGH *IN VIVO, IN VITRO* AND *IN SACCO* TECHNIQUES

4.1 *In vivo* studies

4.1.1 Introduction

Mature pods of annual medics (*Medicago* spp.) are important components of dry pasture residues for sheep during summer and autumn in southern Australia. Furthermore, medic pods are being harvested in some districts for direct pelleting as sheep feed. Inclusion of medic pods in livestock feeds in the Mediterranean-type environment of these areas that are commonly faced with shortage of feed during the hot and dry summer-autumn period of the year, can be a useful management strategy. However, the nutritive value of medic pods and their constituents is largely unknown. Also it is important to know the extent of medic seed survival following ingestion by livestock because the knowledge of seed-seedling dynamics can be incorporated into the management of pasture-livestock enterprises (Carter 1980, 1981a; Thomson *et al.* 1987).

4.1.2 Materials and methods

Feeds: The mature pods of annual *Medicago* species, *M. scutellata* cv. Sava, *M. truncatula* cvs. Parabinga and Paraggio hereafter referred to as Sava, Parabinga and Paraggio (Plate 4.1) were collected from the Athurton and Brinkworth areas north of Adelaide, in the summer of 1990. In order to provide pure pods, the organic residues and stones were separated from the pods using a rotary-sieve and a seed-cleaning machine. The proportions of pure pods and related residues are given in Table 4.1.

Experimental design and timetable: The experiment was conducted in the Waite Institute animal house (Plate 4.2). Eighteen Merino wethers (plus three spares) averaging 50.5 kg body weight and about three years old were selected from the same flock. The wethers that had previously been shorn, dewormed and treated for enterotoxaemia were allocated by stratified randomisation based on body weight to the experimental treatments.

Table 4.1 Purity of medic pods as harvested

Medic species	Pod (%)	Organic residues (%)	Stones (%)
M. scutellata cv. Sava	90	10	0
M. truncatula cv. Parabinga	50	11	39
M. truncatula cv. Paraggio	58	40	2

The experiment was a Completely Randomised Design (CRD) with analysis of covariance. Sheep body weight was regarded as the independent variable (Snedecor and Cochran 1971), although it was suggested that the stratified randomization should balance the effect of different body weights between the treatments. The experiment consisted of three treatments and six replicate sheep. The experimental treatments were three pure-pod diets as follows: pure intact Sava pods; pure intact Parabinga pods and pure intact Paraggio pods.

The sheep were kept in individual pens throughout the experiment. Water was available at all times (Braman and Abe 1977). The experiment was conducted using three periods, as follows.

(a) **Adaptation period**: This period was used to quieten the sheep to pens, indoor conditions and adaptation to the diets.

(b) **Preliminary period**: The test diets were fed *ad libitum* to the wethers in order to measure voluntary intake and to ensure that undigested residues of previously-consumed feedstuffs had been eliminated from the digestive tract (Church 1988).

(c) **Collection period**: Total feed intake and faecal output for each sheep was measured to determine the *in vivo* digestibility of the pods.

The wethers were fed once daily at 0900 hr just after collection of feed residues from the previous day's feeding.

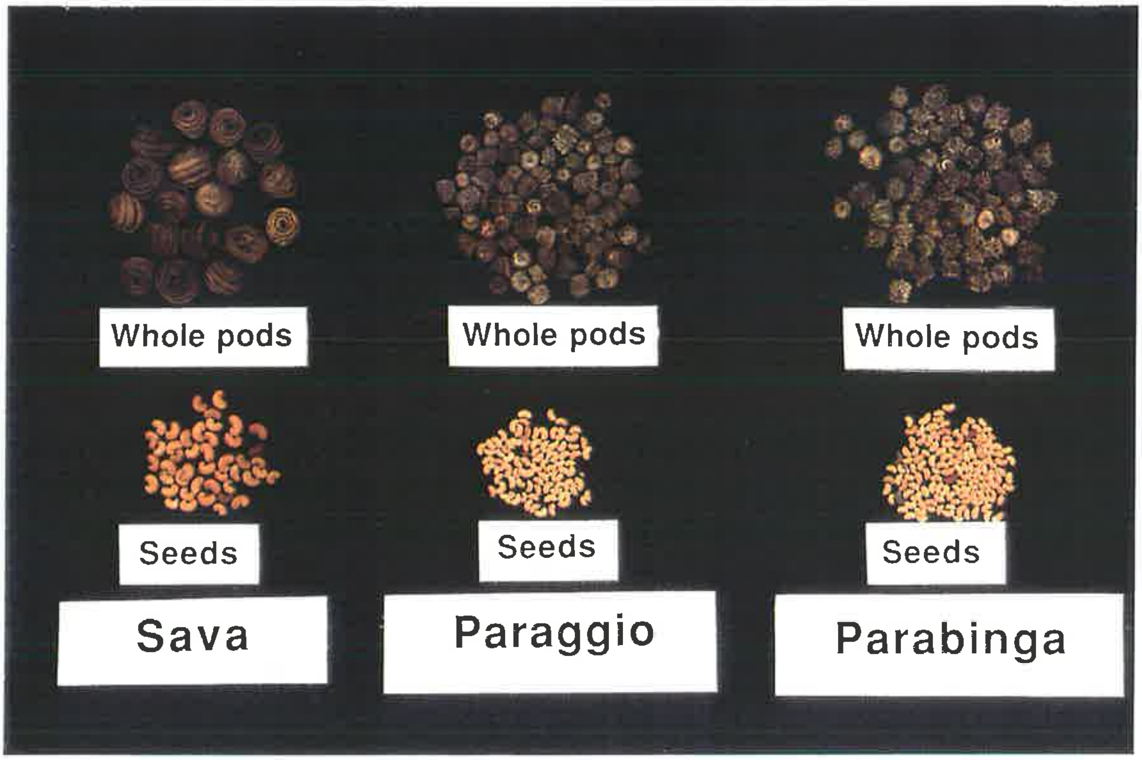
The experimental timetable that was followed is detailed below.

(a) Adaptation period of 9 days

Day 1. All sheep were weighed prior to feeding, placed in individual pens and given a diet of 90% chaffed oaten hay and 10% commercial pellets at the level of 2.5% of sheep body weight.

Plate 4.1 Close-up view of whole, mature medic pods and seeds.

Plate 4.2 General view of the sheep with faecal-collection harnesses used in the *in vivo* digestion experiment.


Whole pods
Whole pods
Whole pods
Seeds
Seeds
Seeds
Sava
Paraggio
Parabinga

Days 2-9. Sheep were allocated to their dietary treatments. Pods were gradually introduced into the sheep diet. On Day 7 sheep were fitted with faecal-collection harnesses.

(b) Preliminary period of 10 days

Days 10-19. Voluntary intake was measured during this period and it was achieved by daily adjusting the quantity of feed offered to each sheep in order to provide between 100 and 200 g residue per day. Residues were collected and weighed every day. If a sheep left less than 100 g on any given day, the amount offered was increased by 100 g, but if no residues were left, the amount offered was increased 200 g over the amount offered the day before. If more than 400 g was left, the amount offered was reduced by 200 g and if the amount of residue was between 200 and 400 g, the offering was reduced by 100 g each day. However, the minimum amount offered (pure pods) was not less than 400 g/d. Residues (refused pods) were never refed. The above-mentioned procedure was followed throughout the period.

On Day 16 all harnesses on sheep were fitted with faecal-collection bags.

Every day, duplicate samples of approximately 100 g were taken from each of the pod diets and residues (if any) then dried at 100°C overnight to constant weight for determination of dry matter content.

(c) Collection period of 12 days (10 days of measurement)

Day 20. All sheep were weighed and fed the average amount of pods eaten during the previous period. At the beginning of the collection period sheep faeces were collected, weighed and sampled for determination of seed throughput. Feeds were sampled (200 g samples) and stored at room temperature.

Day 21. Sheep were fed with pure pods at the same level as day 20. Feed samples were bulked with samples of the previous day.

Days 22-28. Sheep were fed pure pods at the same level as day 20. Faecal-collection bags were changed daily at 08.30 hours, after removing the feed residues.

Faeces were weighed and sampled for dry matter determination, chemical analysis and seed throughput. Every day duplicate samples of fresh faeces were taken and dried at 100°C for 24 hours for determination of dry matter content. These samples were subsequently discarded. Every day one sample of 100 g of fresh faeces was taken for measuring seed survival. A proportional sample (20%) of the remaining faeces from each sheep was taken for chemical analysis and stored in a freezer (-18°C) until required. If the total excreted faeces for an animal was less than the amount required for the above-mentioned samples, total faeces was divided into three parts for determination of dry matter, seed survival and chemical analysis.

Day 29. This was the final day for measuring pod intake by sheep.

Day 30. This was the final day for feed residue collection. Faecal collection and sampling was done as for previous days.

Day 31. This was last day for faecal collection and sampling. All sheep were weighed and released to the wether flock.

Sample preparation for chemical analysis

For chemical analyses and assessing physical characteristics, seeds and hull samples were obtained by dissection of whole pods into these components. Whole pods, seeds and hulls were ground through 1 mm screen for chemical analyses.

Ten sub samples of 25 whole pods were taken from the bulked samples (during pen feeding) in order to determine their physical characteristics. Frozen faeces samples were taken and mixed together. Duplicate sub-samples were taken, dried in a forced draught dehydrator at 45°C for 48 h (Miller *et al.*1979) and ground through a 1 mm screen for analysis.

Analytical techniques

Feed and faeces sub-samples were analysed for dry matter, organic matter, crude protein, crude fibre, ether extract and gross energy contents with the following procedures.

Determination of dry matter (DM): Dry matter content of feed and faeces samples were determined in a slightly different procedure as outlined in Figure 4.1 (Harris 1970). Dry matter content (moisture free) for every nutrient was measured at the time it was subjected to analysis.

Ash determination: Two grams of ground samples were weighed by difference into tared crucibles and placed in an electric muffle furnace at 600°C for at least two hours (AOAC 1990).

Crude protein determination (CP): The CP contents of the samples were determined by the Kjeltec Auto System. Samples of around 1 g (0.9900 to 1.0100) were weighed into the N-free paper (Schleicher and Schuell) and digested with concentrated sulphuric acid in the pre-heated digester (Digestion System 40 1016 Digester, Tecator). The digested samples were analysed by the Kjeltec Auto 1030. The conversion factor of nitrogen to CP was 6.25.

Ether extract determination (EE): Soxhlet apparatus was used for oil extraction. A 2 g sample was weighed by difference into a numbered paper thimble (Whatman 30 x 10 mm). The thimbles containing samples were placed in the soxhlet extraction unit. Shell X-55 was used as oil solvent. Oil extraction by this solvent and through the soxhlet apparatus was continued for at least four hours. At the end of extraction and solvent volatilisation the extracted oil was dried in an electric oven overnight at 100°C.

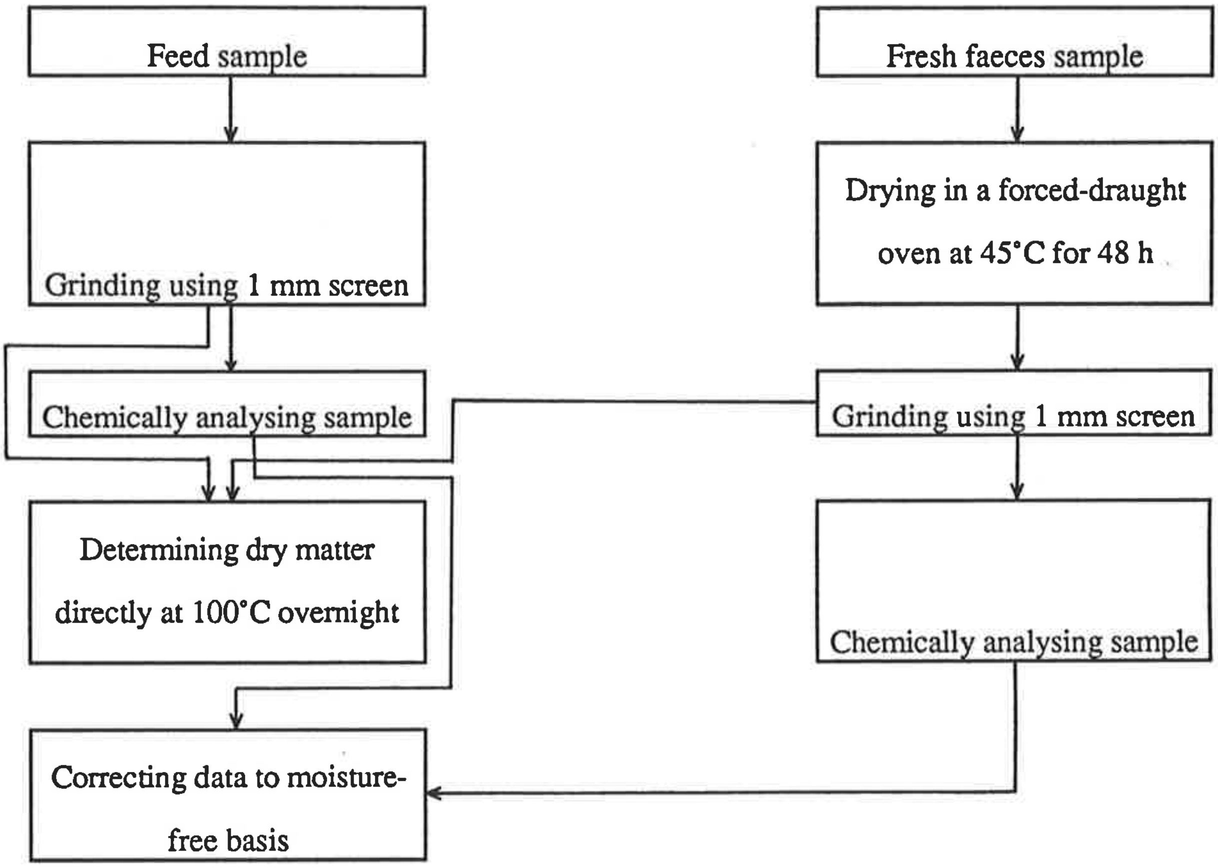


Figure 4.1 Dry matter determination of feed and faeces samples

Crude fibre determination (CF): Solvent-extracted and moisture-free samples were quantitatively (1.5-2 g) transferred to tall beakers and boiled with pre-heated 1.25% (0.255 N) sulphuric acid for 30 minutes. After boiling with acid the contents of the beakers were filtered. The residues on the filter papers were returned to the beakers and boiled with pre-heated 1.25% (0.312 N) sodium hydroxide for another 30 minutes. After digestion with sodium hydroxide the contents of the beakers were filtered and washed with distilled water and ethyl alcohol. The filter papers with residues were dried at 100°C overnight. Dried residues then were ignited at 600°C in an electric muffle furnace for at least two hours. The loss of weight on ignition was regarded as the weight of crude fibre.

Nitrogen-free extraction (NFE): NFE was determined by difference after the analyses had been completed for ash, CP, CF and EE as follows (on moisture-free basis);

$$\text{NFE}\ (\%) = 100 - (\text{Ash}\ (\%) + \text{CP}\ (\%) + \text{CF}\ (\%) + \text{EE}\ (\%)\ )$$

Determination of gross energy (GE) : A ballistic bomb calorimeter (Gullenkamp) was used for determination of the gross energy content of the feed and faeces samples. Samples of approximately 1g were weighed by difference into the metal crucible. The crucible plus sample was placed on the support column in the base of the bomb. One end of the 50 mm length of cotton thread was inserted in the loop of the firing wire, and the other end placed into the sample. The bomb was filled with oxygen at a pressure of 30 Bar/cm^2. The maximum deflection of the galvanometer was recorded about 40 second after firing the bomb. Gross energy content of the samples were calculated after reduction the due deflection of the cotton thread and considering the calibration constant. The gross energy measurement of each feed or faeces sample was replicated six times.

Germination tests: Medic seed germination tests were made on mature intact pods. Pods were randomly taken from the bulked samples. Twenty-five pods were placed in plastic Petri dishes with three pieces of filter paper (Watman ® Quantitative No. 1) on the bottom and one piece on the top of pods. Ten ml of de-ionised water containing 1.6 g/l of the fungicide Thiram were initially gently added to each Petri dish and then the dishes kept moist. Germination tests were of 14 days duration in a humidified incubator at 19°C. Emerged seedlings from the pods were removed and recorded daily. The germination test was replicated four times for each pod population.

In order to determine the total seed throughput, seed survival and hard seed percentage, a sub-sample of 100 g fresh sheep faeces was washed through a square-holed, 0.71 mm laboratory sieve. The residue (including seeds) was removed and placed in petri dishes for the germination test. The germination test was carried out in a humidified incubator for 14 days at

19°C. As in the case of pod samples, Thiram fungicide is essential to obtain reasonable germination data from seeds excreted and derived from the faecal samples.

4.1.3 Results

Chemical composition and physical characteristics: Table 4.2 shows the chemical composition of whole pods, seeds and hulls of the three medic species used. It is evident that there was a wide variation in chemical composition of whole pods, seeds and hulls within each species, whereas between species and cultivars there were no marked differences.

Crude protein content of whole pods, seeds and hulls of the cultivars ranged from 15.75 to 19.94, 38.71 to 44.23 and 5.01 to 8.60 percent respectively (Table 4.2). The mean crude fibre values ranged from 35.44 to 38.57, 7.11 to 8.07, 45.20 to 51.22 percent for whole pods, seeds and hulls respectively (Table 4.2).

Table 4.2 Chemical composition of whole medic pods and pod constituents (Moisture-free basis)

Medic species	Component	Gross energy (MJ/kg)	Ash (%)	Crude protein (%)	Crude fibre (%)	Ether extract (%)	Nitrogen-free extract (%)
M. scutellata							
(cv. Sava)	W[1]	17.06	8.76	15.75	38.57	4.01	32.91
	S[2]	19.58	3.86	38.71	7.95	12.60	36.88
	H[3]	16.28	7.60	5.01	51.22	0.95	35.21
M. truncatula							
(cv. Parabinga)	W	19.05	4.81	17.33	38.05	4.28	35.53
	S	21.78	3.93	44.23	7.11	15.76	28.97
	H	20.63	4.28	7.42	49.76	1.02	37.52
M. truncatula							
(cv. Paraggio)	W	18.43	6.05	19.94	35.44	4.82	33.75
	S	19.94	3.42	40.14	8.07	15.24	33.13
	H	18.00	4.51	8.60	45.20	1.16	40.53

[1] Whole pods; [2] Seeds; [3] Hulls

Ether extract content of seeds was considerably higher than hulls. For example its content in Parabinga seeds was about 15.5 times more than ether extract content of hulls. The high amount of oil in the seed is reflected in the gross energy content of both seeds and whole pods.

Large differences existed between species in pod and seed weight. Mean seeds per pod and seed weight also varied considerably between and within species (Table 4.3). The number of seeds per pod ranged from 0 to 8 for Sava, 2-12 for Parabinga and 1-10 for Paraggio. Mean values are recorded in Table 4.3.

Table 4.3 Physical characteristics of whole pods and their components
(Moisture-free basis; Data show means ± SE)

Medic species	Pod weight (mg)	Mean seeds per pod	Seed weight (mg)	Hard seeds (%)	Seeds ‡ (%)	Hulls‡ (%)
M. scutellata (cv. Sava)	259 ± 3	4.2 ±0.1	18.5 ± 0.1	89 ± 1	30.3± 0.6	69.7 ± 0.6
M. truncatula (cv.Parabinga)	88 ± 2	6.1 ±0.2	3.9 ± 0.1	95 ± 1	27.2 ± 0.6	72.8 ± 0.6
M. truncatula (cv.Paraggio)	57 ± 2	5.1 ±0.2	3.5 ± 0.1	91 ± 1	31.5 ± 1.2	68.5 ± 1.2
Signif. levels	**	**	**	**	**	**
LSD (5%)	8	0.6	0.3	2	2.6	2.6

‡ Seed and hull components determined by dissection; ** = P< 0.01

Voluntary intake: The mean voluntary intake of different nutrients and their relevant statistical analyses are presented in Table 4.4 and 4.5. Analysis of covariance was carried out on voluntary intake data. The regression coefficients indicated that the body weight of experimental sheep in this experiment was ineffective as an independent variable, possibly because of the fact that by using stratified randomisation based on sheep body weight the experiment was well balanced for this independent variable.

There were significant differences between the intake of Paraggio and the other two medic cultivars. Differences in intake between the Sava and Parabinga mature medic pods were not significant. On the basis of intake expressed as percent body weight the observed values were considerably lower than the estimated figures (ARC 1980).

Dry matter intake is dependent not only on the quality of the feed but also on the size of the animal ingesting the feed. On the measurement of feed intake for eliminating the effects of differences in body size, most results of intake experiments have been reported in terms of grams of dry matter eaten per unit metabolic weight, where the 0.75 power of body weight (in kilograms) is regarded as metabolic weight (Minson 1980). On this basis (g/kgW$^{0.75}$/d) mature medic pod intake varied from 13 g for Paraggio to 41 g for Parabinga. Statistical analysis for the data obtained in this method also showed no significant difference in the dry matter intake of whole pods of Sava and Parabinga, but both of them had considerably higher intake of pods than the Paraggio pods. The mean organic matter consumption of Parabinga pods was highest. The lowest organic matter consumption also occurred with the Paraggio barrel medic pods (Table 4.4).

The average voluntary organic matter intake index (kg DM/100 kg body weight) was higher with the pure Parabinga-fed sheep, compared with the groups fed Sava and Paraggio. However, as for dry matter intake, the measured means were largely lower than the recommended index even for the maintenance levels (ARC 1980).

Higher crude protein and fibre content of the pods from the three cultivars led to higher intake of these nutrients (Table 4.5). Generally, Parabinga medic pods led to the highest nutrient intake including crude protein, fibre, ether extract and nitrogen-free extract, while the Paraggio medic pods gave the lowest nutrient intakes. There were significant differences between the levels of nutrient intake from medic pod populations: as for dry matter and organic matter intakes, these were because of the unexpected low intake of Paraggio pods in this study (Table 4.5).

Table 4.4 Voluntary dry matter and organic matter intake of pure-pod rations (Data show means ± SE)

Medic species	Dry matter			Organic matter		
	A	B	C	A	B	C
M. scutellata (cv. Sava)	685 ± 68	36 ± 3	1.36 ± 0.11	625 ± 62	33 ± 2	1.25 ± 0.10
M. truncatula (cv. Parabinga)	769 ± 154	41 ± 8	1.55 ± 0.30	732 ± 147	34 ± 8	1.48 ± 0.29
M. truncatula (cv. Paraggio)	236 ± 59	13 ± 3	0.50 ± 0.13	222 ± 55	12 ± 3	0.47 ± 0.12
Signif. levels	**	**	**	**	**	**
LSD (5%)	310	16	0.60	293	15	0.57

A = (g/sheep/d); B = (g/kg$W^{0.75}$/d); C = (%body weight); ** = $P < 0.01$

Table 4.5 Voluntary intake by penned sheep of individual nutrients of pure-pod rations (Data show means ± SE)

Medic cultivar	Crude protein		Crude fibre		Ether extract		Nitrogen-free extract	
	A	B	A	B	A	B	A	B
Sava	108 ±11	5.7±0.5	264±26	14.0±1.2	27±3	1.2±0.1	225±22	11.9±1.0
Parabinga	133±27	7.2±1.4	293±59	15.7±3.1	33±7	1.8±0.3	273±55	14.7±2.9
Paraggio	47±12	2.6±0.7	84±21	4.6±1.2	12±3	0.6±0.2	80±20	4.4±1.1
Signi. levels	*	*	**	**	*	**	**	**
LSD (5%)	54	2.8	117	6.0	13	0.7	109	5.6

A = (g/sheep/d); B = (g/kgW$^{0.75}$/d); * = P<0.05; ** = P<0.01

***In vivo* digestibility:** The mean *in vivo* digestibility percentages of different nutrients in sheep given the mature medic pods are shown in Table 4.6. Dry matter, organic matter, crude fibre, nitrogen-free extract and energy digestibilities of *M. truncatula* cv. Parabinga were significantly (P<0.01) lower than those of *M. scutellata* cv. Sava and *M. truncatula* cv. Paraggio. The differences between crude protein and ether extract digestibilities of the three cultivars were not significant.

The apparent digestibility of crude fibre of all cultivars was considerably lower than that in any of the other chemical fractions (Table 4.6). Chemical composition and digestibility data in this experiment showed that the most important nutrients from a ruminant nutrition point of view were crude fibre and crude protein respectively.

The trend of digestible nutrient intakes during the main period was similar to voluntary intake of dry matter and organic matter (Table 4.7). However, because of the effect of digestibility on calculation of digestible nutrient intakes, these values are different from the individual nutrient intakes discussed previously (Table 4.5). For example, the higher intake values related to crude protein rather than crude fibre intake in Table 4.7. Again digestible nutrient intakes emphasised that mature medic pods can be considered as a good protein source.

Table 4.6 Apparent *in vivo* digestibility of mature medic pods by sheep
(Data show means ± SE)

Nutrient	Medic species			Significance levels	LSD (5%)
	M. scutellata (cv. Sava) (%)	*M. truncatula* (cv. Parabinga) (%)	*M.truncatula* (cv. Paraggio) (%)		
Dry matter	36.67 ± 0.80	26.90 ± 0.68	32.60 ± 1.42	**	3.07
Organic matter	37.83 ± 0.93	27.63 ± 0.65	32.39 ± 1.34	**	3.06
Crude protein	66.12 ± 1.38	62.20 ± 0.62	65.15 ± 1.6	NS	-
Crude fibre	27.31 ± 1.51	15.01 ± 0.71	18.19 ± 0.95	**	3.34
Ether extract	76.89 ± 1.08	79.65 ± 0.52	79.37 ± 1.26	NS	-
N-free extract	31.89 ± 1.34	18.08 ± 0.82	21.17 ± 1.72	**	-
Gross energy	40.32 ± 0.98	29.64 ± 0.52	35.66 ± 1.79	**	3.66

** = $P<0.01$; NS = Not significant

Total digestible nutrients (TDN), calculated from chemical composition and digestion data (with a conversion factor of 2.25 for ether extract) differed significantly between the species (Table 4.8). The digestible energy (apparently digestible energy) content (MJ/kg) values calculated from the gross energy of the feed consumed minus the gross energy of the corresponding faeces. Mature pods of *M. scutellata* cv. Sava had higher content of digestible energy than those of *M. truncatula* cvs. Parabinga and Paraggio (Table 4.8). These figure were within the ranges reported for low-quality roughages (ARC 1980).

Table 4.7 Digestible nutrient intake by sheep from mature medic pods
(Data show means ± SE)

Medic cultivar	Crude protein		Crude fibre		Ether extract		Nitrogen-free extract	
	A	B	A	B	A	B	A	B
Sava	58±12	3.2 ± 0.6	56±	3.1 ± 0.5	17±3	1.0 ± 0.2	56±10	3.1 ± 0.5
Parabinga	78±15	4.5 ± 0.8	40±	2.3 ± 0.4	25±5	1.4 ± 0.3	46±8	2.6 ± 0.4
Paraggio	39±8	2.4 ± 0.5	20±	1.2 ± 0.2	12±2	0.7 ± 0.1	22±5	1.3 ± 0.3
LSD (5%)	36	1.9	23	1.2	NS†	NS	24	1.26

A = (g/sheep/d); B = (g/kg$W^{0.75}$/d); NS = Not significant

Table 4.8 Total digestible nutrients (TDN) and digestible energy contents of whole mature medic pods (Data show means ± SE)

Medic species	TDN (%)	Digestible energy (MJ/kg)
M. scutellata (cv. Sava)	38.38 ± 0.82	6.88 ± 0.14
M. truncatula (cv. Parabinga)	35.20 ± 1.31	6.57 ± 0.33
M. truncatula (cv. Paraggio)	30.58 ± 0.64	5.65 ± 0.10
Significance levels	**	**
LSD (5%)	2.92	0.66

** = $P<0.01$

Seed survival following ingestion: Seed survival of all cultivars was less than 3%. Barrel medic seeds survived better than snail medic, probably due to smaller size. For all cultivars, the seeds which survived were smaller and mainly hard-seeded. The average hard seed weights (after ingestion) were 14.6, 3.0 and 3.3 mg for Sava, Parabinga and Paraggio respectively, whereas the figures for seeds before ingestion were 18.5, 3.9 and 3.5 mg (Table 4.9).

Measuring the voluntary intake of dried medic pasture is very important in grazing situations. The medic pod intake can be estimated from seed survival values. Both voluntary intake and seed survival are affected by various factors, but as an attempt to test the mentioned hypothesis, seed survival was employed to estimate pods intake. These values are presented in Table 4.10. Mean estimated voluntary dry matter intake values were in agreement with the observed mean voluntary intakes in *in vivo* experiment (Figure 4.2).

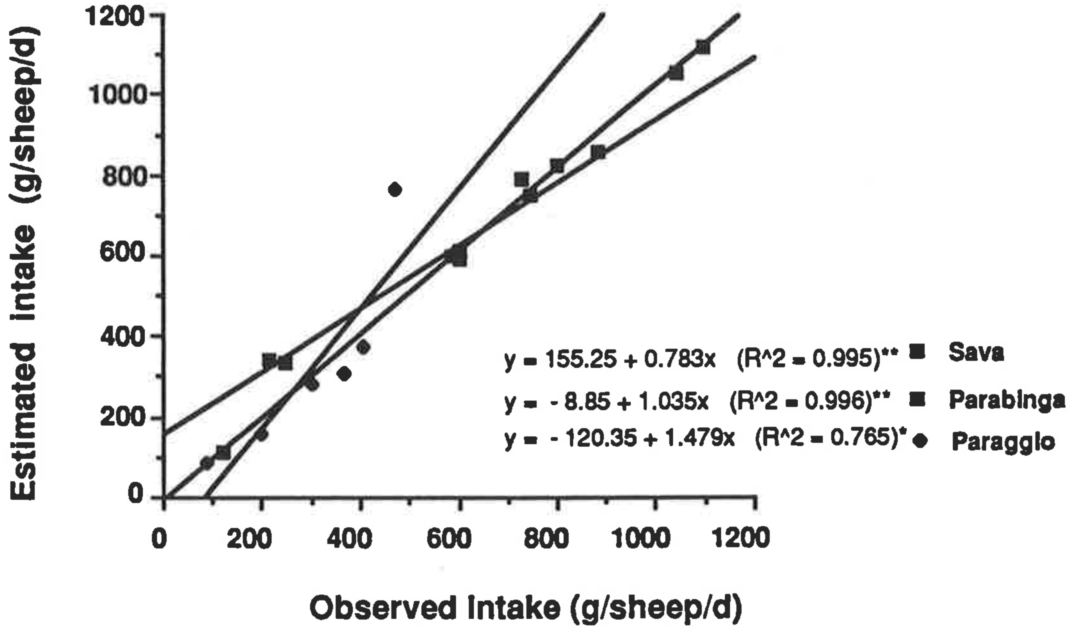


Figure 4.2 The relationship between the estimated intakes (from seed survival data) and the observed intakes in *in vivo* study

Table 4.9 Medic seed survival following ingestion of pods by sheep
(Data show means ± SE)

Medic species	Seed survival (%) Total	Hard	Soft	Hard seed weight (mg)
M. scutellata (cv. Sava)	1.17 ± 0.53	0.87 ± 0.45	0.30 ± 0.14	14.6 ± 0.52
M. truncatula (cv. Parabinga)	2.57 ± 0.54	2.27 ± 0.48	0.30 ± 0.08	3.0 ± 0.05
M. truncatula (cv. Paraggio)	1.76 ± 0.53	1.26 ± 0.57	0.50 ± 0.27	3.3 ± 0.19
Significance level	NS	NS	NS	**

NS = not significant; ** = P<0.01

Table 4.10 Estimated daily intake of medic pods from the seed survival percentage

Medic species	Seed survival (%)	Estimated intake (g/sheep/d)
M. scutellata (cv. Sava)	1.17	858
M. truncatula (cv. Parabinga)	2.57	792
M. truncatula (cv. Paraggio)	1.76	399

Physical characteristics of the residual pods (refused pods) in comparison with the physical characteristics of the original (as fed) pods are shown in Figures 4.3, 4.4 and 4.5. It was found that sheep selected the larger pods which contained more and larger seeds. Plate 4.2 shows the close-up view of pods as fed and residual pods.

Body weight changes: The effects of the different pure-pod rations on sheep body weight changes are presented in Table 4.11 and Figure 4.6. All sheep lost body weight during the experiment. The average body weight losses were 300, 383 and 472 g/d for sheep fed Sava, Parabinga and Paraggio pods respectively. These data indicated either the sheep would not eat enough pure-pod rations to maintain their body weight, or that the intake of digestible nutrients was lower than that required for maintenance.

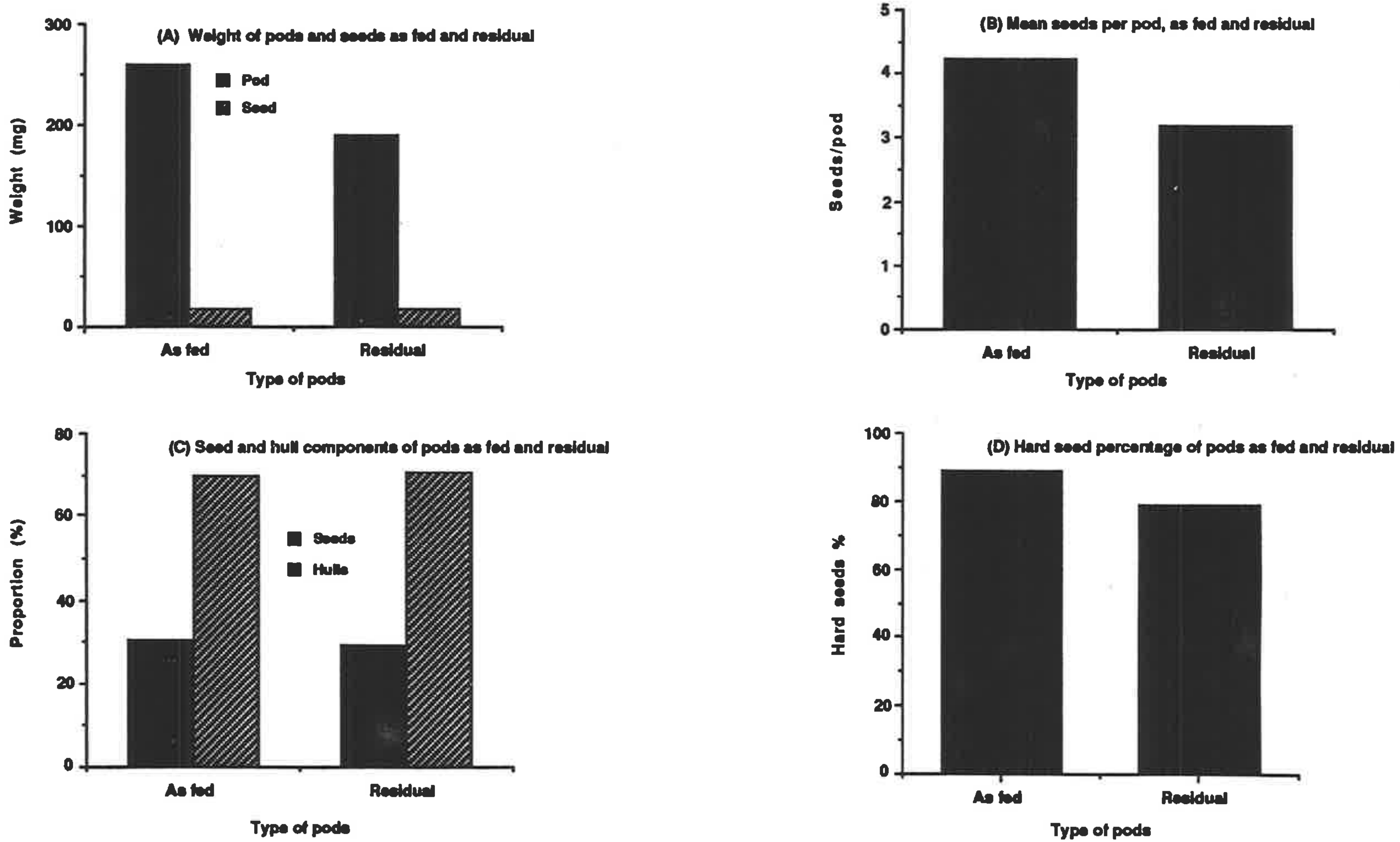


Figure 4.3 Physical characteristics of the original pods (as fed) and residual pods of Sava snail medic

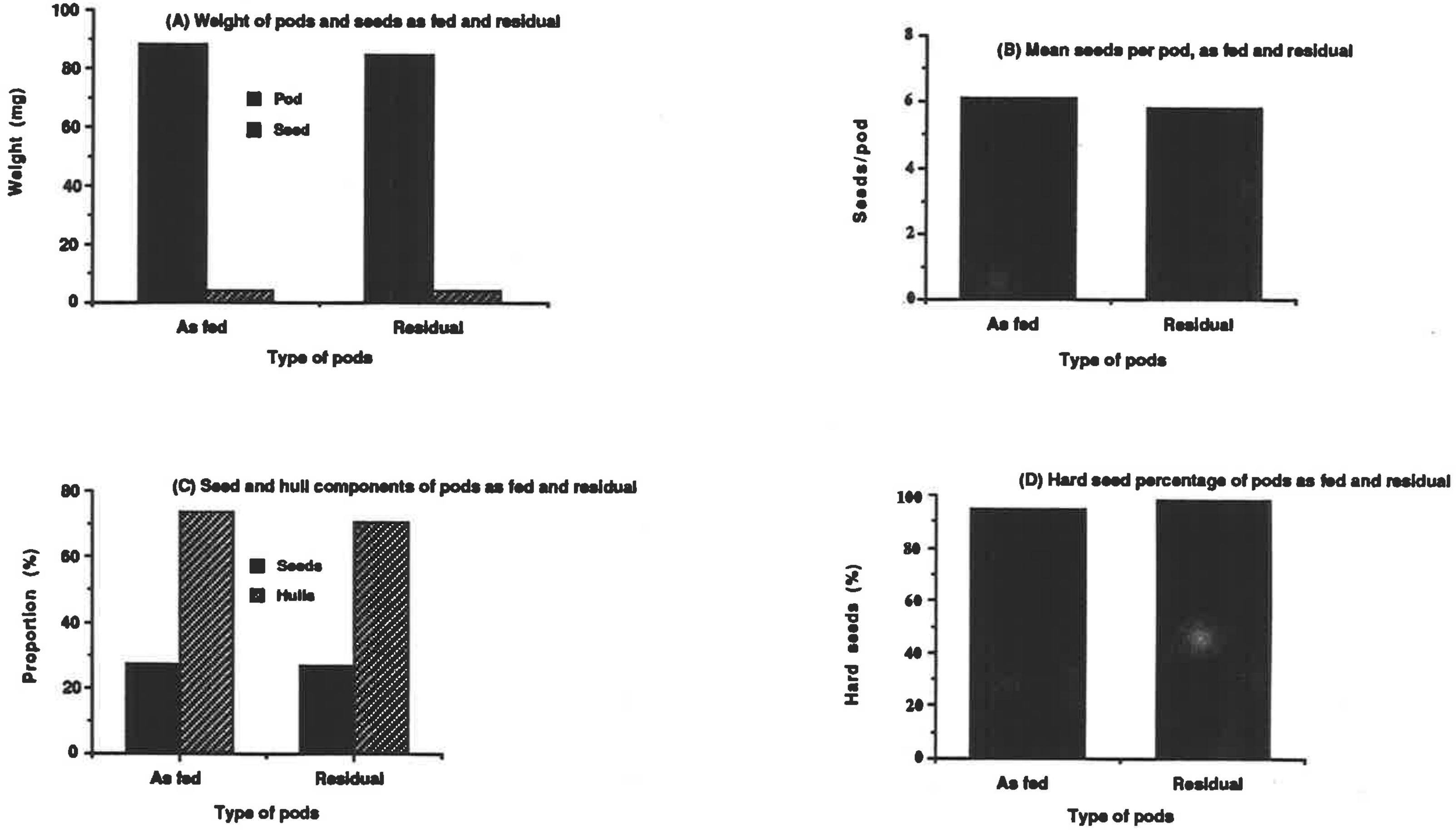
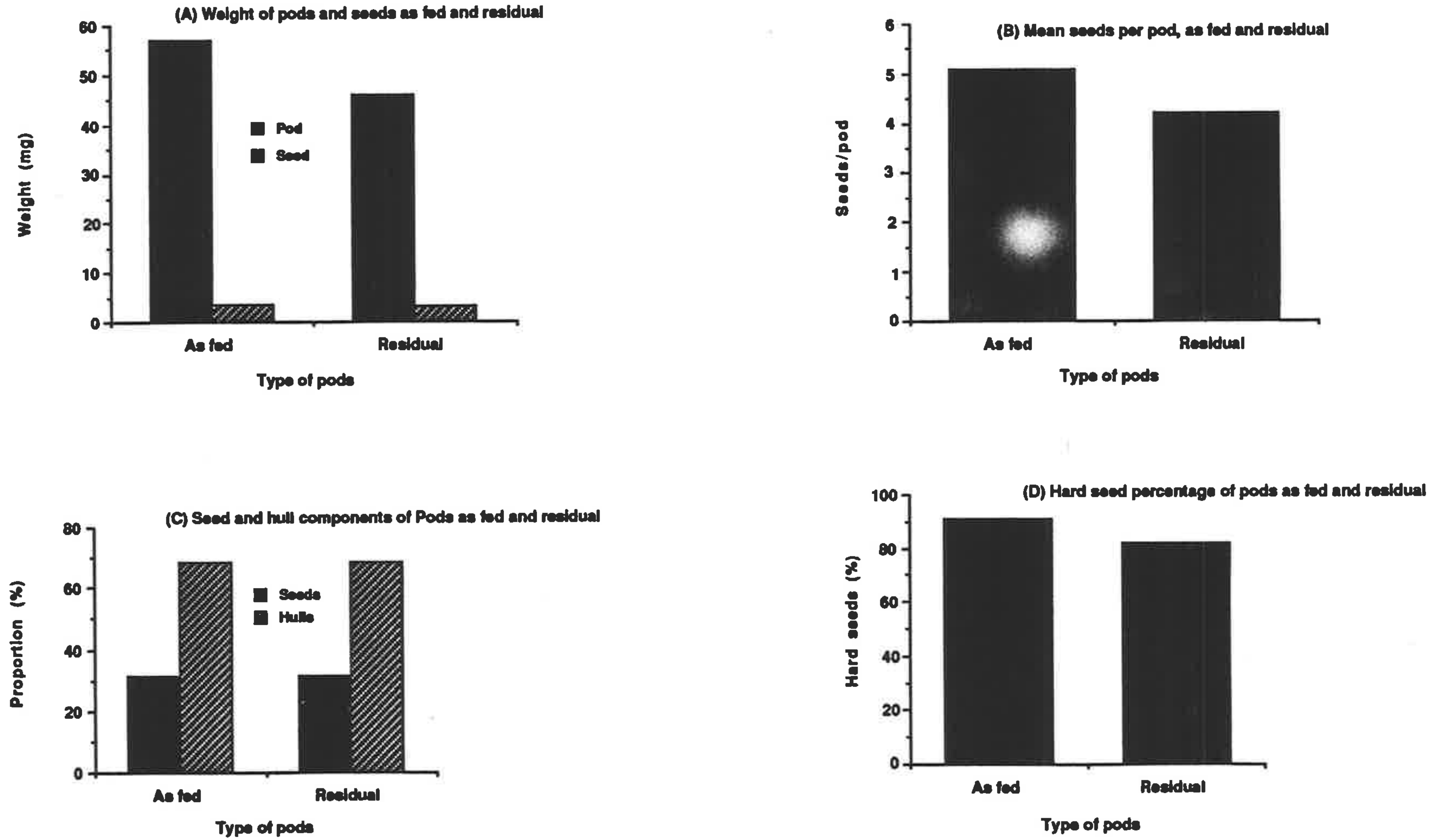


Figure 4.4 Physical characteristics of the original pods (as fed) and residual pods of Parabinga barrel medic



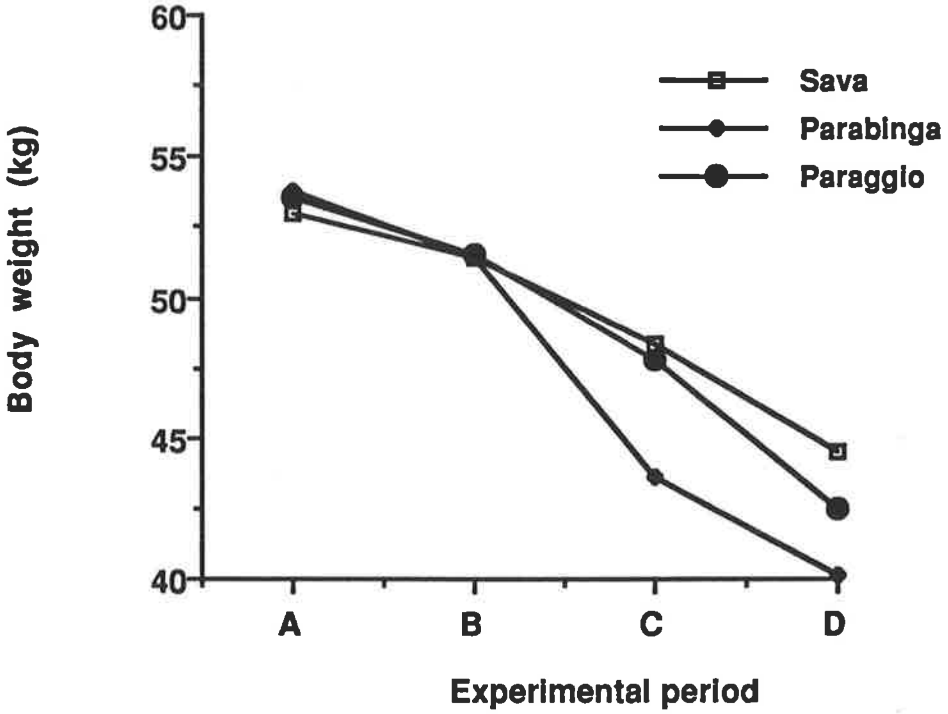
(A) Weight of pods and seeds as fed and residual

(B) Mean seeds per pod, as fed and residual

(C) Seed and hull components of Pods as fed and residual

(D) Hard seed percentage of pods as fed and residual

Figure 4.5 Physical characteristics of the original pods (as fed) and residual pods of Paraggio barrel medic



A = Initial
B = Beginning of preliminary period
C = The end of preliminary period
D = The end of collection period

Figure 4.6 Sheep body weight changes during the *in vivo* experimental periods

Table 4.11 Mean sheep body weight during the experimental periods
(Data show means ± SE)

Medic species	Sheep metabolic body weight W(kg$^{0.75}$)			
	Initial	Beginning of preliminary period	The end of preliminary period	The end of collection period
M. scutellata (cv. Sava)	19.7 ± 1.6	19.2 ± 1.5	18.3 ± 1.6	17.2 ± 1.6
M. truncatula (cv. Parabinga	19.8 ± 1.3	19.3 ± 1.3	18.2 ± 1.1	16.6 ± 1.0
M. truncatula (cv. Paraggio)	19.9 ± 1.7	19.2 ± 1.6	17.0 ± 2.0	15.9 ± 2.0

4.1.4 Discussion

The high crude protein content of mature medic pods presents a special challenge in applied animal nutrition. Denney *et al.* (1979) reported extensive deamination in the rumen and only 20.3% of the protein intake from barrel medic pods was absorbed from the small intestine. It seems that in the presence of the readily-available sources of energy the crude protein of the pods could be utilised more efficiently. Therefore inclusion of mature pods into diets low in protein and balanced for energy should lead to more efficient utilisation of this nutrient.

Various factors influence the quality of feeds, but undoubtedly crude fibre is the most important factor (Van Soest 1981). Although no attempt has been made to clarify the exact chemical and physio-chemical structure of the fibre fraction, the high concentration (Table 4.2) and low digestibility (Table 4.6) of fibre supports the suggestion that, like other low-quality roughages, this fraction of mature pods was made of lignin and other compounds which were less available to the ruminant microbes. Crude fibre content of both whole pods and hulls was similar or even higher than the values for cereal straw, reported elsewhere (AFIC 1987). However, cereal straw usually contains less than 0.5% N and therefore it has insufficient crude protein to allow rumen microorganisms to grow efficiently and requires supplementation with sufficient crude protein (Leng 1982). In spite of large amounts of crude fibre the crude protein content of whole mature medic pods was higher than the cereal hay, comparable to good quality lucerne hay (AFIC 1987). However, the restricting role of this component (CF) can probably be reduced by applying some delignification methods which have been used successfully for improving the feeding value of other fibrous-lignified feeds (Ibrahim 1983).

In contrast to fibre, the crude protein digestibility was relatively high. The higher digestibility and content of crude protein confirmed the conclusion that whole, mature medic pods can be a good source of crude protein for ruminant animals.

The ash content of whole pods, seeds and hulls indicated that whole pods had probably been contaminated by soil and this was reflected in their ash content. Generally, the whole pods in this experiment were made of about 70% hull and 30% seed. In this regard the ash contents of whole pods should be a value close to the sum of the ash content of seed and hull components. The sum of the ash values of whole pods of *M. scutellata* (cv. Sava), *M. truncatula* (cvs. Parabinga and Paraggio) were 6.47, 4.17 and 4.18 respectively. Compared to the ash values of whole pods in Table 4.2 these values were about 2.29% for Sava, 0.63% for Parabinga and 1.88% lower for Sava, Parabinga and Paraggio respectively. These data were very similar to that of *M. tribuloides* pods reported by Vercoe and Pearce (1960). They found that the ash content of whole ground pods was 2.4 percent higher than the estimated ash value from the seed and hull percentage and their ash content. It should be mentioned that *M. truncatula* replaced the earlier name *M. tribuloides*. However, soil contamination between the spines of the mature medic pods in the field probably is a common contamination. In the Waite Institute it seems some of this surface-attached soil has been reduced in threshing to separate the seeds from the hulls.

It was evident from the chemical composition and physical characteristics of the pods that although seeds form only about 30% of whole pods they provide the main source of nutrients such as crude protein and energy (Denney *et al.* 1979) or the most valuable components of annual medic pods. Therefore the feeding value of mature medic pods depends on its content of seed. High amounts of protein and oil and less crude fibre make the seed component a good protein source. However, naturally these seeds are accompanied by a fibrous seed coat (hull) which is highly lignified (Denney *et al.* 1978).

The pure pod intakes of Sava and Parabinga in this experiment were similar to those of Carter (1980) for *M. scutellata* Commercial, *M. truncatula* cv. Jemalong and *M. littoralis* cv.

Harbinger. Feed efficiency and animal performance is largely influenced by voluntary feed intake (Ketelaars and Tollcamp 1992). This variable varies as a function of the feed characteristics, the animals and their environment. However, because of the complexity of feed intake regulation in ruminants the general understanding of what controls feed intake in these animals is poor (Minson 1987). Therefore, it is hard to find out the main reason responsible for the extremely low intake of mature Paraggio medic pods in this experiment. It should be noted that although the resulting intakes of *M. scutellata* cv. Sava and *M. truncatula* cv. Parabinga were within the ranges previously reported (Vercoe and Pearce 1960; Denney *et al.* 1979 ; Carter 1980), the voluntary intake of *M. truncatula* cv. Paraggio was much lower than normal. Possible explanations can be summarised in the following terms.

(i) The small amount of dried animal faeces collected with the pods might have reduced its palatability and intake (Casson and Fisher 1992). It should be mentioned that the total amount of dried faeces was less than 1%, whereas in an *in vivo* experiment reported by Casson and Fisher (1992) the extraneous materials, mainly dried faeces, amounted to 6 and 19% of pod mass.

(ii) Presence of some kind of anti-quality compounds. It is generally known that legumes are excellent high-protein feeds for ruminants, nevertheless, they may contain various anti-quality factors both for human and animals (Li *et al.* 1992; D'Mello 1992). Francis (1973) reported that legumes with a high level of isoflavone glycosides appear to be distasteful to sheep. The fibre and protein digestion of legume feeds in the rumen can be inhibited by high concentrations of tannins (McLeod 1974). Li *et al.* (1992) concluded that there is a large variation in the feeding value of annual legumes because of different levels of anti-quality factors. However, the mature Paraggio medic pods might contain some of these factors in high concentrations which have adversely affected the voluntary intake.

(iii) Fungal contamination of Paraggio pods is another possibility, although no fungal residue was very obvious.

(iv) Unknown factors. Casson and Fisher (1992) also reported that sheep rejected mature pods of Serena barrel medic (*M. polymorpha*) in a diet containing wheaten chaff and the pod (20-50%) because of unknown reasons.

For a better understanding of the very low voluntary intake of the Paraggio pods more detailed studies are needed. In this context the lower intake of Paraggio pods is important for both pasture specialists and animal nutritionists. From the animal nutrition point of view, feeds with higher intakes are preferred. From a pasture ecologist's point of view overgrazing annual medic pasture residues during the dry and hot period of southern Australia adversely affects medic regeneration in the following year mainly because of depletion of pod and seed reserves (Carter 1981b). The medic cultivars or lines that can produce unpalatable mature pods may have the same potential in cereal-sheep farming systems.

The results indicate that the voluntary intake of digestible nutrients (mainly energy) by sheep is inadequate to meet maintenance requirements if they are offered pure-pod diets. Therefore it is not surprising that sheep grazing dried medic pasture lose body weight and condition. However, this depends on the initial level of availability of the dry pasture residues, the stocking density and the duration of grazing.

The apparent dry matter digestibility of pods of all cultivars was very low. It is apparent from Table 4.6, that digestibility of the fibre fraction of the pods was extremely low. Probably, like other low-quality roughages, pod fibre is in a highly-resistant physical form, which makes it less available for the microbial digestion in the rumen. If this is the case, both physical and chemical treatment of medic pods should improve their digestibility.

It is generally accepted that the nitrogen-free extract (cell content) is highly digestible (McDonald *et al.* 1988) but the digestibility of this constituent in this experiment was less than 32%. Possibly the fibrous cell walls protected cell contents from microbial digestion. The apparent digestibility of crude protein and ether extract (lipid) were relatively high in comparison with the digestion of crude fibre and dry matter.

The nutrient digestibilities of mainly *M. truncatula* cultivars were in agreement with the results of Vercoe and Pearce (1960) who reported that crude protein, crude fibre ether extract and nitrogen-free extract digestibilities of *M. tribuloides* (barrel medic) pods were 67.5, 17.9, 74.4 and 21.4 percent respectively. Generally, *M. scutellata* (Sava) pods had higher nutrient digestibilities (except ether extract) than the pods of *M. truncatula* cultivars (Parabinga and Paraggio). However, most of the *in vivo* digestibility values for all of the experimental pod populations were within the ranges which have been reported for cereal straws (AFIC 1987; Capper 1988).

The gross energy content of whole pods measured in this experiment was within the ranges reported for both tropical and temperate pasture dry matter (Hutton 1961; Minson and Milford 1966). It seems that the main problem of medic pods as a feed for ruminants is deficiency in digestible energy (Denney *et al.*1979). However, it was suggested that low digestion of the fibre fraction limited the energy digestibility and intake to 4.72, 4.34 and 1.55 MJ/sheep/day for the Sava, Parabinga and Paraggio pods respectively. It is well documented that the most quantitatively-important nutrient requirement for sheep, as well as other classes of livestock, is energy (ARC 1980; Williams 1982; SCA 1990). Insufficient energy probably limits the performance of sheep more than any other nutrient deficiency and may result from inadequate feed intake or from feed of low-quality. Energy deficiency was probably the main reason for poor performance of the sheep in this *in vivo* experiment.

Sheep require a diet of 8.2-8.6 grams crude protein per MJ metabolizable energy for maximum microbial growth in the rumen (ARC 1984). The metabolizable energy of the pods can be calculated at 82% of the digestible energy as follows:

DE (MJ/kg DM) X 0.82 = ME (MJ/kg DM)

Sava = 6.88 (MJ/kg DM) X 0.82 = 5.64 MJ/kg DM (ME)

Parabinga = 5.65 (MJ/kg DM) X 0.82 = 4.63 MJ/kg DM (ME)

Paraggio = 6.57 (MJ/kg DM) X 0.82 = 5.39 MJ/kg DM (ME)

Crude protein contents of whole pods of Sava, Parabinga and Paraggio were 160, 170 and 200 g/kg DM respectively (Table 4.2). Therefore, the ratios of crude protein to metabolizable energy for these pods are as follows:

Sava	160/5.64 = 28 g CP/MJ ME
Parabinga	170/4.63 = 37 g CP/MJ ME
Paraggio	200/5.39 = 37 g CP/MJ ME

These ratios for alfalfa hay, barley grain and straw approximately are 22, 11 and 5 g CP/MJ ME (ICARDA 1990-1991). Thus mature medic pods can be used as protein sources but they should be supplemented by energy sources. The sheep body weight losses during the experimental periods are in agreement with the above-mentioned conclusion that medic pods require a readily-available energy supplementation or appropriate treatment to be considered as a maintenance feedstuff.

Low percentage of seed survival indicated that medic seeds were highly digestible. This was in agreement with the finding of Carter (1980) who reported that between 90 and 99% of medic seeds were digested by sheep. Similar results also reported from the ICARDA experimental data by Cocks (1988). Apparently chewing and rumination have had the accumulative effects on seed digestion by sheep (Squella 1992). Although seeds of barrel medics (cvs. Parabinga and Paraggio) survived better than snail medic (cv. Sava) this was probably due to their size (Carter 1981a; Carter *et al.* 1989; Thomson *et al.*1989; Squella and Carter 1992). Overgrazing during the dry periods can be a dangerous practice for all cultivars in terms of losing the pod reserves and consequent seed bank. However, more research is needed on the interrelations of grazing pressure during the summer-autumn period, pod/seed survival and the consequences for soil erosion and subsequent pasture regeneration and productivity (Carter *et al.* 1993).

In these *in vivo* studies the general trend of sheep body weight changes showed that medic pods are not ideal as a sole ration to support sheep even at maintenance levels. Therefore, supplementation or treating medic pods with the appropriate methods could be recommended mainly where pods are available in large quantities.

4.2 *In vitro* digestion studies

4.2.1 Introduction

The determination of the digestion of animal feedstuffs has considerable value in the estimation of nutritive value for ruminants (Blaxter 1960). Conventional digestion experiments involving total faecal collection are laborious and require large quantities of feed and animals (Van Keulen and Young 1977). Rate and extent of digestion in the digestive tract of ruminants can be assessed using some laboratory procedures. Laboratory studies are usually lower in cost and more rapid and repeatable than experimentations with animals (*in vivo*). The most accurate and common laboratory procedure for predicting the dry matter digestibility of animal feedstuffs is the two-stage technique described by Tilley and Terry (1963) (Mcleod and Minson 1976). *In* *vitro* digestibility coefficients are highly correlated with *in vivo* coefficients and also digestibility of some feeds such as medic seeds can only be measured by *in vitro* techniques.

4.2.2 Materials and methods

A modification of the procedure of Tilley and Terry's two stage technique (1963) was used for the determination of *in vitro* dry matter and organic matter digestion. Random samples of whole pods, seeds and hulls were ground through a 1 mm screen and sub-samples of c. 0.55 g (range 0.54 to 0.56 g) were weighed into 100 ml numbered glass tubes. Rumen liquor was collected from four fistulated sheep before they received their daily feed ration of equal proportions of chaffed oaten hay and commercial pellets. Rumen liquor was strained through six layers of cheese cloth and added to buffer solution (artificial saliva) in the ratio of 1:4 v/v (one part rumen liquor to four parts buffer solution).

The samples were incubated with the buffered rumen liquor under anaerobic conditions for 48 h in an incubator at 38°C. Tubes were shaken periodically.

At the end of the first stage of digestion, samples were centrifuged and after discarding the supernatant, the hydrochloric acid-pepsin (1:2500) solution added. Digestion of samples in the second stage, continued for 48 h under the same conditions. After digestion the second stage samples were centrifuged and the residues transferred to weighed crucibles and dried in an oven at 100°C for 24 h. In order to determine the organic matter digestibility dried residues were burnt in a muffle furnace for at least 2 h at 600°C (AOAC 1987, 1990).

With every run for *in vitro* digestion two standard samples of known high and low *in vivo* digestibility and four blank glass tubes containing the rumen liquor buffer mixture were also included. The following equations were used for calculating the dry matter and organic matter digestibilities.

Dry matter digestibility (DMD) = Wt of sample-(wt of undigested residue - wt of dry residue of blank)/wt. of sample x 100

Organic matter digestibility (OMD) = Wt of sample organic matter-(wt of undigested organic matter - wt of organic matter of blank)/wt. of sample organic matter x 100

The *in vitro* technique was used mainly for the determination of the digestibility of the constituents of the pods (seed and hull), because of its practicality.

The *in vitro* digestibility of residual pods (pods left by sheep) was measured to detect the possible differences in feeding value between these pods and the pods before feeding (pods as fed).

4.2.3 Results

In vitro dry matter and organic matter digestibilities of medic seeds were relatively high varying from 67.4 to 76.8% for DM and 68.0 to 77.7 for OM (Table 4. 12). In contrast to seeds, the digestibility of hulls was very low (8.9-12.3% for dry matter and 9.5- 12.9% for organic matter).

In vitro digestibility of whole pods were slightly lower than corresponding *in vivo* coefficients but there was a significant correlation between these coefficients (r = 0.971**).

As is evident from Table 4.12 both dry matter and organic matter digestibilities of residual pods were lower than those of the original pods. This was further evidence that sheep selected the medic pods with higher feeding value.

In vitro dry matter digestibilities of residual pods were significantly correlated with hard seed percentage (r = –0.741**) and seed proportion (r = 0.758**), (Figure 4.7).

The *in vitro* dry matter digestibility of residual Sava pods was 7.4 percentage units on average lower than the dry matter digestibility of the original pods, whereas this difference was 2.5 units for Parabinga and 2 units for Paraggio (Table 4.3). Therefore selection by sheep was more efficient for large pods (Sava) than the smaller pods (Parabinga and Paraggio).

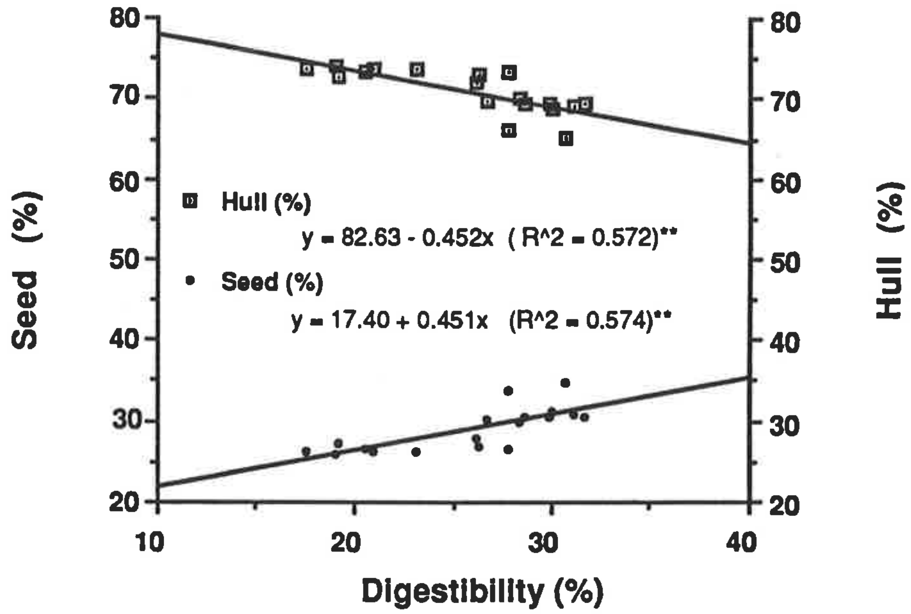


Figure 4.7 Relationship between *in vitro* digestibility and seed and hull components of the residual medic pods

Table 4.12 *In vitro* **dry matter and organic matter digestibility of pods as fed and residual pods and their components** (Moisture-free basis)

Medic species	Component	Pods as fed		Residual pods	
		DM (%)	OM (%)	DM (%)	OM (%)
M. scutellata					
(cv. Sava)	W[1]	34.1	34.7	26.7	30.0
	S[2]	69.2	69.5	-	-
	H[3]	12.3	12.9	-	-
M. truncatula					
(cv. Parabinga)	W	23.4	23.7	20.9	21.6
	S	76.8	77.6	-	-
	H	8.9	9.5	-	-
M. truncatula					
(cv. Paraggio)	W	32.0	32.6	30.0	31.2
	S	67.4	68.0	-	-
	H	9.7	10.2	-	-

[1] W = Whole pods; [2] S = Seeds; [3] H = Hulls

4.2.4 Discussion

In view of the apparently close relationship between *in vivo* and *in vitro* digestibility of whole pods, the *in vitro* techniques appear to be an inexpensive and useful way of rapidly assessing the relative feeding value not only of whole plants but also their constituents, which are impossible to evaluate by feeding to animals. For instance, the digestibility of medic seeds may not be measured economically by *in vivo* procedures whereas they can be evaluated by the *in vitro* methods, especially when only small quantities of the test material are available.

In spite of the fact that pods of Sava and Parabinga represent different species the *in vitro* experiment results (mainly seed component) were similar.

It is clear from the *in vitro* results that both dry matter and organic matter digestibility of residual pods were lower than the original pods. Although it has been reported that sheep are selective animals in grazing annual pasture plants (Broom and Arnold 1986) the *in vitro* digestibility of residual pods in this experiment show that even in the consumption of apparently uniform feeds, sheep use selection ability. Low *in vitro* digestibility of residual pods indicates that in the case of grazing situations (Carter 1981a; de Koning and Carter 1989) sheep first selected the largest pods with more seeds and larger seeds and then small pods with fewer and smaller seeds. Therefore it seems that both ecological size and feeding value of the pods are key factors for their selection in the field or intensive feeding by sheep. The selection ability was more effective for the Sava pods than for the other two cultivars, probably due to the larger size of Sava pods in comparison with Parabinga and Paraggio (259 mg vs 88 and 57 mg).

4.3 *In sacco* digestibility

4.3.1 Introduction

In order to achieve a better understanding of the role of mastication and microbial activities on the digestion of medic pods, four complementary *in sacco* studies were carried out at the Waite Institute animal house.

Carter (1980) reported that generally seed survival of medic seeds after ingestion of a pure intact pod diet by sheep was less than 2%. Medic seeds are accompanied by a fibrous coat (hull or husk) which comprises approximately 70% of the total weight of pods (Denney *et al.* 1978). Total digestibility of whole pods and their fibrous coat is low (Vercoe and Pearce 1960); by comparison seeds are highly digestible (Thomson *et al.* 1987). High digestibility of medic seeds (Carter 1980; Cocks 1988) suggests that during the ingestion and digestion processes, pods and seed-coats are broken into small pieces suitable for microbial and enzymatic digestion. It seems that mastication or chewing, rumination and seed size are the critical factors for medic seed digestion and survival (Squella 1992). It is, therefore, important to try to identify the relative effects of chewing (including rumination) and digestion. The best way to undertake these studies is by using the nylon bag technique. In the first two *in sacco* studies the degradability of ground and unground whole pods, seeds and hull of the three cultivars (Sava, Parabinga and Paraggio) during different incubation times was investigated.

Carter (1981a) and de Koning and Carter (1989) demonstrated that sheep grazing mature pasture first selected the largest medic pods or clover burrs. It was also observed during pen-feeding sheep with mature medic pods, that sheep selected larger pods and left a greater proportion of smaller pods. It is not clear why this occurs. It may be due to the higher feeding value of the larger pods (in comparison with the smaller), or the larger pods may be prehended and ingested by sheep more easily than smaller pods. The third *in sacco* study was therefore designed to examine the degradability of small and large mature medic pods.

In the last *in sacco* study in this series the germination of whole medic seeds after incubation in the rumen for different times was tested.

By better understanding what happens to whole medic pods and pod constituents in the ruminant digestive tract (mainly rumen) it may be possible to develop criteria for selection of medics with pods and seeds resistant to digestion.

4.3.2 Materials and methods

Experiment 1: Dry matter disappearance of ground and unground whole pods, seeds and hulls of *M. scutellata* cv. Sava and *M. truncatula* cvs. Parabinga and Paraggio incubated independently in the rumen of sheep

Animals and feeding management: Four one-year-old Merino wethers weighing on average 37.0 ± 0.6 kg were fitted with a permanent cannula (25 mm internal and 33 mm external diameter). They were allowed to recover from the surgery for 6 weeks before beginning the experiments. The sheep were held in individual pens with galvanised metal mesh floors in the Waite Institute animal house. They were fed commercial pellets (Australian Feed Services Pty. Ltd.) and chaffed oaten hay ration (4:1) at 2.4% of body weight. The pellets were made up of 40% oat hulls, 39% oats, 15% triticale, 2% bentonite, 2% limestone, 1% salt, 0.5% urea, 1% vitamin and minerals. Digestible energy content of the pellets was 9.04 MJ/kg. Apparent dry matter digestibility of the oaten hay was about 65% (Squella 1992). Sheep rations were given once daily at 0900 hr. Water was available *ad libitum*.

The sheep were inspected daily to remove the residues and dirty materials from around the fistula and pens. The wool fibres near to the fistula also were cut by small electric clippers on a regular basis.

Preparation of samples: A representative pod sample (about 4 kg) of each medic cultivar (Sava, Parabinga and Paraggio) was obtained from the same lot of pods as fed to sheep in the *in vivo* experiment reported previously in this chapter but with different percentages of hardseeds. The hardseed percentage of Sava, Parabinga and Paraggio were; 35, 43 and 41 percent respectively. Pods were completely cleaned of visible impurities by hand and then divided into halves, and then in halves again to provide four one kilogram sub-samples. One kg was used as the source of whole unground pods for incubation; 1 kg was ground in a laboratory hammer-mill through a 1-mm mesh screen and 2 kg were dissected and separated into their structural constituents, hull and seed. Each constituent was divided into equal parts, one part was ground and the other part remained unground for incubation.

Statistical design: A factorial-type design was used for DM degradation measurements using four sheep (four replications (R)). The experimental factors were as follows:

Medic cultivar (factor C); Sava (c_1), Parabinga (c_2) and Paraggio (c_3).

Physical form (factor P); unground (p_1) and ground (p_2).

Incubation times (factor I); 0 h (i_1), 24 h (i_2), 48 h (i_3), 72 h (i_4).

Degradation measurements using this design were run independently for whole pods, seeds and hulls. The total number of measurements was 96 (C(3) x P (2) x I (4) x R (4)). All data were subjected to analysis of variance using the Super-ANOVA (Abacus Concepts Inc.) program. Comparison of means was carried out using LSD procedures (Snedecore and Cochran 1971). Analyses of variance and comparison of means were also carried out independently for whole pods, seeds and hulls.

Nylon bag specification: The bags were made from nylon, normal quality synthetic screen (Swiss Screen Pty. Ltd. Sydney, Aust.), with 44 micron pore size. The bags were constructed from a single piece of material measuring 14 x 20 cm that was folded in half and sewn along the open edges using nylon thread. The bottom corners were rounded (to prevent any of the sample being trapped). The tops of the bags were left open for sample placement. The top two edges were folded and double stitched with the nylon thread. The tops of the bags were then fitted with a drawstring in order to be easily closed and tied. The internal dimensions of these bags were 12 x 8 cm (Plate 4.3). All cut edges of the bags were singed in order to prevent fraying in the rumen. The bags were clearly numbered with a permanent marker.

Incubation procedure: Four bags were used for each sample (unground and ground whole pods, seeds and hulls). Samples of about 3 to 5 g air dry were placed in pre-dried and weighed nylon bags to give a sample mass: bag area ratio of 15-25 mg/cm^2. In order to minimise the bag floating a steel ball bearing of 8.4 g weight was also placed in each bag before tightly closing with the drawstring. The drawstrings were tied and the bags were secured at random at approximately one cm intervals near the end of a weighted 30-cm strong nylon line. For securing the bags to the line weighted with a peace of lead (Plate 4.4) antiseptic latex rings (Elastrator Aust. Pty. Ltd.) were used. The line was attached to a wooden handle outside the fistula (Plate 4.5).

The tied bags containing the samples were wetted by placing in tap water for about one minute and then lowered into the rumen to a depth of 25 cm from the top of the fistula before the morning feeding when the rumen was relatively empty. The bags remained in the rumen for 24, 48 and 72 h.

In order to measure the readily-soluble and small particle size materials four bags containing the same amount of sample were moistened and washed under tap water for about five minutes and then dried in the oven similar to other samples. The weight lost due to this washing was regarded as control or zero hour degradation.

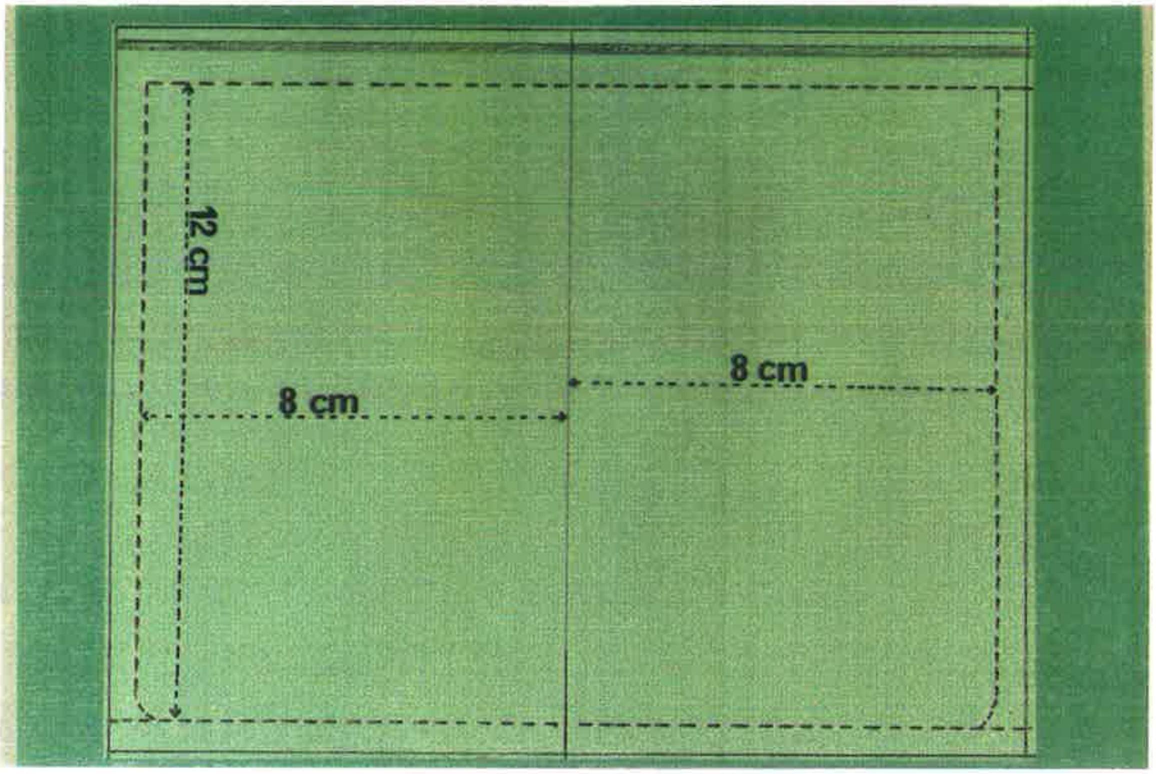
The procedure used in this experiment was as follows: Six nylon bags containing the samples of three cultivars (Sava, Parabinga and Paraggio) were suspended inside the rumen of each fistulated sheep at the same time. At the end of incubation time all the bags (six bags) were withdrawn at the same time. This procedure was undertaken for different incubation times and samples (whole pods, seeds and hulls) independently.

After incubation, the bags were removed and immediately cleaned of adhering digesta by washing under a gentle stream of tap water until the rinsing water was clear. Bags were oven-dried at 65°C for about 48 h to constant weight. This drying procedure also was followed for the zero h (control) bags.

Plate 4.3 Close-up view of the nylon bags used for *in sacco* experiments.

Upper: Pattern for making the bags

Lower: The sewn empty bag with draw string (right) and the filled and tied bag (left).


12 cm
8 cm
8 cm

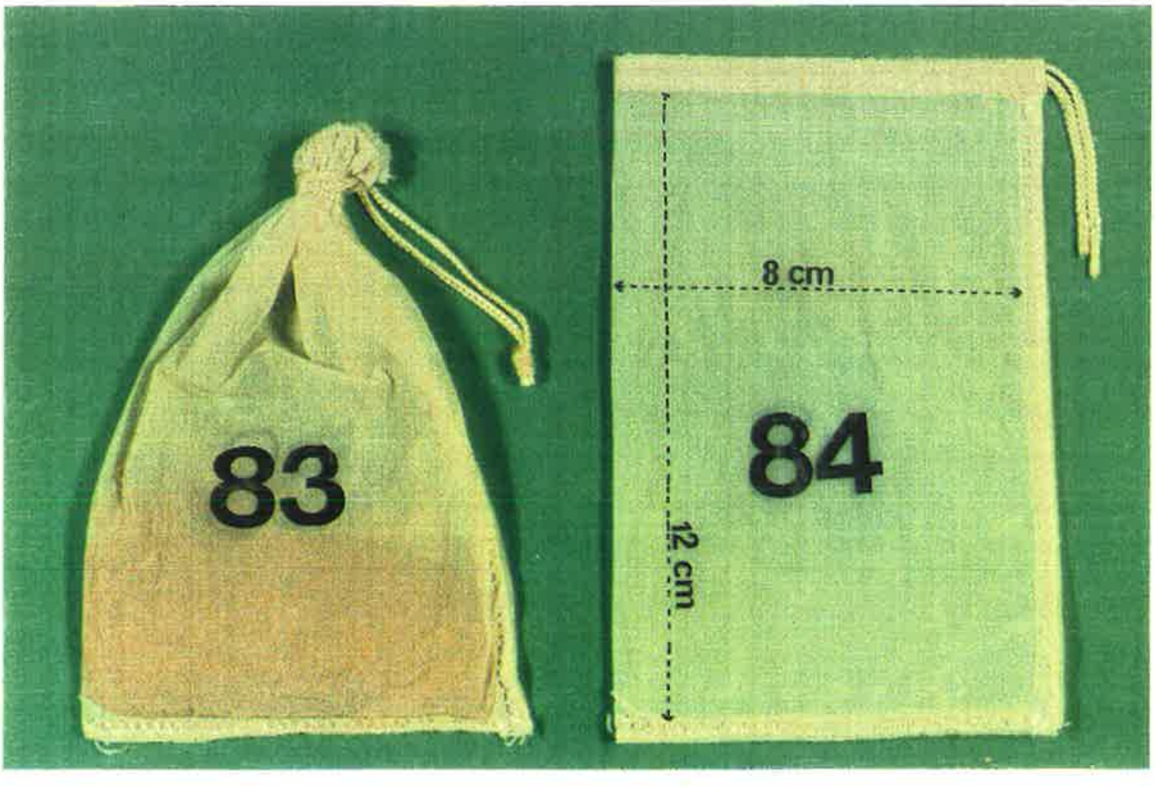

83
8 cm
84
12 cm

Plate 4.4 Close-up view of the bag-securing arrangement used in the *in sacco* experiments: securing line with lead weight (left) and securing line with the bags containing samples ready to suspend in the rumen (right).

Plate 4.5 Close-up view of the fistulated sheep showing the exposed wooden handle.

The DM losses were determined by weight differences between the empty bags, bags containing the samples before and after incubation in the rumen. The actual DM disappearances in the rumen at the end of different incubation times were calculated by subtracting the disappearance at zero h from the total disappearance in the rumen.

After weighing the dried incubated bags and removing the residues, the bags were turned inside out, rinsed and left in soap solution for 24 h. Finally, these bags were washed under running warm water and oven-dried at 65°C for 24 h.

Experiment 2: Dry matter disappearance of unground and ground whole mature pods of *M. scutellata* cv. Sava, *M.* truncatula cvs. Parabinga and Paraggio through consecutive incubation times in the rumen

In the previous experiment DM disappearance of unground and ground whole pods and their constituents was measured by suspending and removing all six bags containing the unground and ground samples at the same time (for any one of the experimental incubation times 24, 48, and 72 h). This method was chosen because of the limitation in the number of bags which can be suspended in the rumen. The following experiment was carried out in order to compare this method with serial sampling the same materials in similar physical states (ground and unground).

It was suggested that if the bags containing the same material (unground and ground) were suspended at the same time but consecutively removed at the end of each incubation time (24, 48, and 72 h) this may give results different from the previously-discussed method. In order to test this hypothesis this experiment was designed.

Animals and feeding management: The same fistulated sheep as used in Experiment 1 were used. The sheep were fed with commercial pellets and oaten hay at a level slightly higher than maintenance (SCA 1990).

Preparation of samples: The procedure used for whole pod sampling and preparation of samples for incubation were the same as described under Experiment 1.

Statistical design: Experiment 2 was also of a completely randomised design with two physical forms (ground and unground whole pods), four incubation times (0, 24, 48 and 72 h) three cultivars and four replicates (sheep).

Incubation procedure: About 3 g samples of each of the cultivars were weighed into nylon bags. A set of six bags containing unground and ground whole pods of one cultivar were placed in the rumen of each fistulated sheep before morning feeding. At the end of each incubation interval of 24 h two bags (one containing unground and the other containing ground samples were removed, washed, dried and weighed as described under Experiment 1. This procedure was repeated with each cultivar.

Experiment 3: Degradation in the rumen of ground large and small mature medic pods

It has been reported that sheep selected large pods during grazing dry medic pasture residues (Carter 1981a). Similar results in pod selectivity by sheep were obtained during the pen-feeding experiment reported in this chapter. In order to achieve better understanding of the digestion of medic pods of different sizes, it was decided to compare DM degradation of large and small pods of annual medics.

Animals and feeding management: Fistulated sheep and their feeding management were the same as in Experiments 1 and 2. Sheep were fed with pellets and chaffed oaten hay at a level slightly higher than maintenance.

Preparation of samples: Representative pod samples of Sava, Parabinga and Paraggio were taken from bulked populations and divided into three categories, large, medium and small according to pod weight. Small and large whole pods were ground separately through a laboratory hammer mill fitted with a 1 mm screen.

Statistical design and incubation procedure: A completely randomised factorial design with the following factors and replications was used as follows:

Medic cultivars (factor C), Sava (c_1), Parabinga (c_2), and Paraggio (c_3)
Pod size (factor S), large (s_1) and small (s_2)

Incubation times (factor I) 0 h (i_1) and 48 h (i_2)

The measurements were replicated (R) four times.

Total measurement = C (3) x S (2) x I (2) x R (4) = 48

The same nylon bags described previously were used. Nylon bags containing the samples were introduced and removed from the rumen at the same time before the morning feeding. The same procedures for washing and drying the samples and nylon bags were followed.

Experiment 4: Medic seed germination after incubation in the rumen

Medic pods either enter the pod reserve or are grazed by ruminants (mainly sheep). It has been reported (Carter 1980) that, in general, not more than 2% of annual medic seeds survive following ingestion of pods by sheep. Simao Neto and Jones (1987) demonstrated that in spite of susceptibility of soft seeds to digestion hard seeds were largely resistant to this process. The digestion of feed eaten by ruminants occurs in different parts of the digestive tract and has not always been well documented in a comprehensive form (Simao Neto *et al.* 1987). However, one rapid and economical way of studying the role of the ruminal site in digestion and viability of medic seeds is using the *in sacco* method.

The aim of this experiment was to study the effects of microbial fermentation on intact medic seeds incubated in the rumen of fistulated sheep for pre-determined periods of time.

Animals and feeding management: The experiment was carried out at the Waite Institute animal house using the same four fistulated sheep and feeding management as in the other *in sacco* experiments .

Statistical design and preparation of the samples: The completely randomised design with factorial arrangement of the following factors was used.

Medic cultivars (factor C): Sava (c_1), Parabinga (c_2), and Paraggio (c_3)

Incubation times (factor I): 0 h (i_1), 24 h (i_2) and 48 h (i_3)

Replication : 4

Total measurments = 3 x 3 x 4 = 36

About 0.5 kg pods were taken at random from the same source of pods used in the *in vivo* experiment previously reported in this chapter. Pods were dissected by hand and pure seeds separated from the other residues.

Incubation procedure: Samples (about 3 g) of whole seed of each cultivar were weighed into nylon bags. Six bags were introduced into the rumen of each sheep through the fistula before daily feeding. Bags were removed consecutively from the rumen at the end of specified incubation periods.

All procedures were the same as for the previous experiments except that in order to prevent heat damage to the seeds, these were dried at a lower temperature (40°C). Seeds were germinated at 19°C for 14 days in a humidified incubator as explained earlier in this chapter.

4.3.3 Results

In sacco studies

Experiment 1: The degradation characteristics of whole medic pods and pod components are given in Table 4.13. Significant differences ($P<0.01$) occurred between medic species, physical forms and incubation times for dry matter disappearance of unground and ground whole pods, seeds and hulls after different incubation times. Furthermore, there were some significant interactions between medic cultivars, physical forms and incubation times (Table 4. 14).

The DM losses of whole pods, seeds and hulls of Sava were significantly ($P<0.01$) higher than those of *M. truncatula* cultivars (Parabinga and Paraggio) after the various incubation times. As in the case of the *in vivo* and *in vitro* studies, Parabinga pods showed the lowest value of DM losses.

Grinding significantly ($P<0.01$) increased the total dry matter losses of all the samples for all incubation periods. Grinding had more effect on the seed component than on whole pod and hull samples.

Actual DM losses (Figure 4.8) were obtained by subtracting the solubility values from the total dry matter losses. The statistical analyses of actual DM losses (DM digested) are given in Table

4.15. The actual degradability of whole ground pods and hulls were similar to the digestibility coefficients determined by *in vivo* and *in vitro* methods (Table 4.16). Correlation coefficients between *in vivo* dry matter digestibility of whole Sava pods and dry matter degradation of corresponding pods after 24, 48 and 72 h incubation time were 0.793, 0.925 and 0.988 respectively. The coefficients for Parabinga and Paraggio pods after the same incubation periods (24, 48 and 72 h) were 0.777, 0.989, 0.761 and 0.675, 0.991 and 0.707 respectively (Table 4.17).

Table 4.13 Percent dry matter losses of unground and ground mature whole medic pods and pod components at different rumen incubation times in fistulated sheep (Data show means ± SE)

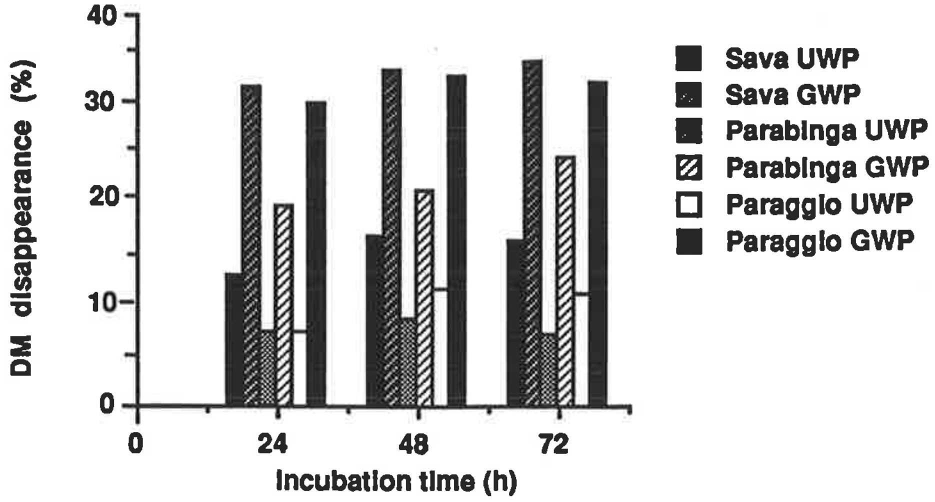
Medic species	Sample	Physical form	Incubation time (h)			
			0[6]	24	48	72
M. scutellata (cv. Sava)	W[1]	U[4]	5.4 ± 0.1	18.1 ± 0.2	22.2 ± 0.6	21.5 ± 1.3
		G[5]	14.2 ± 0.5	45.7 ± 0.5	47.5 ± 0.3	48.2 ± 0.5
	S[2]	U	2.9 ± 0.2	48.0 ± 1.3	72.7 ± 2.4	76.7 ± 1.6
		G	37.0 ± 0.4	86.5 ± 1.0	96.0 ± 1.0	97.1 ± 0.3
	H[3]	U	9.0 ± 0.3	12.6 ± 0.6	13.6 ± 0.2	13.4 ± 0.2
		G	12.2 ± 0.3	22.8 ± 0.5	22.7 ± 0.3	22.8 ± 0.3
M. truncatula (cv. Parabinga)	W	U	4.3 ± 0.2	11.6 ± 0.9	12.7 ± 0.7	11.4 ± 1.2
		G	13.8 ± 0.4	33.4 ± 1.0	35.1 ± 1.6	38.1 ± 0.8
	S	U	3.3 ± 0.1	39.6 ± 0.8	57.7 ± 1.4	59.3 ± 1.0
		G	32.9 ± 1.0	86.3 ± 1.4	94.1 ± 2.1	95.4 ± 0.7
	H	U	7.7 ± 0.6	11.1 ± 0.5	11.2 ± 0.3	11.4 ± 0.5
		G	10.4 ± 0.4	16.6 ± 0.5	17.7 ± 0.8	18.2 ± 0.4
M. truncatula (cv. Paraggio)	W	U	5.3 ± 0.1	12.6 ± 0.9	16.7 ± 0.5	16.3 ± 1.4
		G	12.7 ± 0.3	42.5 ± 1.7	45.3 ± 1.9	44.5 ± 0.5
	S	U	3.0 ± 0.1	43.5 ± 2.3	64.2 ± 1.5	70.8 ± 0.3
		G	35.3 ± 1.2	86.6 ± 1.1	94.7 ± 1.7	96.3 ± 0.6
	H	U	6.4 ± 0.3	12.9 ± 0.2	13.0 ± 0.7	12.7 ± 0.8
		G	10.1 ± 0.3	19.9 ± 0.6	20.8 ± 0.6	20.3 ± 0.6

[1] W = Whole pods; [2] S = Seeds; [3] H = Hulls; [4] U = Unground; [5] G = Ground;
[6] 0 = Readily-soluble materials and small particles which were removed from the nylon bags under tap water.

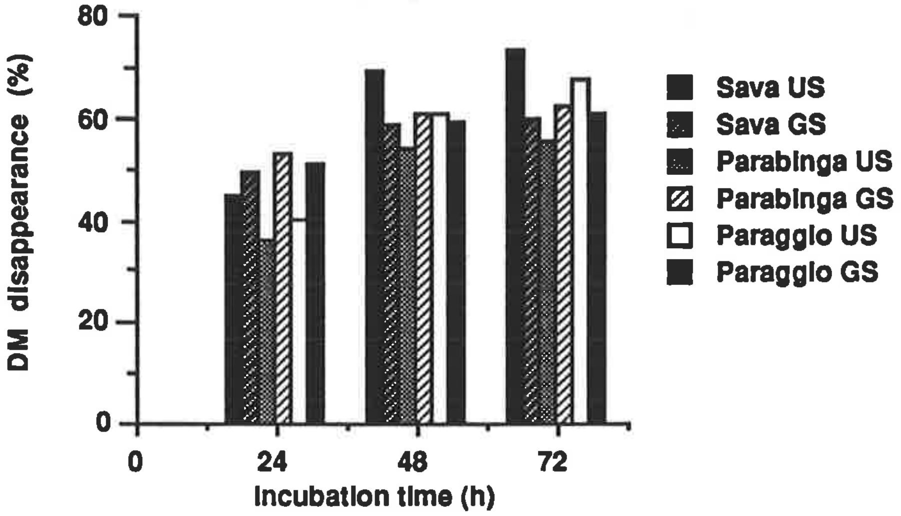
Table 4.14 Summary of analyses of variance made on total dry matter losses in the rumen of whole pods and pod components

Source of variation	Type of sample		
	Whole pods	Seeds	Hulls
		Significance levels	
Medic cultivar	**	**	**
Physical form	**	**	**
Incubation time	**	**	**
Medic cultivar x Physical form	**	**	**
Medic cultivar x Incubation time	**	**	**
Physical form x Incubation time	**	**	**
Medic cultivar x Physical form x Incubation time	**	**	NS

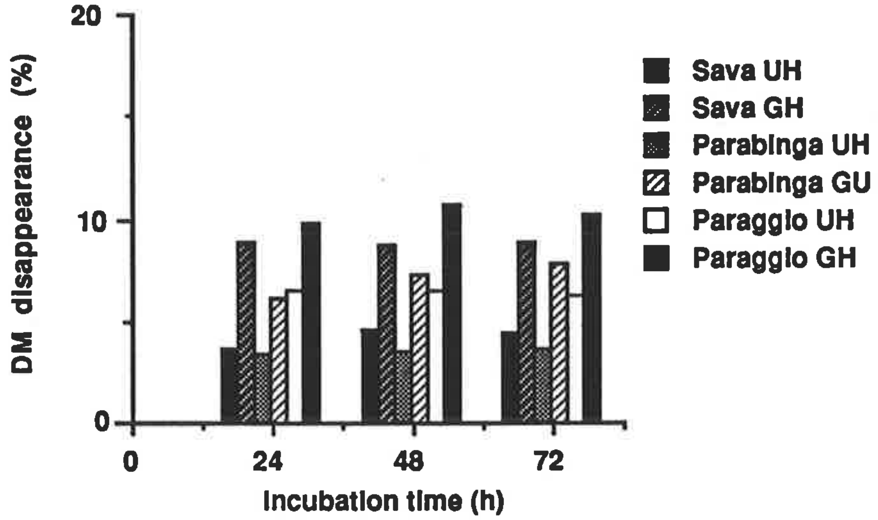
NS = Not significant; ** = P<0.01



Whole pods



Seeds



Hulls

Figure 4.8 *In sacco* Experiment 1. Actual dry matter disappearance (digested DM) of whole medic pods and pod components

Table 4.15 Summary of analyses of variance made on actual dry matter losses in the rumen of whole pods and pod components

Source of variation	Type of sample Whole pods	 Seeds	 Hulls
		Significance levels	
Medic cultivar	**	**	**
Physical form	**	**	**
Incubation time	NS	**	NS
Medic cultivar x Physical form	NS	**	**
Medic cultivar x Incubation time	NS	NS	NS
Physical form x Incubation time	NS	**	NS
Medic cultivar x Physical form x Incubation time	NS	NS	NS

NS = Not significant; ** = P<0.01

Generally, for all samples including both unground and ground whole pods, seeds and hulls the highest degradation values were obtained after 48 h incubation. A longer period of incubation sometimes actually reduced the apparent DM losses, even for low hulls. However, most dry matter loss, even of unground samples, occurred during the first 24 h and was often more than 80% of the highest values obtained in longer periods of suspension in the rumen.

Solubility values (0 h of incubation) of ground hulls were higher than their degradability in the rumen (Figure 4.8). For example, dry matter loss of ground Sava hull at 0 h was 13.9%, whereas degradation losses in the rumen after 24, 48 and 72 h were 8.9, 8.8 and 8.9 percent respectively.

The results of this experiment in terms of the relationship between *in vivo* digestion and *in sacco* degradability after 48 h suspension in the rumen are presented in Table 4.16.

Table 4.16 Percent digestibility of mature whole medic pods and pod components determined by different methods

Medic species	Type of sample	*In vivo* DM digestibility	*In vitro* DM digestibility	*In sacco* DM degradability (48h)
M. scutellata				
(cv. Sava)	W[1]	36.7	34.1	47.5[4]-33.3[5]
	S[2]	-	69.2	96.0-59.0
	H[3]	-	12.3	22.8- 8.8
M. truncatula				
(cv. Parabinga)	W	26.9	23.4	35.1-21.3
	S	-	76.8	94.1-61.2
	H	-	8.9	17.7- 7.3
M. truncatula				
(cv. Paraggio)	W	32.6	32.0	45.3-32.6
	S	-	67.4	94.7-59.4
	H	-	9.7	20.8-10.7

[1] W = Whole pods; [2] S = Seeds; [3] H = Hulls; [4] Total degradability (sum of material degraded by microbial fermentation and small particles washed from the rumen); [5] Actual degradability (determined by subtracting the degradation at zero h from 48 h degradation)

Table 4.17 The relationships between the mean dry matter digestibility of whole pods determined *in vivo* by total faecal collection and actual dry matter digestibility measured using the *in sacco* technique

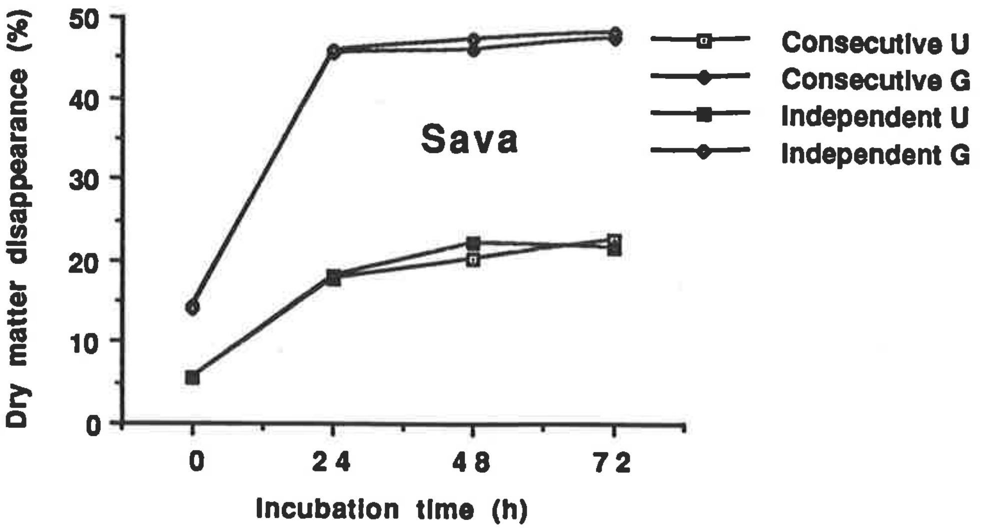
Medic species	Incubation time (h)	Y = a + bX a	b	r	Significance levels
Ideal		0	1	1	
M. scutellata (cv.					
Sava)	24	-0.71	1.16	0.793	NS
	48	-49.97	2.57	0.925	*
	72	-21.70	1.69	0.988	**
M. truncatula (cv.					
Parabinga)	24	15.74	0.53	0.777	NS
	48	16.83	0.43	0.989	**
	72	9.16	0.70	0.761	NS
M. truncatula (cv.					
Paraggio)	24	18.88	0.39	0.675	NS
	48	13.03	0.54	0.991	**
	72	-16.31	1.47	0.707	NS

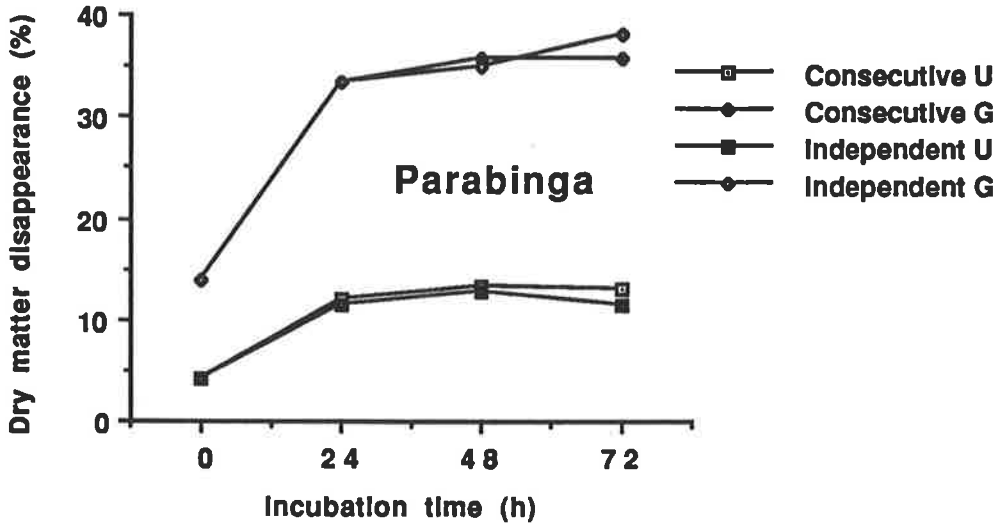
NS = Not significant; * = P<0.05; ** = P<0.01

In sacco Experiment 2

Table 4.18 shows the total dry matter disappearance of ground or unground whole mature medic pods at consecutive incubation times. As for Experiment 1, highly significant differences were found between physical form (ground or unground) and incubation times (0, 24, 48 and 72 h). The interactions between physical forms and incubation times also were significant ($P<0.01$) (Table 4.19). As for Experiment 1, dry matter losses from nylon bags increased up to 48 h. Suspending the samples for a longer time in the rumen did not increase degradability for most of the samples including whole pods, seeds and hulls.

Dry matter degradabilities obtained in this experiment were highly correlated ($r = 0.99^{**}$) with the results of the previous *in sacco* study (Experiment 1). Therefore, the procedure of suspending and removing the nylon bags in the rumen through different incubation times was not a source of variation in these experiments. In considering the *in sacco* method of feed evaluation through different incubation periods both independent or serial sampling procedures could be undertaken depending on the experimental design and facilities. However, the total dry matter disappearance of whole pods obtained by the mentioned procedures are shown in Figure 4.9. It should be noted that in this figure, "independent" and "consecutive" refer to the results of *in sacco* Experiments 1 and 2 respectively.





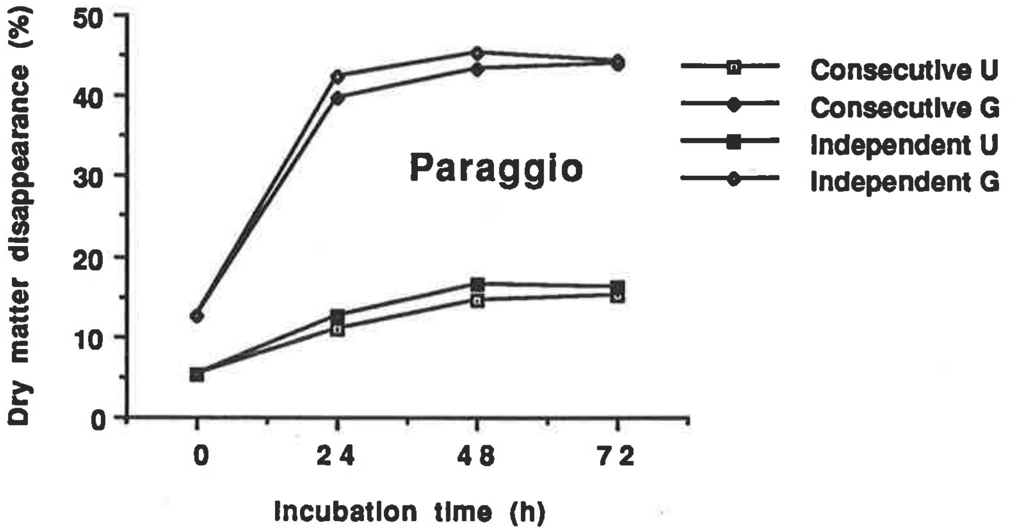


Figure 4.9 Total dry matter disappearance of ground (G) and unground (U) whole pods determined by different incubation procedures in the *in sacco* Experiments 1 and 2

Table 4.18 **Percent dry matter disappearance of whole medic pods during consecutive incubation times in the rumen of fistulated sheep** **(Data show means ± SE)**

Medic species	Physical form	Incubation time (h)			
		0	24	48	72
M. scutellata (cv.					
Sava)	U	5.5 ± 0.2	17.6 ± 0.3	20.4 ± 0.4	22.6 ± 0.2
	G	14.5 ± 0.3	45.4 ± 1.6	46.0 ± 0.3	47.4 ± 1.6
M. truncatula (cv.					
Parabinga	U	4.3 ± 0.2	11.9 ± 0.6	13.3 ± 0.4	13.2 ± 0.3
	G	13.9 ± 0.2	33.5 ± 0.4	35.7 ± 0.3	35.9 ± 0.4
M. truncatula (cv.					
Paraggio)	U	5.4 ± 0.1	11.0 ± 0.4	14.6 ± 0.6	15.2 ± 0.4
	G	12.6 ±0.2	39.7 ± 0.4	43.5 ± 0.6	43.9 ± 0.2

U = Unground; G = Ground

Table 4.19 ***In sacco*** **Experiment 2. Summary of analyses of variance made on dry matter degradation of whole medic pods during consecutive incubation times in the rumen of fistulated sheep**

Source of variation	Medic cultivar		
	Sava	Parabinga	Paraggio
		Significance levels	
Physical form	**	**	**
Incubation time	**	**	**
Physical form x Incubation time	**	**	**

** = P<0.01

In sacco Experiment 3

The physical characteristics of two sizes of pods (large and small) are given in Table 4.20. Differences between all characteristics were significant (P<0.01). The main points in comparing the physical characteristics were differences in number of seeds per pod and in percentage of the seed component. Although mean seeds per pod in small pods were significantly lower than the corresponding values for large pods, in percentage terms the seed component for small pods was higher than for large pods. For example, mean seeds per pod of large and small Sava pods were 5.1 and 3.3 seeds respectively, but seed components were 29.9

and 33.3 percent for the respective pods. The same trend of differences was found for the pods of other cultivars (Table 4.20).

Table 4.20 Physical characteristics of small and large medic pods incubated in the rumen of fistulated sheep (Data show means ± SE)

Medic species	Pod size	Pod weight (mg)	Mean seeds per pod	Seed weight (mg)	Hard seed (%)	Seeds‡ (%)	Hulls ‡ (%)
M. scutellata (cv. Sava)	S^1	144 ± 2.6	3.3 ± 0.1	14.4±0.3	79.6±3.6	33.3±0.9	66.7±0.9
	L^2	352 ± 9.3	5.1 ± 0.1	20.7±0.6	78.4±5.3	29.9±0.9	70.1±0.9
Significance levels†		**	*	**	**	**	*
M. truncatula (cv. Parabinga)	S	46 ± 2.0	5.1 ± 0.2	2.7±0.0	81.3±3.5	30.0±0.9	70.0±0.9
	L	140 ± 2.8	7.3 ± 0.2	4.7±0.1	79.5±4.8	24.6±0.6	75.4±0.6
Significance levels		**	**	**	**	**	**
M. truncatula (cv. Paraggio)	S	40 ± 1.1	4.7 ± 0.3	3.0±0.1	80.5±2.3	35.0±1.4	65.0±1.4
	L	99 ± 2.4	6.2 ± 0.3	4.9±0.1	78.5±3.8	30.5±1.1	69.5±1.1
Significance levels		**	**	**	**	*	*

^{1} S = Small; ^{2} L = Large; ‡Seed and hull components determined by dissection;
* = P<0.5; ** = P<0.01

A summary of the analyses of variance for the dry matter disappearances between all the experimental factors and their interactions (Table 4.22) shows that all were highly significant (P<0.01). Dry matter disappearance of small pods was greater than that of large pods, probably because of the higher percentage of seed component in total composition.

The solubility values of small and large pods for all cultivars were similar. Generally small pods had higher DM losses than the large pods. The differences between DM losses of small and large Sava pods were higher than the corresponding values for barrel medics (Parabinga and Paraggio). For example, the difference between dry matter losses of large and small Sava pods was 8 percentage units, whereas this difference for other cultivars was only two percentage units (Figure 4.10).

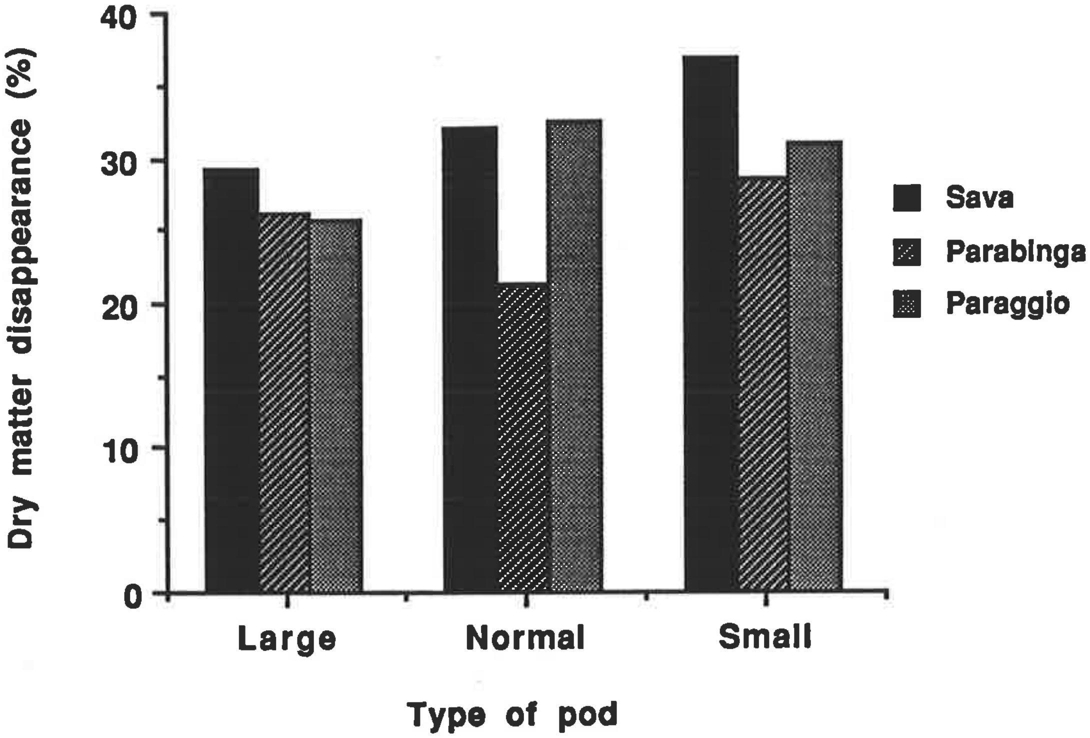


Figure 4.10 Actual dry matter disappearance of different sizes of medic pods

Table 4.21 ***In sacco* Experiment 3. Percent dry matter disappearance of ground small and large mature medic pods incubated in the rumen (Data show means ± SE)**

Medic species	Small pods		Large pods	
	Incubation time (h)		Incubation time (h)	
	0	48	0	48
M. scutellata (cv. Sava)	13.6 ± 0.4	50.6 ± 0.7	13.1 ± 0.2	42.2 ± 0.3
M. truncatula (cv. Parabinga)	13.4 ± 0.4	36.1 ± 0.2	15.0 ± 0.3	35.8 ± 1.0
M. truncatula (cv. Paraggio)	14.7 ± 0.3	45.6 ± 0.4	14.7 ± 0.4	43.4 ± 0.1

Table 4.22 Summary of analyses of variance made on dry matter disappearance of ground large and small medic pods incubated in the rumen

Source of variation	Significance levels
Medic cultivar	**
Pod size	**
Incubation time	**
Medic cv. x Pod size	**
Medic cultivar x Incubation time	**
Pod size x Incubation time	**
Medic cultivar x Pod size x Incubation time	**

** = P<0.01

As in the other digestion studies including *in vivo*, *in vitro* and *in sacco* generally both Sava pods (large and small) had the highest dry matter disappearance values. Parabinga showed the lowest degradability of the tested cultivars (Table 4.21 and Figure 4.10).

In sacco Experiment 4

The results were similar to those in *in sacco* Experiment 1 in terms of dry matter disappearance of intact seeds. The highest degradability values were obtained after 48 h incubation. Degradation values after 24 h were about 66% of the figures measured after 48 h (Table 4.23).

The effects of rumen fermentation on seed germination are shown in Figure 4.11. It is evident from this figure that germination is adversely affected by incubation in the rumen. The greatest effect was on Paraggio seeds. At 0 h of incubation germination was 65%, whereas after incubation for 48 h this figure was reduced to only 4%. In another words, most of the soft seeds, even in an intact form, can be killed and digested by the fermentation process in the rumen while significant amounts of hard seeds remained unchanged.

Table 4.23 Percent dry matter disappearance of intact medic seeds incubated in the rumen of sheep (Data show means ± SE)

Medic species	Incubation time (h)		
	0	24	48
M. scutellata (cv. Sava)	2.9 ± 0.1	46.8 ± 0.4	69.6 ± 0.7
M. truncatula (cv. Parabinga)	3.3 ± 0.4	37.4 ± 1.1	56.6 ± 0.4
M. truncatula (cv. Paraggio)	3.1 ± 0.2	43.1 ± 1.2	64.2 ± 1.0

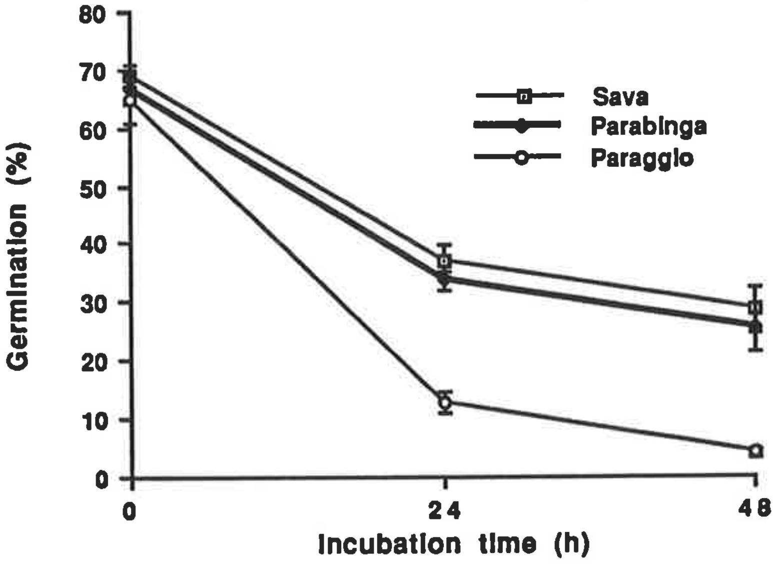


Figure 4.11 Germination of intact medic seeds after incubation in the rumen of sheep (Vertical bars are ± SE)

4.3.4 Discussion

In general, grinding increased the "solubility" (DM loss at 0 h) of all samples, probably because of significant reduction in particle size, which allowed some fine particles to pass through the pores of the nylon bags. This happened to a greater extent for seeds than for whole pods or hulls. The solubility values of whole pods, seeds and hulls of Sava were 2.6, 12.8 and 1.5 times more than the corresponding values of unground samples respectively. These figures for Parabinga were 3.2, 10.0 and 1.4 and for Paraggio 2.4, 11.8 and 1.6 respectively.

The results indicated that significant amounts of intact seeds were killed and digested in the rumen. Degradability of different medic seeds which were incubated in the rumen in this experiment varied between 13.5 to 21 times more than their solubility in tap water (zero h of incubation). With regard to hard-seededness of the medic seeds (see Materials and method of *in sacco* Experiment 1 and the results of *in sacco* Experiment 4) nearly all of the digested intact seeds in the rumen have been soft seeds whereas hard seeds are hardly affected. Such results have been reported by other workers (Squella and Carter 1992). It is suggested that medic seeds can be easily digested in the rumen, if the seed coat is scarified rendering seeds permeable, a process enhanced by chewing and rumination. Therefore, in addition to the initial level of seed hard-seededness, the physical process of ingesting whole mature medic pods and subsequent chewing and rumination are the most important factors in medic seed survival.

Although grinding hulls increased their solubility about 1.5 times, no improvement in the actual rumen degradation was obtained. The results indicated that rumen fermentation of hulls is very low even after 72 h incubation (Figure 4.8). The relatively high degradation of whole pods in comparison with the hull component shows that most of this degradation is due to the seed component.

The results of analyses of variance (Tables 4.14 and 4.15), indicate that the effects of physical form, incubation times and cultivars for most of the samples were not additive. Generally, degradability of whole pods, seeds and hulls in both physical forms (ground and unground) increased linearly up to 48 h incubation. Further incubation was ineffective in maintaining the same rate of fermentation. Each physical form had its own pattern of rumen degradability during the incubation times. Normally, differences between degradation values obtained following different incubation times for unground samples were higher than the corresponding values of ground samples. For instance, the difference between degradation values of unground whole pods of Sava determined, 24 and 48 h after incubation in the rumen was 4.1 percentage units, whereas the corresponding value for the ground samples was 1.8 percentage units. This was probably because the breaking down of large particles by animals and their rumen microbes needs more time than for the small particles.

In general, the degradability of larger seeds (Sava) was greater than that of smaller seeds. Therefore, it may be concluded that smaller seeds have more chance to survive through the digestive tract of ruminants than the largest seeds. This is in agreement with the finding of Carter (1980,1981a) Carter *et al.* (1989) and Squella (1992).

Although physical treatment (grinding) has had little effect on solubility and degradability of hulls from a nutritional point of view it is suggested that the physico-chemical processes in the animal should be more effective and results in better intake and digestibility.

When the results of this experiment were used for comparison with values found *in vitro* the data showed that the digestibility coefficients determined by nylon bags after 48 h incubation are the closest to the *in vivo* coefficients. The mean digestibility coefficients determined by different methods presented in Table 4.16 were in agreement with the results obtained by Wanapat *et al.* 1985 and Navaratne *et al.* 1987.

The results of the second *in sacco* experiment showed that the incubation method does not significantly affect the results obtained, because suspension time in the rumen is the key factor, not incubation procedure. In other words either all of the samples can be incubated and taken out at the same time or incubated at the same time and taken out consecutively at the end of each incubation period.

Despite the similarity in solubility of large and small whole pods of the three medic cultivars, their rumen degradability differed significantly, presumably due to the higher seed component of small pods. It is clear from the physical characteristics of large and small pods used in *in sacco* Experiment 3, that the large pods contain more and heavier seeds. Nevertheless, the pod weight ratio of large pods to the small pods is higher than the corresponding ratios for mean seeds per pod and seed weight. For example, the pod weight ratio of large pods to the small pods of Sava was 2.4, whereas the corresponding ratios for mean seeds per pod and seed weight were 1.5 and 1.4 for this cultivar respectively. Such ratio differences had led to differences in total weight of seed and hull components.

The results of these studies (*in vivo* and *in sacco*) show that besides the effect of seed component on consumption of larger pods, ecologically these pods are more visible and available for sheep than the smaller pods. As grazing continues large pods with more seeds are probably more easily prehended and ingested by sheep and small pods with less seeds are left. The results of the *in vivo* experiment suggest the above-mentioned conclusion. However, more research is needed to distinguish the ecological effects from the effects of seed and hull components on the consumption of mature pods of annual medics.

Incubation of intact medic seeds in the rumen severely affected seed germination. For example, germination of Paraggio seeds fell from 65% at 0 h incubation to 4% after 48 h incubation. Degradation values of intact seeds recorded in Table 4.23 show that hard seeds are barely digested in the rumen, probably due to a impervious cuticle which is more resistant to microbial digestion. The similar germination response of medic species was reported by Squella (1992) after incubation of seeds in the rumen of sheep.

In conclusion, it can be noted that the mature medic pods are a good feed resource for sheep during the dry months of summer in the cereal-livestock zone of southern Australia mainly when other feed resources are in short supply. Mature medic pods undoubtedly are able to provide the protein requirements for nearly all classes of sheep, but are deficient in digestible energy. Therefore considerable losses in body condition and weight of the sheep which are grazed on these pastures can be expected. Supplementary feeding in these situations is strongly recommended in order to maintain both sheep and pastures. Medic pods may be added to the complete rations for balancing the crude protein content or given as a pure ration without adverse effects. However, for better utilization of this feed resource, mainly in intensive or lot-feeding situations, more studies are required for identification and improving the physical and chemical structure of the crude fibre component of pods.

5.0 STUDIES ON THE POOR INTAKE OF ONE LINE OF MATURE PODS OF *MEDICAGO TRUNCATULA* CV. PARAGGIO

5.1 Introduction

An important constraint to the utilisation of feeds by ruminants is the voluntary intake of the feed by the animals. Simply, the target level of intake for a certain animal or group of animals may be defined as that level of intake that normally supplies the nutrients required for the pre-determined level of production or physiological status of the animals (Garnsworthy and Cole 1990). Voluntary feed intake in ruminants is influenced by many factors relating to the type and physiological status of the animals, feed characteristics and various components of the environment (Weston 1978, 1981). Animal production may be improved by increasing intake as well as by making digestion and metabolism more efficient (Grovum 1988).

The *in vivo* study reported in Chapter 4 indicated that the voluntary intake of Paraggio pods was only about 30% of that of the other two cultivars (Parabinga and Sava). Hence a study of factors responsible for the very low intake of the Paraggio pods seemed important for the following reasons.

(i) As the grazing of dry residues of medic pastures based on Paraggio and other medic cultivars by sheep during the dry summer and early autumn in southern Australia is necessary, the palatability and high voluntary intake of medic residues (especially mature pods) is very important and leads to higher sheep numbers and production.

(ii) When medic pasture residues are heavily grazed during the summer and early autumn months the low palatability of medic pods may lead to long-term stability of the pastures and grazing systems. In these situations growing medic cultivars that generally produce mature pods with lower intakes may be important for pasture stability if not for sheep production.

(iii) Possibly the management system used for pod harvesting and storage has affected palatability, intake and consequent feeding value. Therefore, detection of causal reasons for the low intake of Paraggio pods should provide useful information in this context. In other words if the responsible factor is related to undesirable methods of pod conservation, it can be minimised by making appropriate changes.

5.2 Voluntary intake and disappearance of mature pods of *Medicago truncatula* cv. Paraggio in the rumen of sheep

It was suggested that the low intake of the Paraggio pods used in previous studies (Chapter 4) may reflect the fact that the pods were harvested in a poor season and were smaller than normal size. In order to test this hypothesis it was decided to compare the intake and *in sacco* disappearance of these pods with larger pods of the same cultivar grown in a good season.

5.2.1 Materials and methods

In vivo study

Medic pods: Two lines of pods of *M. truncatula* cv. Paraggio harvested following a good growing season in 1987 (G-Paraggio) and a poor growing season in 1989 (P-Paraggio) were used (Plate 5.1). The P-Paraggio pods were from the same source as described in Chapter 4.

Average weight of the pods, seeds, number of seeds per pod, seed:hull ratio and percentage of hard seeds were recorded for six independent representative samples of 25 pods (Table 5.1).

Table 5.1 Physical characteristics of the two lines of mature pods of Paraggio barrel medic

Type of pods	Pod weight (mg/pod)	Mean seeds per pod	Seed weight (mg)	Seeds† (%)	Hulls† (%)	Hard seeds (%)
G-Paraggio	73.4	5.80	3.77	29.8	70.2	86
P-Paraggio	56.7	5.08	3.52	31.5	68.5	91

†Seed and hull components determined by dissection

Experimental animals: Eighteen mature (over two years old) Merino wethers with mean body weight (±SE) of 60.9 ± 0.5 kg were selected from the Waite Institute wether flock. The sheep were held in individual pens in the Waite Institute animal house and allocated by stratified randomisation based on body weight to the treatments (nine sheep per treatment).

Plan of the experiment: Two dietary treatments were used as follows: pure-pods of G-Paraggio and pure pods of P-Paraggio.

Plate 5.1 Close-up view of the two lines of Paraggio barrel medic pods and the pod components (seeds and hulls).

Upper: G-Paraggio

Lower: P-Paraggio


0
10mm 20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180


0
10mm 20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170

Voluntary dry matter and organic matter intakes of the pure-pod rations were compared in an unpaired experiment (an experiment consisting of two independent samples of equal size). The feeding procedure covered two periods: a preliminary period of 7 days and a main period.

In the preliminary period, sheep were accustomed to the pens, indoor conditions and new diets. At the start of the preliminary period sheep were fed a maintenance ration of oaten chaff and pellets at a level of about 2.5% of body weight. The medic pods were gradually introduced into the diets. By the end of the preliminary period, sheep were fed solely on Paraggio pods.

The voluntary intake in the main period of 14 days was measured by the method recommended by Harris (1970). This involved adjusting the quantity offered to each sheep daily to provide between 100 and 200 g residue per day. The sheep were fed once a day at 0900 hr. The residual (uneaten) pods were collected every day before feeding. Residues were not re-used. Sheep were weighed at the beginning of each period and at the end of main period, prior to morning feeding.

Samples of the two lines of pods were taken daily and bulked over the main period for determination of dry matter and chemical analyses including ash, crude protein, crude fibre, ether extract, nitrogen-free extract determinations. The analytical procedures were the same as those described for the *in vivo* experiment in Chapter 4.

In sacco studies

In sacco digestibility of the two lines of pods and their constituents was determined using nylon bags and the procedure previously described (Chapter 4). For this *in sacco* study, four Merino wethers (mean body weight 39.3 ± 0.6 kg) each fitted with a permanent rumen fistula were used. These wethers were held in individual pens at the Waite Institute animal house and fed at a level slightly above maintenance using oaten chaff and commercial pellets (SCA 1990).

Experiment 1 Dry matter disappearance of ground whole pods, seeds and hulls of two lines of Paraggio medic during three incubation periods

A factorial design was used for this experiment with the following factors and replications. Lines of pod (G-Paraggio and P-Paraggio) x Incubation times (4) x Replications (4) = 32. This procedure was undertaken independently for whole pods, seeds and hulls. Six bags (three of each line) were placed in the rumen at the same time before morning feeding. The bag of each line was removed after 24, 48 and 72 h incubation.

Experiment 2 Dry matter disappearance of ground and unground whole pods, seeds and hulls of the two lines of Paraggio medic pods during 48 h of incubation

The design of this experiment also was factorial with the following factors. Lines of pod (G-Paraggio and P-Paraggio) x Physical forms (Ground and Unground) x Incubation times (0 and 48 h) x Replications (4) = 32.

Separate *in sacco* digestion measurements were made for whole pods, seeds and hulls to avoid any possibility of interaction occurring if whole pods and their components were suspended at the same time in the rumen. In order to test this hypothesis, in the other *in sacco* study of this series, the disappearance of whole pods and their constituents was determined after incubation in the rumen together at the same time. As previously mentioned a maximum of six nylon bags were incubated at the same time in the rumen. Because of this limitation the dry matter disappearance determinations were made separately for ground and unground samples.

5.2.2 Results

In vivo study

Chemical composition: The chemical composition of the two lines of Paraggio pods and their constituents is shown in Table 5.2.

Table 5.2 Chemical composition of the two lines of Paraggio whole pods and their constituents (Moisture-free basis)

Type of pod	Component	Nutrient (%)				
		Ash	CP	CF	EE	NFE
G-Paraggio	W	5.79	17.93	31.87	5.03	39.37
	S	3.27	41.50	6.35	15.90	32.98
	H	4.73	7.51	42.82	0.75	44.20
P-Paraggio	W	5.93	18.87	33.68	4.96	36.56
	S	3.50	41.02	7.94	15.30	32.24
	H	4.42	8.13	44.10	1.05	42.30

W = Whole pods; S = Seed; H = Hull; CF = Crude fibre; CP = Crude protein; EE = Ether extract; NFE = Nitrogen-free extract

The results are similar to the data reported previously in Chapter 4 in this thesis. There were no marked differences in chemical composition between the two lines of pods.

Voluntary intake: Voluntary intake data is summarised in Table 5.3. The daily intake of G-Paraggio was about 5.4 times more than the intake of P-Paraggio (1837 v 343 g dry matter/sheep/day and 1743 v 323 g organic matter/sheep/day). The differences are highly significant ($P<0.001$), for both dry matter (DM) and organic matter (OM) intakes. The dry matter intake of G-Paraggio pods also was 2.4 and 2.7 times more than the dry matter intake of Parabinga and Sava mature pods previously reported in this thesis (Chapter 4).

When the daily intake figures were expressed on the basis of metabolic weight the voluntary intake of G-Paraggio pods still was 5.0 times more than that for P-Paraggio pods. In other words this difference was still highly significant.

During this experiment those sheep fed P-Paraggio pods lost more than 400 g body weight per head per day while sheep fed G-Paraggio almost maintained body weight.

Table 5.3 Voluntary dry matter and organic matter intake of mature Paraggio barrel medic pods (Data show means ± SE)

Type of pods	Dry Matter Intake		Organic Matter Intake	
	(g/sheep/d)	(g/kg $W^{0.75}$/d)	(g/sheep/d)	(g/kg $W^{0.75}$/d)
G-Paraggio	1837± 39	83.9 ± 1.8	1734 ± 36	79.2 ± 1.6
P-Paraggio	343 ± 56	16.9 ± 2.8	323 ± 53	15.9 ± 2.6
Significance of difference	***	***	***	***

*** = $P<0.001$

In sacco studies

Dry matter disappearance of all samples including whole pods, seeds and hulls increased sharply from 0 h, to 24 h rumen incubation (Figure 5.1). The disappearance of dry matter also increased gradually from 24 h to 48 h in the rumen but the rates of disappearance were much lower. In this experiment most digestion occurred during the period of 48 h for whole pods, seeds and hulls. However, in spite of the large differences in voluntary intake, rumen dry matter disappearance did not differ significantly between the two lots of ground whole Paraggio pods or for any of the constituents (Table 5.4).

Mean data for dry matter disappearance of different physical forms of the two lines of Paraggio mature pods and their constituents suspended in the rumen are given in Figure 5.2. Dry matter disappearance of ground and unground whole pods, seeds and hulls of the two lines followed a similar pattern and were high for all the ground samples.

The grinding treatment was more effective for whole pods and hulls than for seeds (Figure 5.2). For example, while the differences between dry matter disappearance of ground and unground whole pods and hulls of G-Paraggio were 21 and 8 percentage units, this value for the seeds was less than 4 percentage units. It shows that not only was the ground form of Paraggio seeds highly digestible but also that the intact seeds of this cultivar can be degraded in the rumen to a large extent. However, the dry matter disappearance from the nylon bags obtained for different physical forms of pods and their constituents had a similar pattern for the two lines (Figures 5.3 and 5.4).

Table 5.4 Summary of analyses of variance of dry matter disappearance of ground whole pods, seeds and hulls of the two lines of Paraggio barrel medic

Source of variation	Total Whole pod	Total Seed	Total Hull	Actual Whole pod	Actual Seed	Actual Hull
			Significance level			
Line of pod	NS	NS	NS	NS	NS	NS
Incubation time	**	**	**	**	**	**
Line of pod x Incubation time	NS	NS	NS	NS	NS	NS

Total = Solubility + disappearance; Actual = Disappearance; NS = Not significant; ** = P<0.01

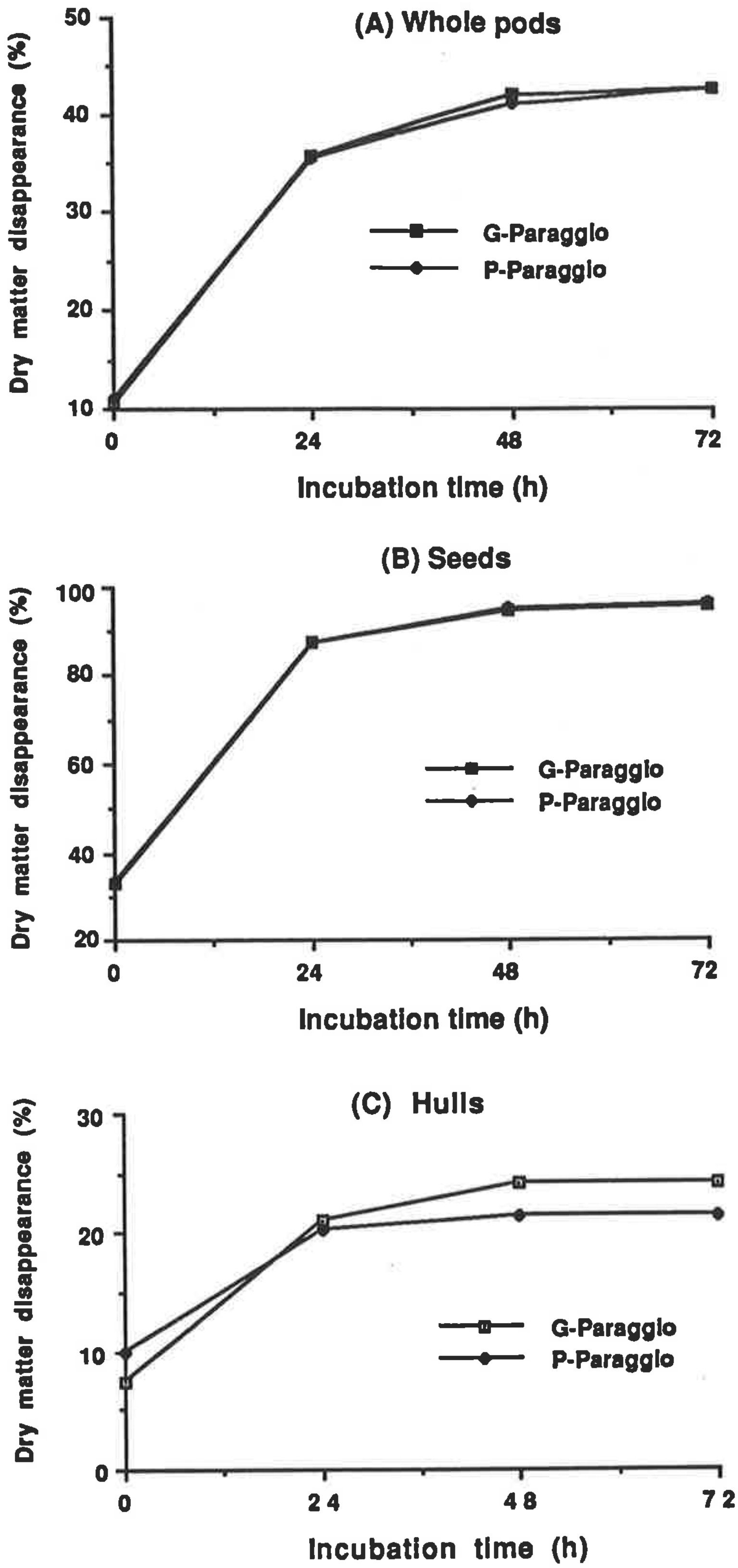


Figure 5.1 Dry matter disappearance of the two lines of Paraggio medic pods and their components during three incubation times

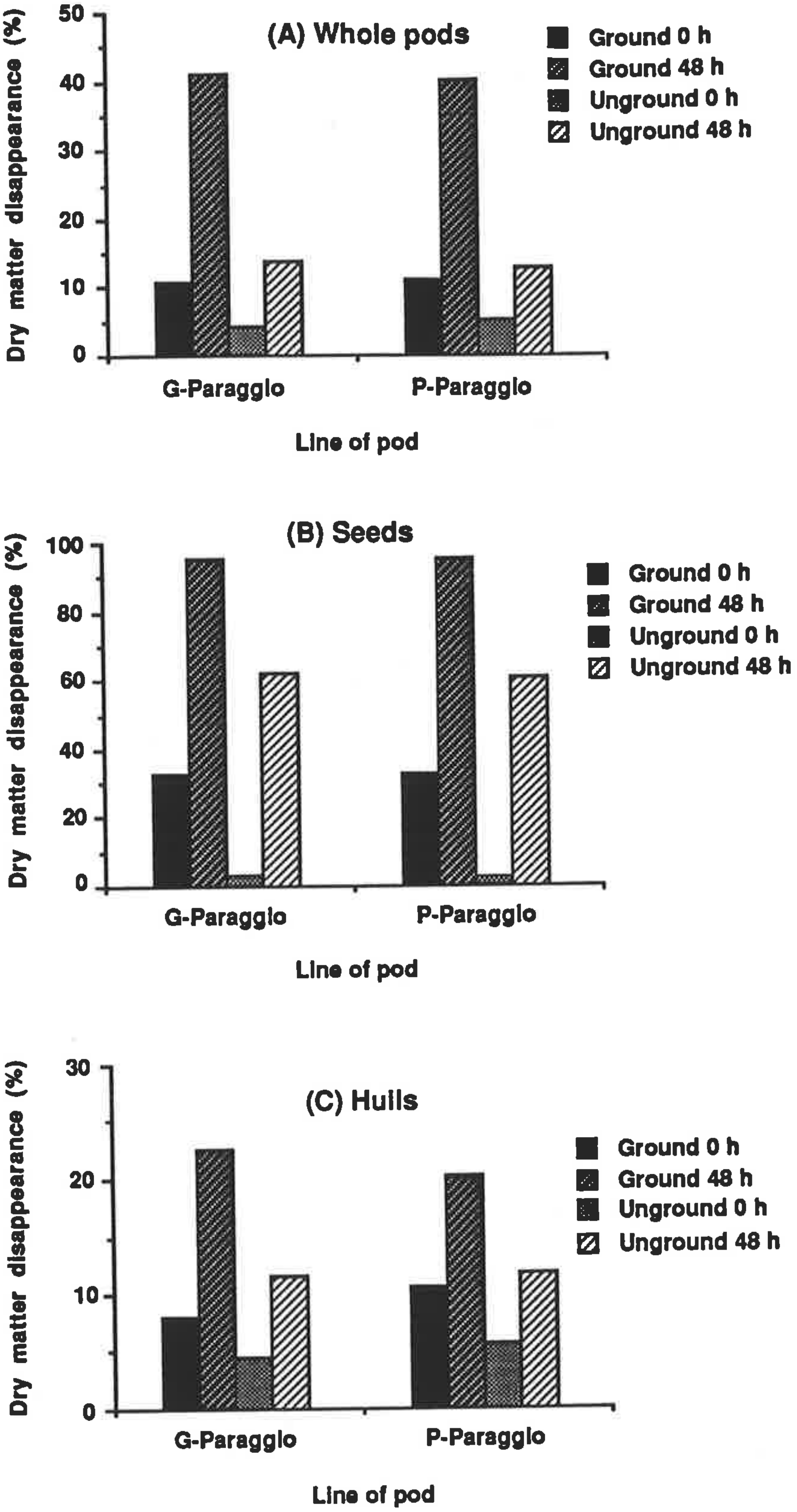


Figure 5.2 Dry matter disappearance of ground and unground mature whole pods, seeds and hulls of the two lines of Paragglo

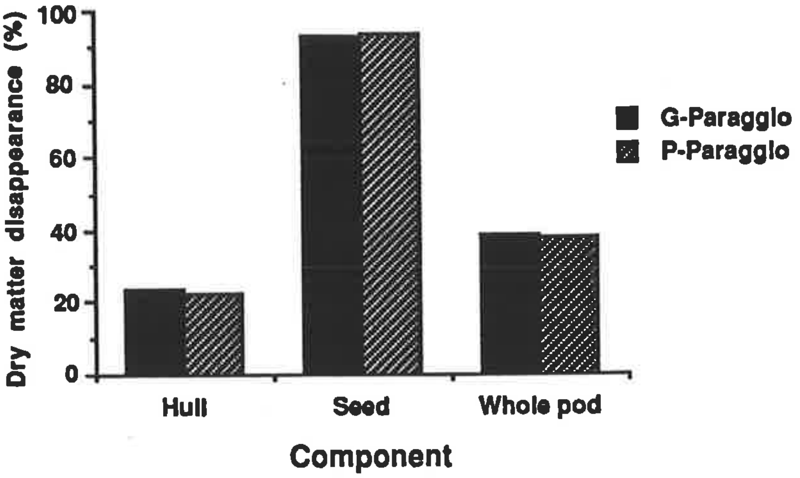


Figure 5.3 Total dry matter disappearance of ground whole pods, seeds and hulls of two lines of Paraggio incubated together for 48 h at the same time and in the same rumen

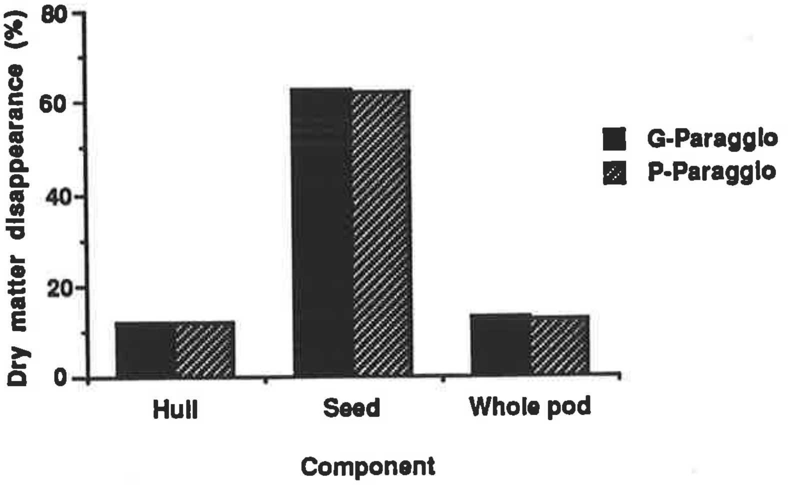


Figure 5.4 Total dry matter disappearance of unground whole pods, seeds and hulls of two lines of Paraggio incubated together for 48 h at the same time and in the same rumen

Table 5.5 **Summary of analyses of variance of dry matter disappearance of ground and unground whole pods, seeds and hulls of the two lines of Paraggio barrel medic**

Source of variation		Total			Actual	
	Whole pod	Seed	Hull	Whole pod	Seed	Hull
			Significance level			
Line of pod	NS	NS	NS	NS	NS	NS
Physical form†	**	**	**	**	**	**
Incubation time	**	**	**	**	**	**
Line of pod x Physical form	NS	NS	NS	NS	NS	NS
Line of pod x Incubation time	NS	NS	*	**	NS	**
Physical form x Incubation time	**	**	**	**	**	NS
Line of pod x Physical form x. Incubation time	NS	NS	*	NS	NS	*

Total = Solubility + disappearance ; Actual = Disappearance; †Ground and unground
NS = Not significant; * = $P<0.05$; ** = $P<0.01$

Total dry matter disappearance of ground whole pods, seeds and hulls from the nylon bags suspended together at the same time in the same rumen for 48 h were 38.8, 92.6 and 23.3 percent for samples of G-Paraggio and 37.9, 93.3 and 22.2 for samples of P-Paraggio. Total dry matter disappearance figures for unground samples were 13.3, 62.5 and 12.0 percent for whole pods, seeds and hulls of G-Paraggio and 12.6, 62.3 and 12.2 percent for P-Paraggio respectively. The differences between these measurements were not significant , but they were highly correlated (r = 0.99**) to the values obtained in the *in sacco* (1) experiment reported in this Chapter. Apparently the potential disappearance of the samples was not affected by the associative effects. In this context quite similar results were found between the two lines of Paraggio barrel medic.

5.2.3 Discussion

In vivo study

The chemical compositions of the two lines of Paraggio barrel medic pods were very similar, which was probably a reflection of cultivar traits. On the other hand, most of the physical characteristics of the two lines differed significantly. For example, the mean pod weight of G-Paraggio was 1.3 times more than that for P-Paraggio. In spite of the significant differences between mean seeds per pod and seed weight, the proportion of seed to hull did not differ significantly between the G-Paraggio and P-Paraggio. Although both seed number and seed weight of G-Paraggio were higher than for P-Paraggio, the higher pod weight of G-Paraggio was not solely because of the seed component. The hull component of G-Paraggio also was higher than P-Paraggio. For instance, the seed weight ratio of G-Paraggio to P-Paraggio was 1.22 but this ratio for the hulls was 1.33. It is most likely, therefore, that the higher hull ratio has covered the influence of higher seed weight and seed number of G-Paraggio in comparison with P-Paraggio in determination of seed/hull ratio.

The most important result of this experiment was the highly significant difference between the intakes of the two lines of medic pods. Whereas the voluntary dry matter intake for P-Paraggio was 17 g/kg$W^{0.75}$/d the corresponding intake of G-Paraggio was 84 g/kg$W^{0.75}$/d. The intake of G-Paraggio pods also was higher than the intake of other annual medic pods that have been reported by other workers (Vercoe and Pearce 1960; Carter 1980). No data were found in the literature showing such a big difference in voluntary intake between two lines of a cultivar and no data were found showing such a high intake of medic pods as that recorded here for G-Paraggio. However, since intake in ruminants is influenced by so many factors (Weston 1982, 1984; Mertens 1987), conditions in the present experiment may have been more favourable than in previous work for achieving a high intake.

Differences in voluntary intake of the two lines must be related to differences in their characteristics, since all animals were under the same environment and feeding management. Since the proximate chemical analyses of the two lines were very similar (Table 5.2), differences in intake were probably not related to these nutrients. However, experience has shown that feed intake and efficiency can be limited by the presence of substances such as antinutritional factors (Howarth 1988; Liener 1990). Studies of these substances which are found in different parts of the plants in small amounts, have received considerable attention, mainly in legumes (Howarth 1988; Li *et al.* 1992). The presence and identification of undesirable substances requires specific methods, facilities and chemicals which were not available in this study. However, a possible cause of the extremely low intake of P-Paraggio was content of some kind of anti-nutritional substance(s). The acceptability of animal feedstuffs is sometimes associated with the presence of antinutrional factors (Marten 1985). Nevertheless, palatability of such feeds can be improved by taste-modifiers such as molasses (McSweeney and Wesley-Smith 1986).

The other reason for the low intake of P-Paraggio mature pods could be due to contamination by fungal residues. Although laboratory examination (which will be reported later in this Chapter) showed there was no difference between the two sources of Paraggio pods, in terms of type of fungi present, the absence of undesirable viable fungi does not imply the absence of their metabolites (mycotoxins). Some plants may be contaminated with mycotoxins of fungi in the field. The active fungi in the field normally die out after harvesting and can be replaced by other types of fungi when the harvested materials are stored. Several hundred mycotoxins have been reported, mainly in laboratory cultures. No further attempt, except the identification of some common types of fungi, has been made in this study. However, it can be assumed that P-Paraggio pods were contaminated by fungi and their metabolites in the field or during storage (Buckle and Scudamore 1990). Both lines of medic pods had been stored in the field: the P-Paraggio may well have had greater fungal contamination following rain at some stage during storage. Such contamination probably affected palatability and led to lower intake of the P-Paraggio pods.

The environmental factors that vary from year to year and season to season can cause unexplained and expected differences in feed quality (Meyer and Jones1962; Marten *et al.* 1988). The P-Paraggio pods were harvested following a poor growing season. Therefore, it is probable that some part of the lower intake of these pods can be attributed to the adverse effects of the poor season. Finally, the possibility of the involvement of other factors such as poisonous chemicals introduced by man (pesticides and herbicides) (Reid 1973) reducing forage or fodder intake cannot be entirely eliminated.

In sacco

There is very little information on the microbial degradation and consequent disappearance of annual medic pods and their constituents. While there were large disappearances in the dry matter disappearance of whole pods, seeds and hulls the differences between the two lines of medic were not significant.

The greatest source of variation in dry matter disappearance from the nylon bags was that between the different incubation times. The dry matter disappearance values at 48 h were the most important coefficients because they were very close to the *in vivo* and *in vitro* digestibilities previously determined (Chapter 4). Similar results for low quality roughages have been reported elsewhere (Tuah *et al.* 1986).

Grinding treatment increased dry matter disappearance, but no significant differences were found between the two lines of Paraggio medic. Therefore, the large differences in voluntary intake of the two lines of Paraggio pods could not be explained from the *in sacco* data.

The *in sacco* results show that the real reasons for differences in voluntary intake of the two lines might not be so important for rumen microorganisms, because the dry matter disappearance of whole pods and their constituents did not differ significantly between the two lines. If this hypothesis be accepted, it might be concluded that the presumable antiquality factor (s) in P-Paraggio has influenced the nervous system of the experimental sheep rather than depressing the rumen fermentation. Thus, in spite of the fact that experimental sheep were hungry, they did not consume a reasonable amount of P-Paraggio pods.

In conclusion, the reasons for low intake of P-Paraggio pods remain unclear and need further study.

5.3 The nutritive value of medic pods following treatment with sodium hydroxide or supplementation with molasses

5.3.1 Introduction

In southern Australian farming systems, the mature pods of annual medic (*Medicago* spp). are often present in large quantities over the summer-autumn period and constitute a valuable source of nutrients at a time when dry pasture residues are declining in quantity and quality. In the previous *in vivo, in vitro* and *in sacco* experiments different nutritional aspects of two populations of these pods were studied. The voluntary intake of Paraggio barrel medic pods referred to as P-Paraggio was significantly lower than for Parabinga and Sava. In the *in vivo* experiment reported in this chapter voluntary intake of P-Paraggio was also much lower than for another line of Paraggio referred to as G-Paraggio, despite a similarity in chemical composition and rumen disappearance characteristics.

Although it was impossible to conclude why the voluntary intake of P-Paraggio pods was very low, it was suggested from observation that one possibility could be that the pods were contaminated by some kind of surface fungal residues. The presence of unpalatable factors in the chemical composition of pods was another possibility. Further work with these pods (P-Paraggio) was warranted to try to determine the reasons for their very low intake and to see if various treatments could overcome the problem of low intake.

Medic pods are rich in protein but poor in digestible energy because of a high indigestible fibre content. The digestibility and voluntary intake of various high-fibre feeds have been improved by physical, chemical and supplementation methods (Ibrahim 1983; Doyle *et al.* 1986). However, there is no information about the application of these methods for improving the nutritive value of mature annual medic pods. Most high-fibre feeds are deficient in nitrogen, but its concentration in medic pods exceeds that necessary for maintenance and even production requirements of sheep (Dunlop and McDonald 1986). Therefore, chemical treatment or supplementation of medic pods with energy sources should give better results than for other fibrous feeds such as cereal straws.

The reasons for undertaking this experiment were: (1) to test suggestions from the previous experiment reported in this thesis that low intake of P-Paraggio pods may be attributed to surface contamination by fungi or mycotoxins or the presence of some anti-nutritional substances and (2) to examine the effects of supplementation and other treatments on the nutritive value of pods and the possibility of overcoming the low intake problem.

5.3.2 Materials and methods

Animals: A flock of 20 adult Merino wethers (plus two spares) averaging 61 ± 3 kg body weight and over two years old were kept in individual pens in the Waite Agricultural Research Institute animal house. The sheep were dewormed prior to the experiment. The sheep were allocated to experimental treatments by stratified randomisation based on body weight.

Statistical design: A completely randomised design (CRD), consisting of five treatments and four replications was used.

Treatments: The five experimental treatments using pure-pod rations were as follows:

(a) Untreated. P-Paraggio barrel medic pods harvested following a poor growing season

(b) Washed. P-Paraggio pods were soaked in tap water for 30 minutes (ratio of water: pods was 8:1), washed under running water for five minutes then immediately transferred to a basket and the free liquid allowed to drain for two hours. This treatment was selected in order to remove surface contamination by fungal residues or mineral matter.

(c) Water sprayed. P-Paraggio pods were sprayed with tap water at the level of 400 g per kg pods while mixing. This treatment was selected as a control for treatments (d) and (e).

(d) Molasses-treated. P-Paraggio pods were sprayed with a cane molasses/water mixture (1:2.5) at the rate of 15% (W/W). Molasses was added in order to improve palatability.

(e) NaOH-treated. P-Paraggio pods were sprayed with a 10% solution of sodium hydroxide (This concentration of NaOH was selected after treating the pods with different levels of NaOH which will be reported in next chapter). Treatment (e) was chosen to verify that treating the P-Paraggio pods with sodium hydroxide can improve their acceptability by hydrolysing the fibrous hull and the possible anti-nutritional residues or removing possible pollutant materials from the pods.

Pods were prepared daily on the afternoon of the day before feeding and given as a sole ration at 0900 hours. At the time of offering the pods to sheep the dry matter contents of the treated pods were approximately the same, and generally not less than 50%.

The experiment consisted of two periods:

(1) Preliminary period: in this period of 10 days, the sheep adjusted to the diets, pens and indoor conditions.

(2) Main period: the voluntary intake of untreated and treated pods was measured daily in this feeding period of 10 days. Feed residues were collected daily, weighed and sampled for each sheep separately. Feed refusals were never refed.

A mineral blend salt block containing sodium chloride (NaCl), molasses and major and trace elements (Olsson Industries Pty. Ltd.) was provided in each pen. The chemical composition of the blocks is given in Appendix 5.1. Clean water was available at all times.

Feeds were sampled daily and the samples dried at 60°C to constant weight. Dry samples were bulked for chemical analyses. The chemical components were: organic matter calculated after ignition at 600°C for at least two hours; crude protein determined by the Kjeldahl method of Kjeltec Auto System (Tecator Analytical Instrument, Sweden); ether extract, measured by Soxhlet extraction (Faichney and White 1983) and crude fibre by the method of AOAC (1984).

All sheep were bled from the jugular vein at the beginning and the end of the main feeding period. Blood samples were taken daily three hours after the morning feeding After centrifuging, the plasma was frozen and later analysed for urea-N (Trace Scientific Pty. Ltd. Aust.).

Rumen fluid samples were collected concurrently with blood samples via a stomach tube. Rumen fluid pH was determined at the time of sampling. For determination of volatile fatty acids (VFA), rumen fluid was treated with a protein precipitant (at the rate of 5 to 1) and centrifuged. The super-natant liquid was decanted, and frozen until analysed. The concentration of volatile fatty acids was determined by gas chromatography (GC-14A, Shimadzu, Corp. Kyoto, Japan). Before analysis, the frozen samples were thawed, shaken and allowed to stand for about one hour for solids to settle.

Samples were injected into the column of 25x0.53 mm ID with the phase of BP 21, 0.5 μm film, initial temperature of 85°C and sensivity of 64×10^{-12} AFS. The VFA data were analysed by Delta Data Systems (Digital Solutions Pty. Ltd.).

Sheep were weighed after an overnight fast at the commencement of the experiment and every 10 days thereafter.

In the previous experiments it was shown that *in sacco* dry matter degradabilities were highly correlated to the *in vivo* dry matter digestibility coefficients. In this experiment dry matter digestibilities of the experimental diets were measured using the *in sacco* procedure.

As in the case of *in sacco* studies previously reported in this thesis, four Merino wethers each fitted with a permanent rumen cannula, were used to determine *in sacco* digestibility of ground treated and untreated pods. These sheep were fed with the normal shed ration (pellets and chaffed oaten hay) at around maintenance level. The nylon bags and incubation procedure were the same as used in the previous *in sacco* experiments (Chapter 4).

5.3.3 Results

The chemical composition of the P-Paraggio pods treated in different ways are given in table 5.6. No consistent differences in chemical composition occurred between treated and untreated pods. Sodium hydroxide treatment resulted in a lower content of crude fibre and higher ash concentration, because of the high amount of sodium. This is in agreement with the report by Felix *et al.* (1990) who observed that soya-bean straw treated with NaOH and $Ca(OH)_2$ had higher ash concentrations than control and NH_4OH-treated soya-bean straw.

Table 5.6 Chemical composition of treated and untreated whole, mature Paraggio barrel medic pods (Moisture-free basis)

Treatment	Chemical composition (%) Ash	CF	CP	EE	NFE
Untreated	6.2	33.5	20.2	4.9	35.2
Washed	5.6	35.0	19.4	3.6	36.4
Water-sprayed	6.4	30.0	20.5	4.3	38.8
Molasses-treated	7.0	29.7	18.8	3.4	41.1
NaOH-treated	10.2	28.0	18.4	4.0	39.4

CF= Crude fibre; CP= Crude protein; EE= Ether extract; NFE= Nitrogen-free extract

Voluntary intake: Voluntary dry matter intake ranged from 3 to 31 g per kg $w^{0.75}$ per day. There was a highly significant difference ($P<0.01$) between the voluntary dry matter and organic matter intakes of treated and untreated Paraggio pods (Table 5.7). While the average voluntary intake of untreated pods was similar to the intake of P-Paraggio previously discussed in this chapter (327 v 343 g/sheep/d), the intake of washed, NaOH-treated and water-sprayed pods was 5.0, 4.2 and 1.9 times lower than the intake of untreated pods. Thus, not only was there no improvement following treatment with NaOH and washing but their acceptability was, in fact, reduced severely (Table 5.7). In contrast to these very low intakes, the voluntary intake of molasses-treated pods was 2.1 times higher than that for untreated pods ($P<0.01$).

Table 5.7 Average voluntary intake of treated and untreated whole mature Paraggio barrel medic pods

Treatment	g/sheep/d		$g/kgW^{0.75}/d$	
	DM	OM	DM	OM
Untreated	327	307	15	14
Washed	66	62	3	3
Water-spayed	173	162	8	7
Molasses-treated	694	645	31	29
NaOH-treated	77	69	4	3
LSD (5%)	138	128	6	6

g/sheep/d = Grams per sheep per day; $g/kgW^{0.75}/d$ = Grams per kg metabolic weight;
DM= Dry matter; OM = Organic matter

Body weight: The sheep body weight changes during the experimental periods are shown in Figure 5.5. The relatively low intake of both the treated and untreated Paraggio pods led to significant body weight losses in all treatments as follows: 8.3, 10.0, 9.5, 3.6 and 11.0 kg for untreated, washed, water-sprayed, Molasses-treated and NaOH-treated respectively over a period of 10 days.

Rumen pH: Rumen pH values for all treatments (Figure 5.6) were similar three hours after feeding on both Day 1 and Day 10 indicating that ruminal pH was not significantly affected by any of the experimental treatments. In other words presumably the fermentation patterns were similar for all treatments and not likely to be responsible for differences in voluntary intake.

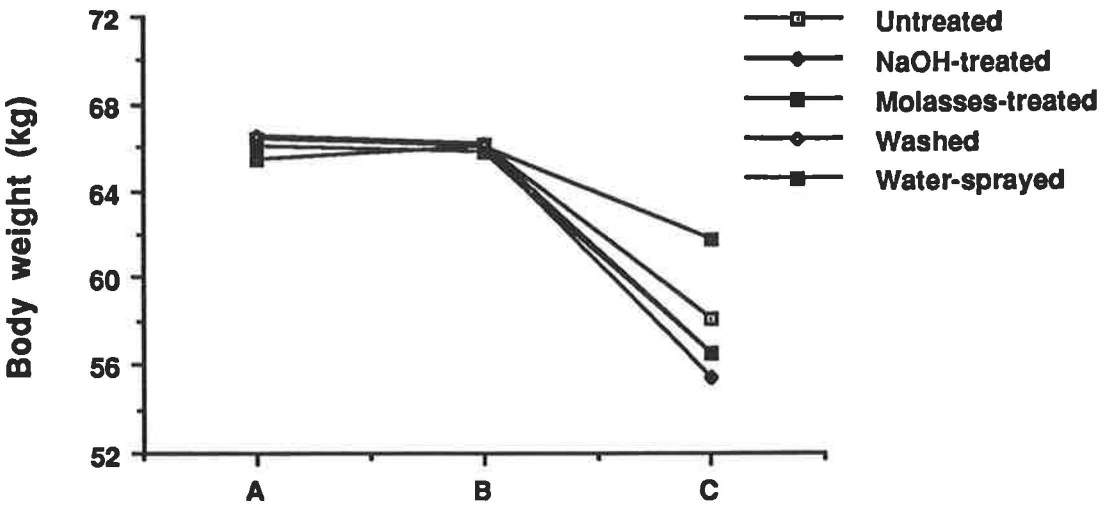
Plasma urea-N: On both sampling occasions there was a tendency for plasma urea-N values from sheep given molasses-treated pods to be higher than those for the other treatments (Table 5.8). In contrast, the plasma urea-N concentrations of NaOH-treated pods (on both occasions) and of washed and water-sprayed pods on Day 10 were lower than for the untreated pods. The plasma urea-N values on Day 10 indicated that those treatments which depressed voluntary intake also resulted in lower plasma urea-N levels.

Volatile fatty acids (VFA): The mean concentrations of rumen volatile fatty acids are presented in Table 5.9. In general, total concentrations of VFA were higher at the end of the main period (Day 10) with some fluctuation in the molar proportions of individual fatty acids.

The differences between concentrations of VFA on Day 1 were significant, whereas no significant differences were found between VFA concentrations on Day 10. Generally, the molar proportions (%) of acetic acid on Day 1 were higher than Day 10 and the reverse was found for propionic acid.

Table 5.8 Plasma urea-N concentration (mg/l) in Merino wethers fed treated and untreated whole Paraggio barrel medic pods
(Data show means ± SE)

Treatment	Day 1	Day 10
Untreated	84±4	99±3
Washed	103±9	71±10
Water-sprayed	108±14	69±15
Molasses-treated	116±17	107±24
NaOH-treated	81±12	46±12



Experimental period

A = Beginning of preliminary feeding period;

B = Beginning of the main feeding period;

C = The end of main feeding period

Figure 5.5 Sheep body weight changes in response to feeding treated and untreated medic pods

Table 5.9 Ruminal volatile fatty acids (VFA) of sheep fed treated or untreated Paraggio pods

Component			Treatment			Signif. level
	Untreated	Washed	Water-sprayed	Molasses-treated	NaOH-treated	
Day 1:						
Total VFA (mmol/l)	48.8	42.8	42.5	56.5	46.9	**
Molar prop. (%)						
Acetic	67.8	77.6	73.4	71.2	81.0	**
Propionic	24.2	14.3	19.8	24.1	13.4	**
Butyric	0.6	0.2	0.2	1.1	0.4	**
Valeric	1.4	0.0	0.7	0.9	0.0	**
Day 10:						
Total VFA (mmol/l)	61.0	64.3	64.6	57.8	57.2	NS
Molar prop. (%)						
Acetic	58.5	56.9	60.1	59.5	62.6	NS
Propionic	37.0	39.3	36.4	36.7	27.4	NS
Butyric	1.1	1.1	0.9	1.0	1.4	NS
Valeric	2.5	1.9	1.7	2.2	2.1	NS

***In sacco*:** Means of total dry matter disappearance of ground pods are shown in Figure 5.7. Dry matter disappearance of all samples increased up to 48 h, but most samples about 70% of the 48 h loss occurred during the first 24 h of incubation.

Total dry matter disappearance of the treated and untreated pods after both 24 and 48 hours differed significantly (Figure 5.7). The actual dry matter disappearance (total-solubility) of the dietary treatments incubated for 24 hours were 36.0, 25.8, 25.7, 24.2 and 28.1 percent for untreated, washed, water-sprayed, molasses-treated and NaOH-treated respectively. It is apparent from these coefficients that the differences between them were much lower than the differences between the total disappearances. Although the differences between the actual disappearance of treated and untreated pods were significant ($P<0.01$), the treatment mean square for this comparison was 8.2 whereas it was 63.9 for the corresponding total dry matter disappearance incubated for 24 h. The same results were obtained after 48 h incubation time. It was apparent from these data and water solubility of treated and untreated pods that treating with NaOH and molasses increased the simple solubility of the pods.

The critical difference (LSD) between the means of total and actual dry matter disappearances determined after 24 h incubation in the rumen was 1.67 percent. In general, the differences between the mean of NaOH-treated pods and other treatments were higher than this value. It indicated that pod treatment with NaOH increased the solubility and disappearance of pods.

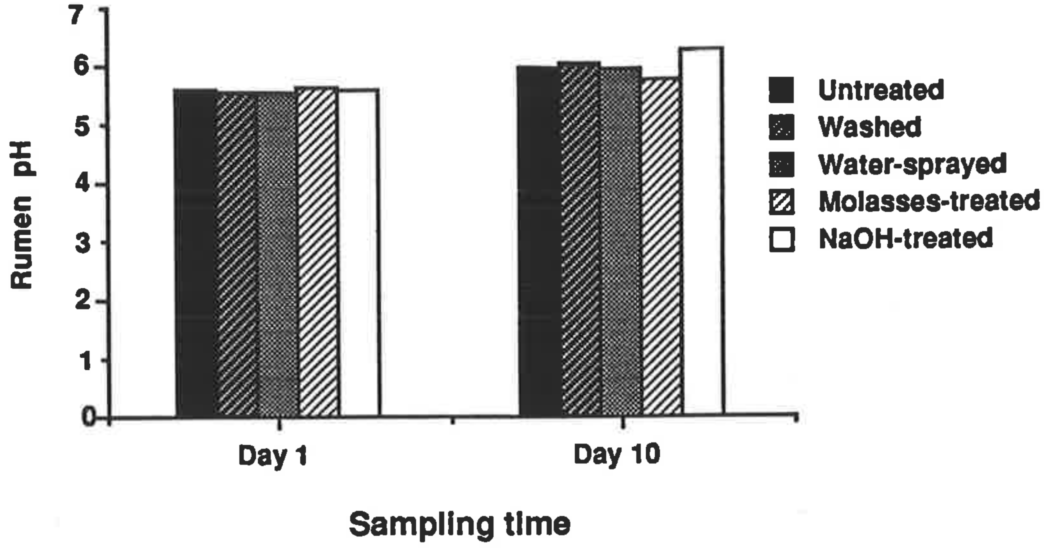


Figure 5.6 Rumen pH in wethers fed treated and untreated whole Paragglo pods

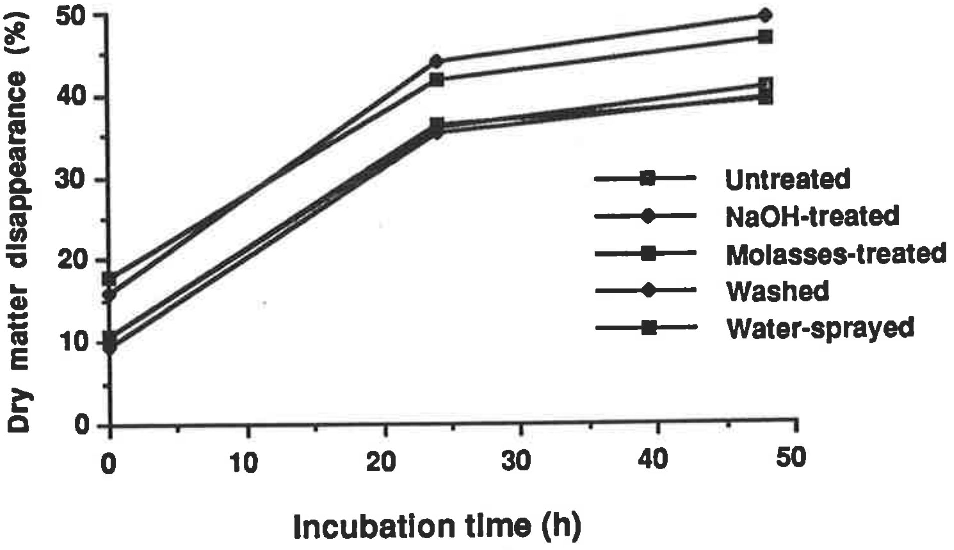


Figure 5.7 Total dry matter disappearance of treated and untreated Paragglo pods

5.3.4 Discussion

To maintain body weight, adult sheep need to consume about 900 g DM/d of a feed with the digestibility coefficient of 55-60% (Warren *et al.* 1990). This level of intake was not achieved in this study: also, as will be reported later, the digestibility coefficients were much lower than the required coefficients.

Voluntary intake of the washed, water-sprayed and NaOH-treated Paraggio pods was considerably reduced in comparison with untreated pods, although the voluntary intake of untreated Paraggio pods itself was much lower than the other sources of medic pods (see Chapter 4 and the first experiment in this chapter). It has been reported that the voluntary intake of roughages such as wheat straw and cotton by-products was reduced with NaOH treatment (Singh and Jackson 1971; Levy *et al.* 1977). It was concluded that the reduced intake was related directly to the amount of NaOH used and could be related to a reduced acceptability. However, the extremely low intake on NaOH-treated pods in this experiment cannot be solely related to this effect. An intake of 77 g/sheep/d or only 4g/kgw$^{0.75}$/d is quite abnormal. Therefore, not only did the NaOH-treament not remove the substantial anti-quality factor of Paraggio pods but also it apparently had a synergistic effect in combination with any anti-quality factors.

It has been pointed out that voluntary intake of fibrous feeds can be increased by soaking (Castillo *et al.* 1982). In a feeding experiment with growing Philippine Carabao heifers carried out by Roxas *et al.* (1987) voluntary intake and daily gain of the animals fed soaked rice straw were significantly higher than of unsoaked straw. However, soaking and washing the pods in this experiment dramatically reduced the level of voluntary intake.

Although soaking and washing the pods could remove some types of soluble materials and result in dry matter losses, the abnormal voluntary intake of the washed pods in this experiment cannot be entirely related to these disadvantages. It seems that the adverse effects of the possible anti-quality factors in Paraggio pods has significantly increased in the presence of water. For example, the voluntary intake of water-sprayed Paraggio pods was significantly reduced but their intake was still 2.6 times higher than that for washed pods, while the amount of water applied to the washed pods was much higher than in the water-sprayed method.

Voluntary intake of the molasses-treated pods was about two and four times higher than that for untreated and water-sprayed pods respectively. It has been known for a long time that molasses is a palatable feed (Morrison 1957; McDonald *et al.* 1988) and inclusion of molasses into animal diets based on low-quality feeds increases voluntary intake (Ernst *et al.* 1975; Schiere *et al.* 1988).

The stimulating role of molasses on voluntary intake was quite clear in this experiment. The lower body weight losses of sheep fed Paraggio pod-molasses mixture indicates that rumen fermentation in this treatment was probably more efficient than for the other treatments, because both essential nutrients, nitrogen (from the pods) and energy (from the molasses) were provided. However, even adding considerable amounts of molasses did not result in intakes comparable with those for good Paraggio pods (harvested following a good growing season) (see Table 5.3).

The crude fibre content of the NaOH-treated pods was considerably lower than that of untreated pods. It has been frequently reported that the main effect of treating low-quality roughages with alkalis is delignification (Jackson 1977; Han 1978). Although in this study, using the spray method for NaOH treatment, the different constituents of the crude fibre fraction were not measured it seems that the decreased concentration of crude fibre following NaOH treatment could be due to an alteration of hemicellulose that renders it much more soluble in water (Gailared 1962).

The crude fibre concentration of molasses-treated pods also has been decreased about four percentage units, but presumably it was because of the presence of molasses, not as a result of the delignification process.

The ash content of the NaOH-treated pods was higher because of the high concentration of sodium. The high ash content in NaOH-treated, low-quality roughages may influence the dry matter disappearance (Wanapat *et al.* 1986) and organic matter digestibility. For example, Greenhalgh (1980) concluded that if the ash content of straw was doubled because of alkali treatment from 7% to 14% an improvement in organic matter digestibility (OMD) from 45 to 65% (+44%) will improve digestible organic matter in dry matter from 42 to 56 (+33%).

On Day 1 the total VFA and proportion of individual fatty acids differed significantly between the treatments. However, the differences between treatments on Day 10 were not significant. During the preliminary feeding period, sheep were changed over from a standard sheep ration to either untreated or treated Paraggio pods and differences between treatments could reflect differences between the feeds during this period. In the main feeding period when sheep were fed solely with the pods, similar concentrations of fatty acids were recorded. However, proportions of propionic acid on Day 10 were higher than on Day 1. The Day 10 fermentation pattern was similar to that generally observed in ruminants fed energy-rich diets such as cereal grain. At the time rumen fluid was collected (three hours after feeding) it was mainly the seed component of the pods which had been fermented and this would result in higher propionic acid levels. Nevertheless, no explanation can be offered from the VFA results for the differences in levels of intake between treatments.

Probably because of a better physiological status, sheep fed molasses-treated pods had higher plasma urea-N concentrations. On the contrary, the plasma urea-N values on Day 10 indicated that those treatments which depressed voluntary intake also resulted in lower plasma urea-N levels.

In sacco data indicated that treatment of Paraggio pods with NaOH and molasses resulted in higher solubilisation of pods in water. It has been suggested that solubilisation of low-quality roughages is the primary step in improving their digestibility and nutritive value to ruminants (Ololade *et al.* 1970; McManus and Choung 1976). These results are in agreement with the finding of Adebowale and Nakashima (1992) who reported that treatment of cowpea husk, maize stover, orchard grass hay and rice straw with NaOH resulted in extensive solubilisation of all roughages in water. The higher solubilisation in water indicates the samples could probably be solubilised in the rumen and precipitated further down the digestive tract at the higher rates (Wanapat *et al.* 1986).

Treatment of medic pods with NaOH also increased their disappearance in the rumen, contrary to the molasses treatment that had no effect on actual disappearance of the pods in the rumen. It seems, therefore, that the wide range of voluntary intake of untreated and treated Paraggio pods cannot be explained by the data on *in sacco* disappearance.

The very low intake of the poor sample of Paraggio pods (harvested following a poor growing season) is probably not related to any toxic effects of the pods on the animals, but it may be due to factors that influence palatability. This is supported by the intake observed following treatment with molasses.

The undesirable factor in P-Paraggio pods cannot be removed by washing or water spraying the pods. Despite some evidence that spraying low-quality feed with water could increase intake (Leibholz 1981), no improvement in intake of pods was observed in this study.

6.0 ALKALI TREATMENT OF CROP RESIDUES

6.1 Introduction

Crop residues have had an important role in livestock feeding since the early evolution and development of agriculture. Unfavourable weather conditions and lack of appropriate facilities and equipment to conserve forages at reasonable prices increases the importance of crop residues as animal feeds in many areas of the world including Australia. Certainly, good quality hay and silage can be made in southern Australia especially in the more-predictable Mediterranean-type environment but substantial costs are involved in addition to weather risks. Hence, every year considerable amounts of cereal and grain legume straws and dry pasture residues are used during the summer-autumn period for animal feeding in southern Australia. These residues are potentially a great feed resource for ruminants. Feeding these residues provides an important flexibility in the integrated crop-livestock farming system during the dry summer-autumn period.

Damage to the soil (erosion) and newly emerged seedlings can be significantly reduced by feeding the above-mentioned residues (Aitchison 1988).

In intensive cropping sequences farmers have a problem disposing of crop residues in the field after harvesting the grain. Although some farmers burn the residues in the field this depletes soil organic matter and increases air pollution. Leaving the residues on the ground harbours harmful pests like mice (as happened during autumn 1993) red legged earth mite and lucerne flea. If residues are ploughed under it is expensive in terms of energy requirements (Guggolz *et al.* 1971) and may involve the need for increased nitrogen application. Therefore in general, it is desirable that these residues be reduced, fragmented or removed from the field by grazing or other means. However, excessive grazing can damage the soil by treading and cause erosion (Carter *et al.* 1993).

Crop and pasture residues are abundant sources of energy for ruminants (Jung *et al.* 1992). In these types of animal feedstuffs, the cellulose and other structural carbohydrates are associated with lignin and other components that make them less available to the microbial fermentation in the digestive tract (Han 1978). Because of the particular physico-chemical structure of the cell wall component of crop residues, they have not been used to their full potential (Jung 1989).

Because of the adverse effects of lignin in the cell wall, the highly-lignified materials of many straws are of little value as ruminant feedstuffs (Latham 1979). However, it has been understood for the past century that the feeding value of fibrous materials can be upgraded by physical and chemical treatment (Ibrahim 1983). In order to improve the accessibility and digestibility of structural carbohydrate of highly-lignified materials to microbial enzymes in the rumen, chemical treatments have been used. Most attention has been directed to use of alkalis, although a wide range of other chemicals have been tried (Wilkins 1981).

Sodium and calcium hydroxide are the two important alkalis that have been routinely used in experimentation to increase the digestibility of roughages for livestock. Calcium hydroxide is safe and cheaper than sodium hydroxide but its effectiveness is reduced because of low solubility. However, it seems that the method of treating fibrous materials with calcium hydroxide is the key factor in determining its ability to improve the feeding value (Ibrahim 1983).

Although alkali treatment of crop residues has been researched extensively, estimations of the level of alkali and reaction times that result in highest digestibility of different crop residues require ongoing research. There appear to be few reports on the feeding value and alkali treatment of the above-mentioned crop and pasture residues in Australia.

Therefore, the purpose of this series of experiments was to:

(a) Determine the nutritive value of some common crop residues,

(b) Determine the effects of types and levels of alkalis,

(c) Compare some methods of using alkalis, and

(d) Provide useful information for doing cost-effective feedlotting of sheep.

6.2 Nutritive value of cereal straws and grain legume residues

Historically, crop residues, mainly cereal stubbles, have been very important feed sources for sheep during the summer-autumn period and for drought feeding (Ashton and King 1990). In more recent times there has been an increasing availability of grain legume residues due to increased areas of crops such as peas and faba beans. In the present study, a comparison was made of the nutritive value of cereal straws and a range of grain legume residues.

6.2.1 Materials and methods

Samples (10-15 kg) of cereal straws (containing no grain) and grain legume straws (some containing a few seeds) were collected from various districts in South Australia during the 1990-91 summer (Table 6.1). The samples were hammer-milled through a large (25 mm) screen followed by a small (1 mm) screen. Proximate chemical analysis (AOAC 1984) and *in vitro* dry matter digestibility (DMD) and organic matter digestibility (OMD) were determined for all samples as described previously (Chapter 4). The standard samples for *in vitro* digestibility were grain and stubble of Narbonne vetch.

6.2.2 Results

There was considerable variability in chemical composition and digestibility coefficients of the samples within each group and overlap between groups (Tables 6.1 and 6.2). The mean crude protein (CP) content of grain legume residues was higher than that for cereal straws (7.5% vs 3.1%). Both the dry matter digestibility and organic matter digestibility of grain legume residues tended to be higher than those for cereal straws (Table 6.2). Within groups the variability in digestibility was higher with cereal straw ranging from 42% (wheat) to 56% (oats) and grain legume residues ranging from 42% (chick pea) to 60% (lupins) for both dry matter and organic matter. The grain legume residues (containing a few seeds) showed higher values for *in vitro* digestibility.

Chick pea residues stood out as the worst grain legume residue with the lowest crude protein content and digestibility and the highest fibre content.

Table 6.1 **Characteristics and percentage chemical composition of cereal straws and grain legume straws** (moisture-free basis)

Type of sample	Place of collection	Cultivar	Chemical composition					
			DM	Ash	CF	CP	EE	NFE
Cereal straws:								
Barley	Waite Institute	Galleon	94	9.6	35.5	2.6	0.4	51.9
Oats	Waite Institute	Avon	95	7.3	34.4	4.4	2.0	51.9
Triticale	Urrbrae High school	Venus	92	7.3	39.4	3.0	0.1	50.2
Wheat	Waite Institute	Molineux	93	6.6	41.0	2.3	0.1	50.0
Grain legume straws:								
Broad beans	Kapunda	Aquadulce	93	7.4	41.9	6.5	0.7	43.5
Chick peas	Kapunda	Semsen	91	4.5	48.3	3.1	1.0	43.1
Faba beans	Charlick Station	Fiord	88	7.3	34.6	7.8	1.0	49.3
Lentils	North field	ILL 5750	93	5.1	35.1	11.1	0.7	48.0
Lupins‡	Kapunda	Gunguru	89	6.2	35.5	8.8	1.1	48.4
Peas‡	Kapunda	Alma	89	5.3	36.4	9.4	2.2	46.7
Peas	Kingsford	Early Dun	93	5.9	45.1	5.7	1.3	42.0

CF = Crude fibre;..CP = Crude protein; DM = Dry matter; EE = Ether extract; NFE = Nitrogen-free extract; ‡Containing a few seeds

Table 6.2 ***In vitro*** **dry matter and organic matter digestibility of crop residues** (Data show means ± SE on moisture-free basis)

Type of sample	Digestibility (%)	
	Dry matter	Organic matter
Cereal straws:		
Barley	50.8 ± 0.7	51.6 ± 0.9
Oats	56.2 ± 0.2	56.7 ± 0.5
Triticale	46.1 ± 0.4	47.0 ± 0.4
Wheat	41.8 ± 0.5	42.3 ± 0.6
Grain legume straws:		
Broad beans	46.7 ± 0.5	52.1 ± 0.8
Chick peas	42.1 ± 0.4	41.3 ± 0.5
Faba beans	54.7 ± 0.4	54.7 + 0.4
Lentils	45.7 ± 1.1	46.1 ± 1.1
Lupins	60.0 ± 0.5	60.7 ± 0.4
Peas	59.7 ± 0.5	60.3 ± 0.5
Peas (Early Dun)	49.8 ± 0.3	50.9 ± 0.2

6.2.3 Discussion

The higher crude protein content of legume residues is an important advantage of these feedstuffs in comparison with cereal straws. Nitrogen deficiency is a major problem with utilisation of low-quality roughages in ruminant feeding. For example, adult sheep diets should contain about 8% crude protein for maintenance (Dunlop and McDonald 1986) whereas the crude protein content of the cereal straws in this study averaged about 3%. In contrast to cereal straws, the crude protein content of the grain legume residues on average is sufficient regardless of protein/energy ratio that is an important factor in utilisation of feedstuffs by ruminants with appropriate feed efficiency.

Although the feed quality of crop residues varies greatly between species, regions and seasons the values generally obtained here are similar to those which are reported elsewhere (AFIC 1987; Capper 1988). However, in spite of the higher feeding value of many grain legume residues, their use in livestock feeding systems including drought feeding has received little attention.

6.3 Alkali treatment of cereal straws and grain legume straws with calcium hydroxide and sodium hydroxide

In this series of studies the effects of calcium hydroxide and sodium hydroxide were firstly tested and then the appropriate concentrations of alkalis were used in subsequent experiments.

6.3.1 The effects of different levels of calcium hydroxide using the soaking method on disappearance of wheat and lentil straws in the rumen

Calcium hydroxide ($Ca(OH)_2$) is less caustic than sodium hydroxide (NaOH), therefore it may have to be used at higher concentrations than sodium hydroxide to obtain similar results. In comparison with sodium hydroxide fewer experiments have been conducted with calcium hydroxide. Some have indicated that the soaking method is better than the spray method for calcium hydroxide (Djajanegara *et al.* 1985; Doyle *et al.* 1986), whereas for sodium hydroxide the spray method is the one most generally used. Kristensen (1982) expressed the view that more information was required about calcium hydroxide.

Materials and methods

Straws: Wheat (*Triticum aestivum* cv. Molineux) and lentil (*Lens culinaris* cv. ILL 5750) straws were obtained from Waite Agricultural Research Institute and Northfield Research Centre, respectively. The straws were initially hammer-milled through a 25-mm screen.

Experimental design: A completely randomised design (CRD) was used to compare the effects of different levels of calcium hydroxide (Technical grade) on dry matter disappearance of straw. The experimental treatments consisted of untreated straw and straws treated with 0%, 3%, 6%, 9% and 12% calcium hydroxide using the soaking method. Treatments were replicated four times.

Straw treatment procedure: The treated straws were prepared by soaking representative samples for 24 hours in jute bags with a pore size of 2x2 mm in a suspension containing different concentrations of the alkali, in 60 litre buckets. The liquid-to-straw ratio (w/w) was 12:1. The suspensions of calcium hydroxide containing straws were stirred every six hours. At the end of the soaking period the jute bags containing the straws were transferred from buckets to a basket for drainage of free liquid from the straws.

The treated straws were dried in a forced-draught dehydrator at 60°C for 48 h. The treated and dried straws were then ground through a mill fitted with 1 mm mesh sieve. Representative samples were taken for rumen incubation and other measurements.

Four rumen fistulated adult Merino wethers with mean body weight of 41.4 ± 0.3 kg were used for determining *in sacco* digestibilities. The wethers were fed at a maintenance level with a diet based on cereal hay and commercial pellets. Nylon bags with the same dimensions and pore size as described in Chapter 4 were used. Six bags were incubated in each rumen, for 48 hours (It was previously reported in this thesis that dry matter disappearance of low-quality feeds was best correlated to *in vivo* digestibility after incubation in the rumen for 48 hours).

Incubation and related procedures before and after incubation were the same as previously described for *in sacco* studies. A "Zero hour" incubation was undertaken in order to obtain a value for the soluble dry matter contents of the samples.

Samples for dry matter content and for analysis were taken concurrently with the samples for incubation. Dry matter content was measured on two replicates of each treatment by drying in an oven at 100°C for 24 h. Ash content of the samples was determined by heating the samples at 600°C for at least two hours (AOAC 1984).

6.3.2 The effects of different levels of calcium hydroxide and sodium hydroxide using the spraying method on disappearance of wheat and lentil straws in the rumen

The objective of this study was to examine the effects of different concentrations using the spray method of two alkalis (commonly used for the treatment of fibrous feeds) on the dry matter disappearance of cereal (wheat) and grain legume (lentil) straws in the rumen.

Materials and methods

Straws: Both wheat straw and lentil straw used in this experiment came from the same sources as those used in Experiment 6.3.1. Straws were hammer-milled through a 25-mm screen, treated and then reground in a laboratory hammer-mill fitted with a 1-mm mesh sieve.

Experimental design: A completely randomised design (CRD) was used to examine the effects of different concentrations of both alkalis on the dry matter disappearance of the straws in the rumen. The treatments consisted of untreated straws and straws treated with 0%, 3%, 6%, 9% and 12% $Ca(OH)_2$ and 0%, 2%, 4%, 6% and 8% NaOH.

Treatment procedure: The hammer-milled (25 mm) straws were divided into a series of samples, some were used as control (untreated) and the others were spread on the smooth surface covered with thick plastic sheet and treated either with water (0% of alkali) or with the solutions containing different concentrations of alkalis. The required amounts of alkalis were dissolved in as much water as was necessary to produce a straw dry matter content of about 50% (water / straw ratio (w/w) 1:1).

The required water or alkali solutions were sprinkled over the straws using a plastic garden watering can. The straws were thoroughly mixed with the solutions by hand and then sealed in double plastic bags and held at ambient temperature in plastic containers.

After 24 hours the bags were opened and the contents transferred to trays and placed in a forced-draught dehydrator at 60°C for 48 h. After drying, the straws were ground (as previously described) and samples taken for determination of dry matter disappearance and required measurements. The same rumen-fistulated sheep, nylon bags, incubation technique and retention times as used in Experiment 6.3.1 were used in this experiment.

Results of Experiments 6.3.1 and 6.3.2

Calcium hydroxide treatment significantly increased dry matter disappearance of both wheat straw and lentil straw (Figure 6.1). Although all $Ca(OH)_2$ concentrations resulted in greater disappearances of dry matter of treated straws as compared to untreated and water-soaked (0% alkali) straws the maximum dry matter disappearance was obtained with 9% and 12% concentrations of $Ca(OH)_2$ for lentil straw and wheat straw respectively. The total dry matter disappearance of wheat straw increased almost linearly from about 37% for untreated to more than 50% after treating with 12% calcium hydroxide. The dry matter disappearance of the lentil straw increased from around 47% for untreated to over 55% for straw treated with 9% $Ca(OH)_2$. Soaking (0% alkali) reduced the soluble DM component of the straws significantly ($P<0.01$). However, the digested fraction (Total DM disappearance-soluble DM) increased because of this treatment.

When treating straws (wheat and lentil) with calcium hydroxide by the spraying method there was a significant difference between total and actual disappearances and solubility of both wheat straw and lentil straw treated with different levels of $Ca(OH)_2$ (Figure 6.2). A significant ($P<0.01$) improvement in total dry matter disappearance and solubility was observed by increasing the calcium hydroxide concentration from 3 to 12% for wheat straw and 3 to 9% for lentil straw. The water-soluble fraction of both straws increased almost linearly following calcium hydroxide treatment. It should be noted that these relationships were significant for quadratic comparisons (Table 6.3), the sum of squares for this comparison being much lower than that for the linear comparisons.

Ash content of wheat straw and lentil straw (Figure 6.5) increased sharply by increasing concentration of the alkali, although spraying or soaking with water only resulted in a lower ash content. Apparently, solubilisation in water was positively related to their total ash content.

In assessing the effectiveness of treating with $Ca(OH)_2$, the desirable levels of this reagent for wheat straw and lentil straw were 12% and 9% respectively. In order to better understand these effectiveness trends the data were graphically fitted by orthogonal polynomial (Figures 6.3 and 6.4). While the total disappearance of wheat straw linearly increased with increasing level of $Ca(OH)_2$ to the maximum applied level (12%), the disappearance of lentil straw levelled off after 9% $Ca(OH)_2$. The appropriate regression equations and coefficients of determination are given in Table 6.3.

There was also almost linear increases in washing loss or soluble content (solubility) of both straws with increasing concentration of calcium hydroxide applied by the spraying method but with higher regression coefficients (Table 6.3). For example, while the maximum increments in solubility obtained in treating the straws with $Ca(OH)_2$ by the soaking method were 5.4 and 2.2 percent units for wheat straw and lentil straw respectively, straws treated with 0% $Ca(OH)_2$ had values of 11.0 and 3.9 percentage units for the same straws treated by the same alkali but the spraying method (Figure 6.2).

The ash content of both straws increased sharply after treatment with different levels of alkali (Figure 6.5), probably because of the accumulation of high amounts of calcium by this procedure.

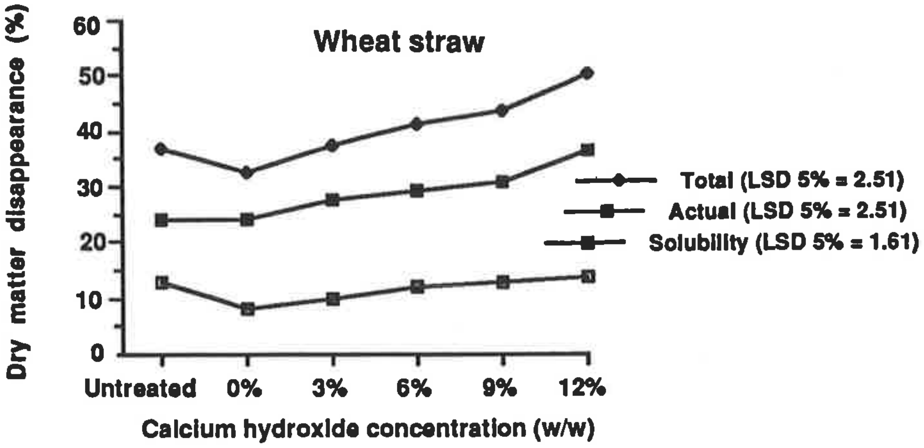
As expected, the calcium hydroxide treatment by the spraying method did not improve the actual dry matter disappearance of either straw. This was the opposite of the actual disappearances resulting from $Ca(OH)_2$ treatment by the soaking method (Experiment 6.3.1). For example, the differences between the actual disappearances of untreated and treated wheat and lentil straw with 12% and 9% were 0.7 and 1.7 percentage units respectively. These differences for the same untreated and calcium hydroxide-treated straw with soaking methods were 12.5 and 12.6 percentage units respectively. This big difference between the actual disappearance of calcium hydroxide-treated straws by different methods was probably because of the high amount of calcium added by the spraying procedure. The total dry matter disappearance and water solubility of 0% $Ca(OH)_2$ or water-treated straws remained unchanged as compared to untreated straws.

The effects of different concentrations of sodium hydroxide on water solubility and dry matter disappearance of wheat straw and lentil straw are shown in Figure 6.6. All the NaOH concentrations significantly acted on total disappearance of both straws.

Water solubility of wheat straw increased by increasing the concentration of sodium hydroxide (Figure 6.7 and Table 6.3). While the water solubility of water-treated wheat straw was on average 12.9%, it increased to 16.9, 22.1, 25.1 and 31.0% after treating with 2, 4, 6 and 8% NaOH respectively. The increment rate was much slower for lentil straw. For example, the solubility of lentil straw was not significantly affected by treating with 2 and 4% NaOH, but it was increased 3.1 and 6.8 percentage units following treatment with 6 and 8% NaOH respectively as compared to water-sprayed lentil straw. Treating both straws with water (0% of NaOH) did not significantly affect their solubility and total dry matter disappearance (Figure 6.6). While these results were similar to the results of treated straw with 0% $Ca(OH)_2$ by the spraying method, they were opposite to the solubility and disappearance values of straws treated with 0% $Ca(OH)_2$ by the soaking method. However, it should be noted that in the soaking method the straws were soaked in a large amount of water for 24 hours rather than moistening with much lower amounts of water by spraying procedure.

The ash content of straws treated with NaOH increased linearly by increasing the alkali concentrations (Figure 6.8). These results were in agreement with Braman and Abe (1977), who reported ash content of ground wheat straw increased following treatment with increasing levels of sodium hydroxide.

Treatment with sodium hydroxide significantly increased ($P<0.01$) the fraction digested compared with untreated straws. For both straws the highest coefficients for the digestible fraction were obtained following treatment with 4.0 g NaOH per 100 g straw (Figure 6.7 and Table 6.3). 4.0



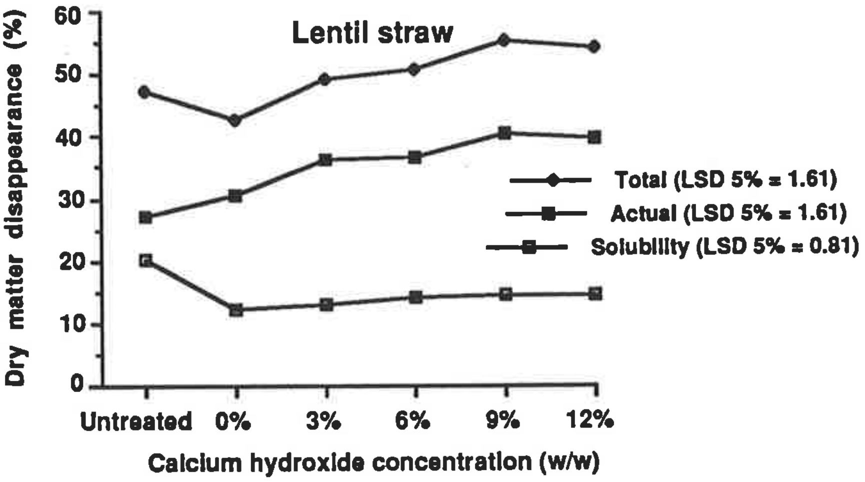
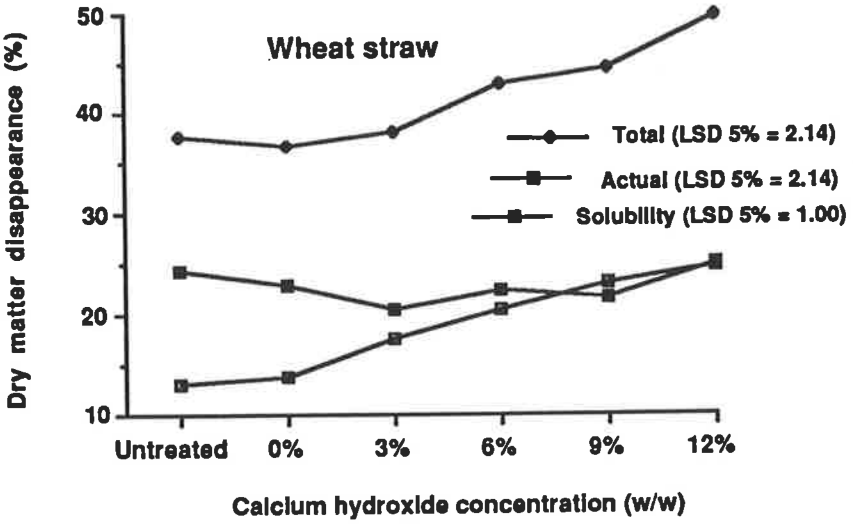


Figure 6.1 The effects of calcium hydroxide treatment by the soaking method on dry matter disappearance of wheat and lentil straws (Experiment 6.3.1)



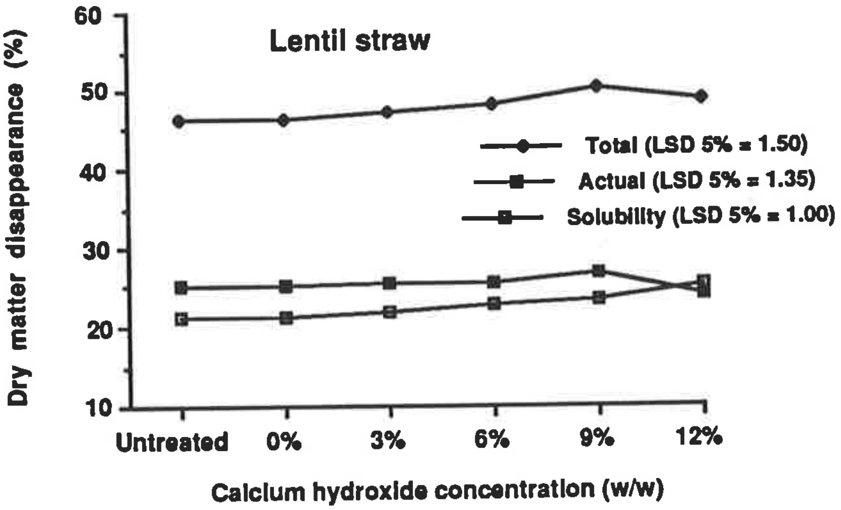


Figure 6.2 The effects of calcium hydroxide treatment by the spraying method on dry matter disappearance of wheat and lentil straws (Experiment 6.3.2)

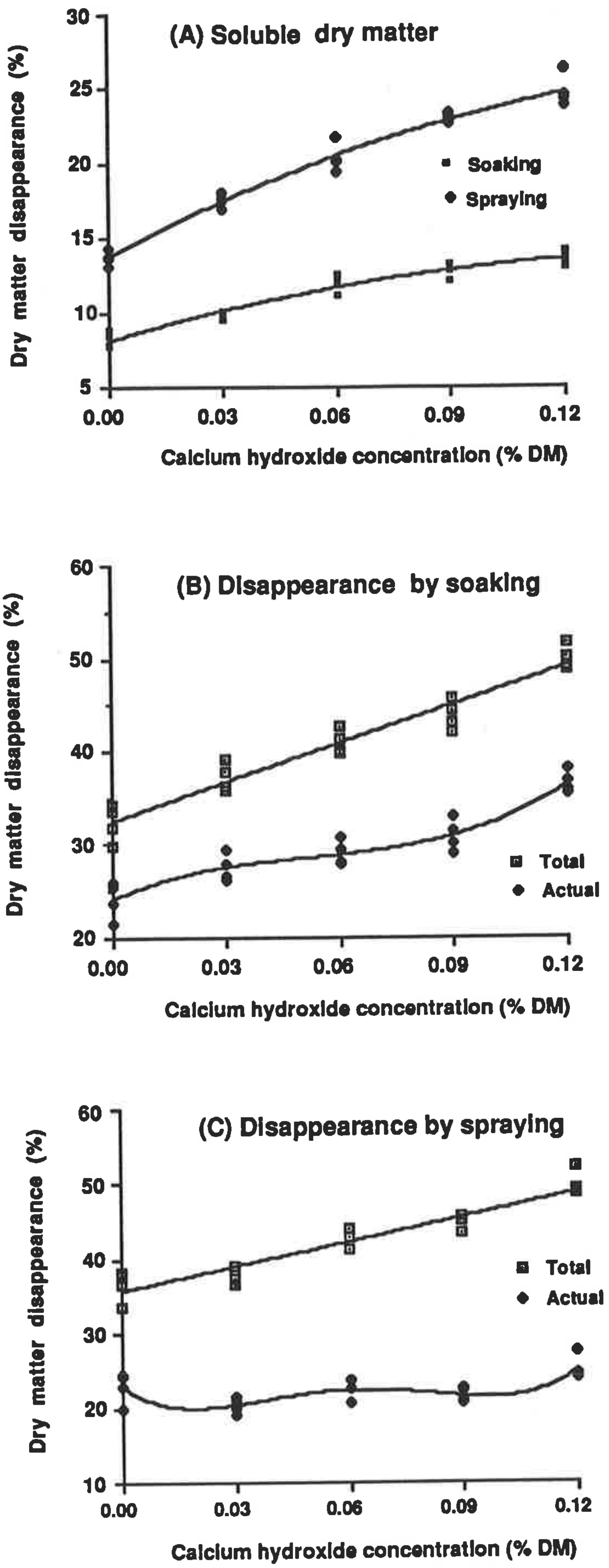
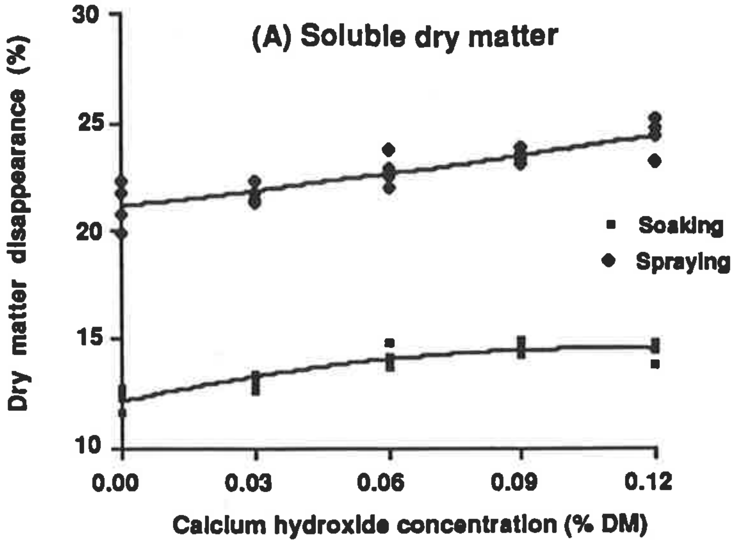
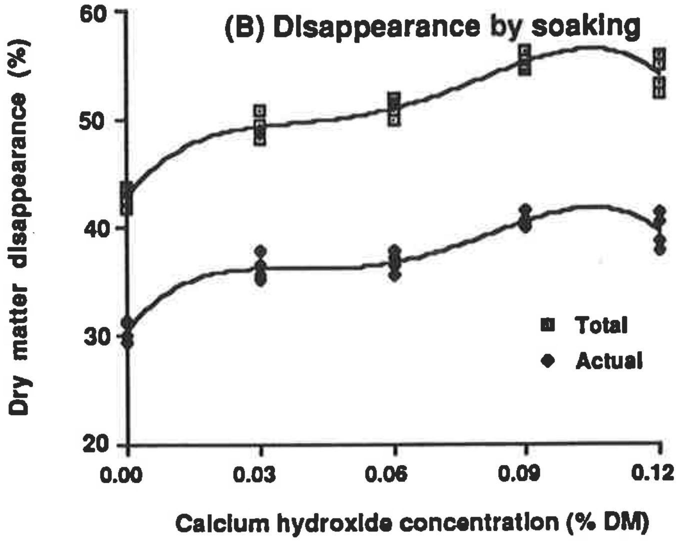


Figure 6.3 Regression (polynomial) of soluble and dry matter disappearance of wheat straw on calcium hydroxide concentrations applied by different methods (Experiments 6.3.1 and 6.3.2)





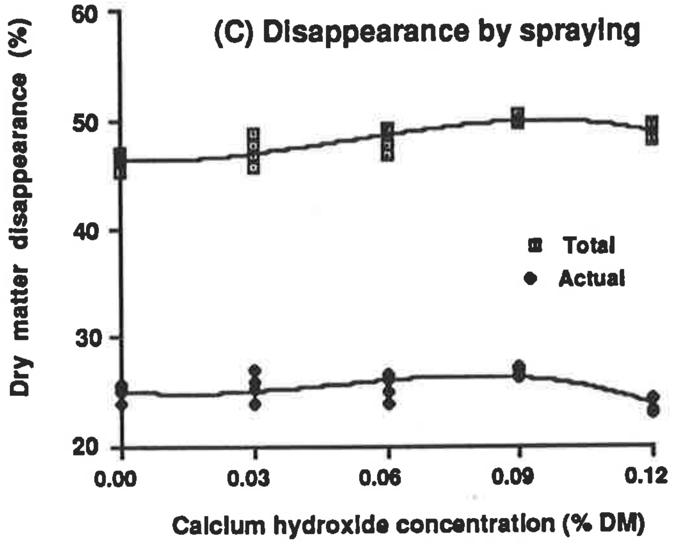
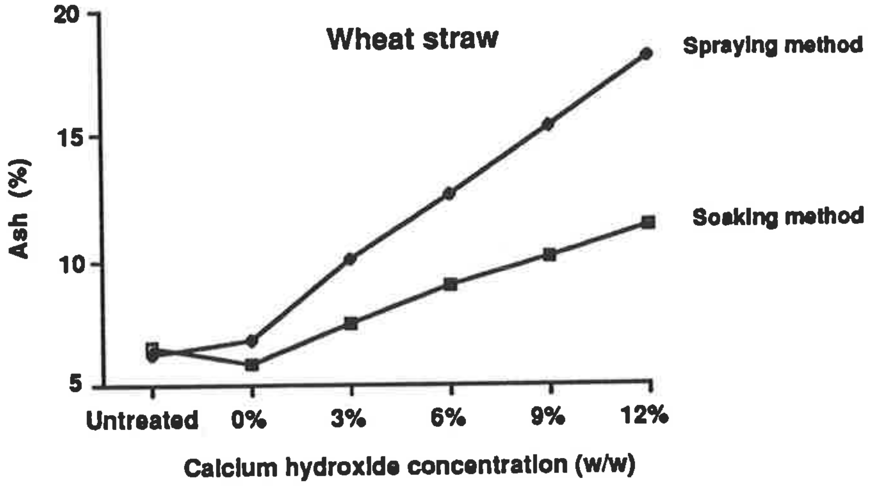


Figure 6.4 Regression (polynomial) of soluble and dry matter disappearance of lentil straw on calcium hydroxide concentrations applied by different methods (Experiments 6.3.1 and 6.3.2)



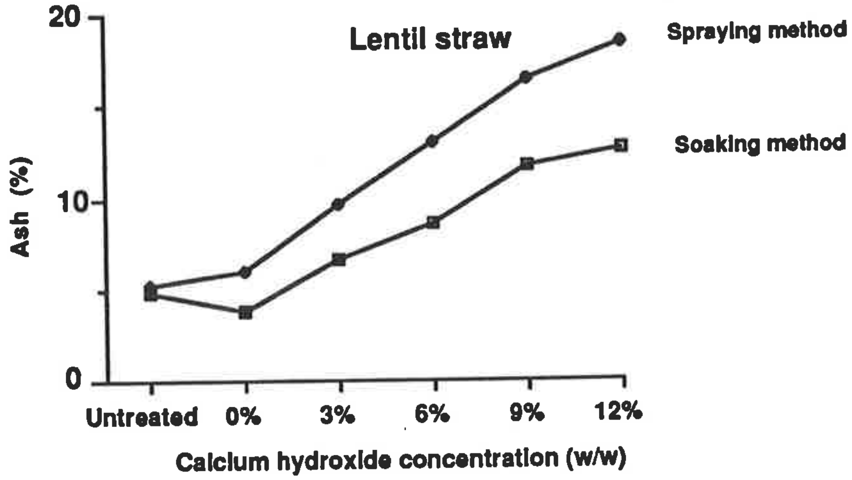
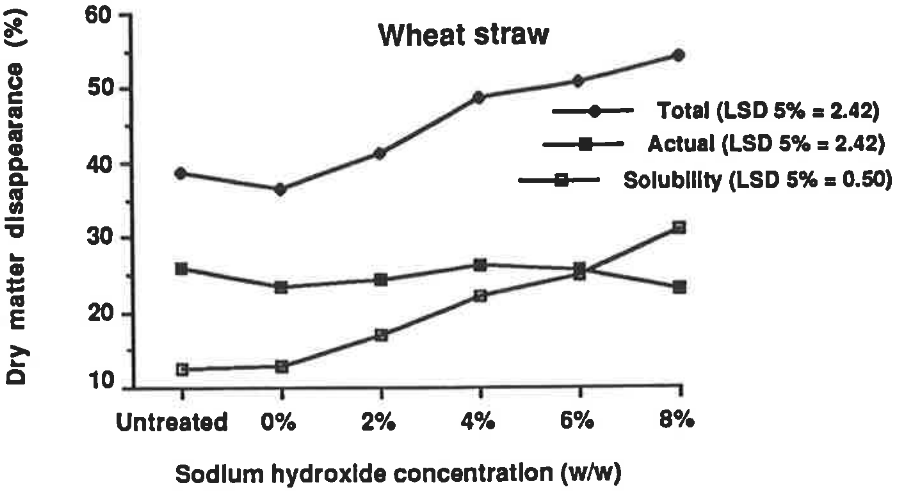


Figure 6.5 Ash content of untreated straw and calcium hydroxide treated straw (Experiments 6.3.1 and 6.3.2)



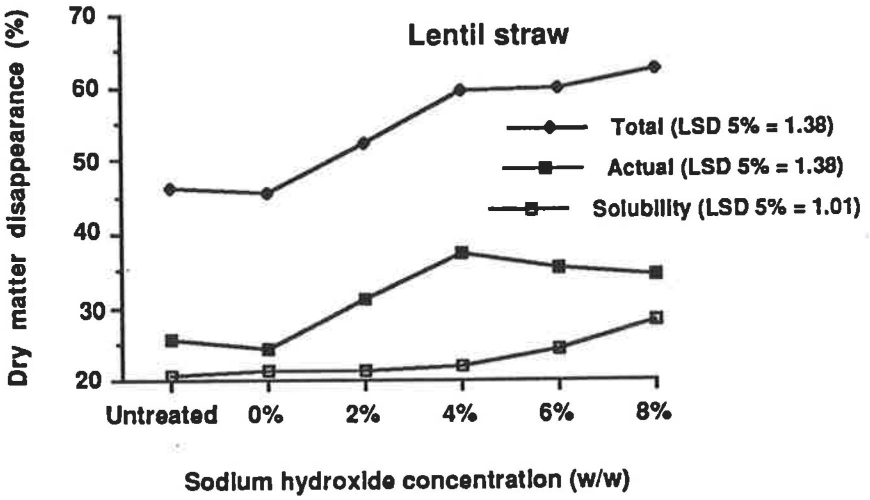


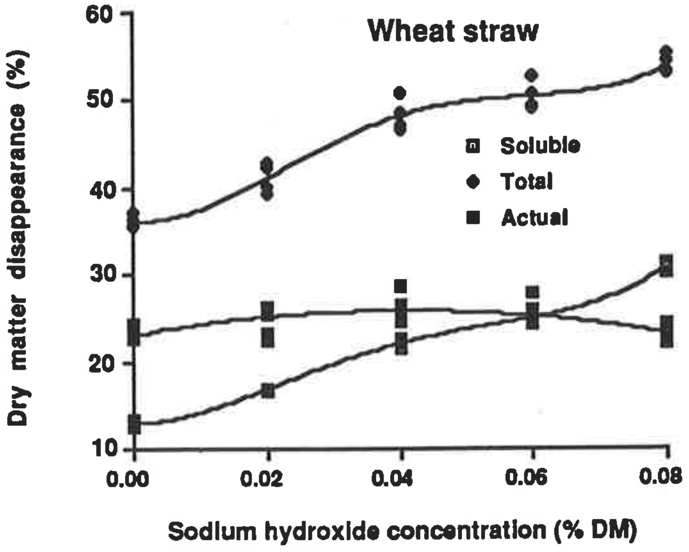
Figure 6.6 The effects of sodium hydroxide treatment by the spraying method on the dry matter disappearance of wheat and lentil straws (Experiment 6.3.2)

Table 6.3 Relationships between alkali concentration and rumen disappearance characteristics of lentil straw and wheat straw treated with calcium and sodium hydroxides (Experiments 6.3.1 and 6.3.2)

Y	X	r^2	Regression equation
Solubility	$Ca(OH)_2$ concentration (0, 3, 6, 9, and 12%) applied by **soaking**	L = 0.849** W =0.954**	(L) $Y = 12.17 + 44.44X - 204.37X^2$ (W) $Y = 8.12 + 73.92X\ 236.11X^2$
Total dry matter disappearance	" " " " " "	L = 0.935** W =0.937**	(L) $Y = 42.83 + 504.51X - 14791X^2 + 190820X^3 - 803760X^4$ (W) $Y = 32.53 + 139.17X$
Actual dry matter disappearance	" " " " " "	L = 0.932** W =0.901**	(L) $Y = 30.53 + 504.51X - 15865X^2 + 203780X^3 - 844910X^4$ (W) $Y = 24.15 + 178.72X - 2664.70X^2 + 16898X^3$
Solubility	$Ca(OH)_2$ concentration (0, 3, 6, 9, and 12%) applied by **spraying**	L = 0.759** W =0.973**	(L) $Y = 21.08 + 26.92X$ (W) $Y = 13.73 + 134.36X - 357.14X^2$
Total dry matter disappearance	" " " " " "	L = 0.701** W =0.898**	(L) $Y = 46.35 - 17.38X + 1547.60X^2 - 10185X^3$ (W) $Y = 35.78 + 109.50X$
Actual dry matter disappearance	" " " " " "	L = 0.473** W =0.604**	(L) $Y = 25.19 - 42.90X + 1674.60X^2 - 11728X^3$ (W) $Y = 22.90 - 361.11X + 14032X^2 - 180710X^3 + 751030X^4$
Solubility	NaOH concentrations (0, 2, 4, 6 and 8%) applied by **spraying**	L = 0.960** W =0.998**	(L) $Y = 21.34 - 45.77X + 1620.50X^2$ (W) $Y = 12.93 - 2.50X + 16025X^2 - 346880X^3 + 2278600X^4$
Total dry matter disappearance	" " " " " "	L = 0.984** W =0.963**	(L) $Y = 45.55 - 3.02X + 28477X^2 - 664320X^3 + 4277300X^4$ (W) $Y = 36.28 - 91.56X + 26643X^2 - 555470X^3 + 3391900X^4$
Actual dry matter disappearance	" " " " " "	L = 0.970** W =0.422*	(L) $Y = 24.25 + 15.31X + 28185X^2 - 685160X^3 + 4381500X^4$ (W) $Y = 23.02 + 140.84X - 1727.70X^2$

Y = dependent variable; X = Independent variable; r^2 = Coefficient of determination;
* = $P<0.05$; ** = $P<0.01$; L = Lentil straw; W = Wheat straw

The main reason for this study was to determine whether the NaOH treatment by the spraying method would improve the feeding value of typical straw residues from cereal and grain legume crops and, if so, what concentration of this alkali can give the maximum effect. The total dry matter loss of lentil straw increased by 3.5, 2.4 and 2.1% units/g NaOH added for straw treated with 2, 4, 6 and 8% NaOH respectively. For wheat straw, the dry matter disappearance increased by 2.5, 3.0, 2.4 and 2.2 percentage units per g NaOH for straws treated with 2, 4, 6 and 8% NaOH respectively.



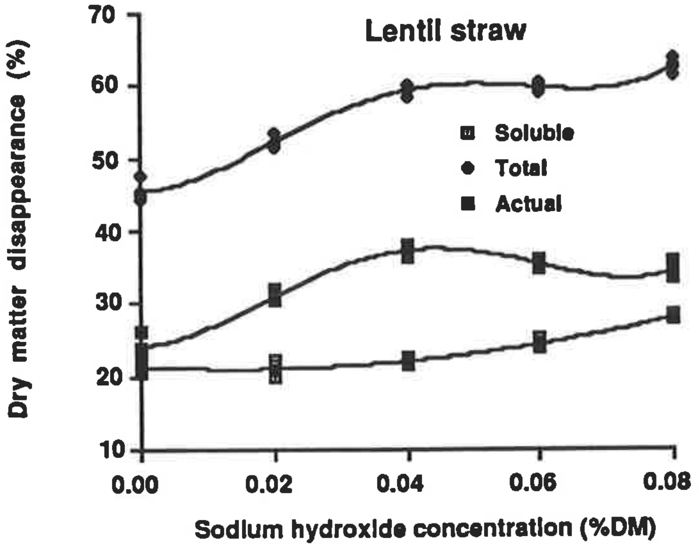
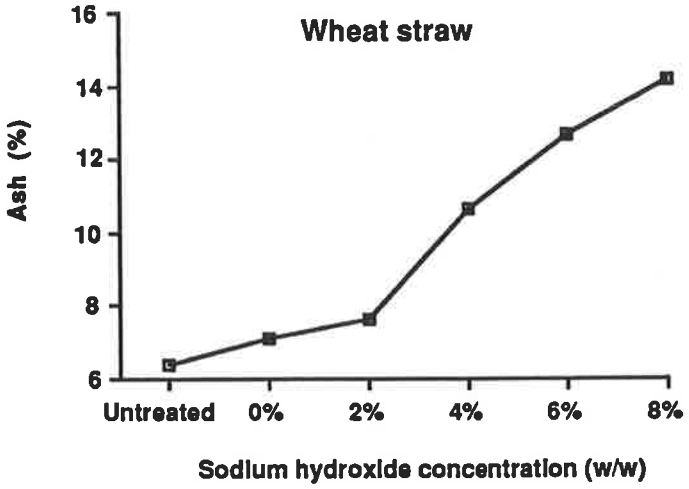


Figure 6.7 Regression (polynomial) of soluble and dry matter disappearance of wheat straw and lentil straw on sodium hydroxide concentrations applied by the spraying method (Experiment 6.3.2)



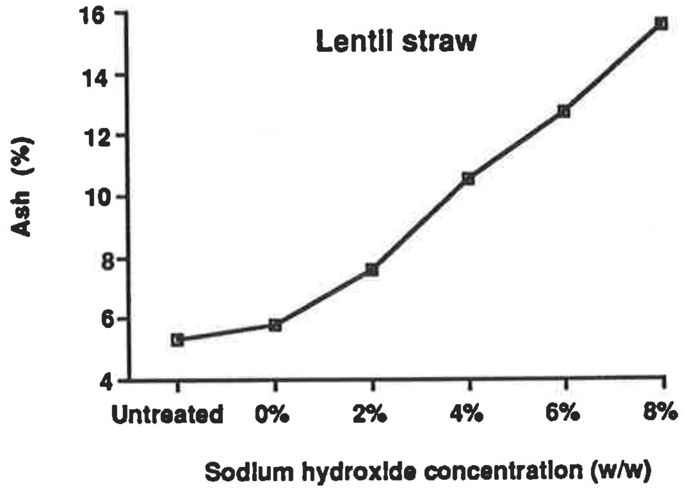


Figure 6.8 Ash content of the untreated straw and sodium hydroxide treated straw (Experiment 6.3.2)

6.3.3 The effects of treatment with optimum concentrations of calcium hydroxide using the soaking method and sodium hydroxide using the spray method on disappearance of several cereal and grain legume straws in the rumen

Following determination of the optimum concentrations of alkalis and the best method of applying calcium hydroxide an experiment was carried out to build on the results obtained in parts 6.3.1 and 6.3.2.

Materials and methods

Straws:

Cereal straws; In addition to wheat straw (cv. Molineux), barley straw (*Hordeum vulgare* cv. Galleon) and oat straw (*Avena sativa* cv. Avon) were collected from the Waite Institute.

Grain legume straws: Three grain legume straws were used in this experiment: broad bean (*Phaseolus vulgaris* cv. Aquadulce), lentil (*Lens culinaris* cv. ILL 5750) and pea (*Pisum sativum* cv. Early Dun). Broad bean straw was provided from Kapunda and pea crop residues from the Kingsford area of South Australia. Lentil straw was from the same source as for other experiments in this chapter (6.3.1 and 6.3.2). The straws were hammer-milled through a 25-mm screen before use.

Experimental design: The experimental treatments were assigned in a completely randomised design (CRD) viz. Number of straws per group (3) x Type of treatments (3) x Replications (4) =36. This type of design was used independently for each alkali and straw group.

The results of experiments 6.3.1 and 6.3.2 showed that the desirable level of sodium hydroxide in terms of improving *in sacco* digestibility of cereal and grain legume straws was 40 g of alkali per kg of the roughages. Therefore in this experiment this 4% concentration of NaOH was applied to all straws either in the cereal group or grain legume group. The other two treatments within the groups were water treatment and untreated straws.

The desirable levels of $Ca(OH)_2$ for cereal straw and grain legume straws were 120 and 90 g of alkali per kg straws by the soaking method respectively. Therefore, these concentrations were applied to both the cereal and grain legume straws. Treatment methods were the same as in previous experiments.

Analysis of results: The results were subjected to analysis of variance to test for significance of the effects of alkalis (Snedecor and Cochran 1971). There were four groups of data: (a) cereal straws treated with $Ca(OH)_2$; (b) cereal straws treated with NaOH; (c) grain legume straws treated with $Ca(OH)_2$ and (d) grain legume straws treated with NaOH.

Results of Experiment 6.3.3

Tables 6.4 and 6.5 show mean values for dry matter disappearance and solubility of the different groups of straws treated with water, calcium hydroxide and sodium hydroxide. There was a significant difference between disappearance and solubility of the straws with each group (Table 6.6).

Table 6.4 Percent dry matter disappearance of the untreated and treated cereal straws with calcium hydroxide (soaking method) and sodium hydroxide (spraying method) (Experiment 6.3.3)

Treatment	Straws								
	Barley			Oats			Wheat		
	S	T	A	S	T	A	S	T	A
$Ca(OH)_2$									
Untreated	15.9	47.3	31.4	22.0	54.4	32.4	12.5	38.0	25.5
Water -treated	9.0	48.3	39.3	12.3	49.0	36.7	8.9	30.5	21.6
$Ca(OH)_2$-treated	15.5	62.1	46.6	14.4	59.5	45.1	13.1	49.0	35.9
NaOH									
Untreated	15.9	47.2	31.3	23.3	54.5	31.2	12.4	39.4	27.0
Water-treated	16.5	48.8	32.3	22.5	52.0	29.5	12.2	35.5	23.3
NaOH-treated	20.0	63.0	42.9	26.6	64.0	37.4	21.3	49.2	27.9

S = Solubility; T = Total disappearance; A = Actual disappearance

The dry matter disappearance and water solubility of oat straw were both significantly higher than those for barley and wheat straw. The lower dry matter losses from the nylon bags of wheat straw compared with the corresponding value for oat straw and barley straw have been reported by other workers (Tuah *et al.* 1986). Water-treatment (soaking) significantly reduced the solubility and total dry matter disappearance of almost all cereal and grain legume straws (Table 6.1 and 6.2) probably because of the removal of readily-soluble materials or small particle sizes during 24-h soaking in tap water. In contrast, the total dry matter disappearance of all straws (cereals and grain legumes) and the solubility of most straws remained unchanged following treatment with tap water by the spraying method. In this respect the actual disappearance also showed a similar trend (Tables 6.4 and 6.5).

Within grain legume straws untreated and water-treated (soaking and spraying) pea straw showed the highest values for total and actual disappearance. While the 48-h total dry matter disappearance of water-treated (by soaking or spraying method) broad bean was similar to pea straw, its actual dry matter disappearance was significantly lower than those for pea straw (Table 6.5).

Table 6.5 Mean dry matter disappearance of the grain legume straws, untreated and treated with calcium hydroxide (soaking method) and sodium hydroxide (spraying method) (Experiment 6.3.3)

Treatment	Straws								
	Broad bean			Lentil			Pea		
	S	T	A	S	T	A	S	T	A
$Ca(OH)_2$									
Untreated	17.7	47.6	29.9	20.8	46.6	25.8	14.2	51.5	37.3
Water -treated	12.0	47.4	35.4	11.9	41.2	29.3	9.0	48.1	39.1
$Ca(OH)_2$-treated	16.5	53.2	36.7	14.1	53.8	39.7	15.4	58.0	42.6
NaOH									
Untreated	17.8	46.2	28.4	21.4	47.1	25.7	14.7	48.6	33.9
Water-treated	20.2	46.1	25.9	21.9	46.9	24.9	16.5	47.0	30.5
NaOH-treated	23.3	56.1	32.8	22.3	58.7	36.4	18.9	56.7	37.8

S = Solubility; T = Total disappearance; A = Actual disappearance (digested DM)

Table 6.6 Summary of analyses of variance of untreated and treated cereal and grain legume straws with different alkalis (Experiment 6.3.3)

Source of variation	Cereal straws			Grain legume straws		
	S	T	A	S	T	A
		Significance level				
$Ca(OH)_2$ (soaking method)						
Type of straw	**	**	**	**	**	**
Straw treatment	**	**	**	**	**	**
Type of straw x Straw treatment	**	**	**	**	**	**
NaOH (spraying method)						
Type of straw	**	**	**	*	*	**
Straw treatment	**	**	**			
Type of straw x Straw treatment	**	**	**	NS	**	**

S = Solubility; T = Total disappearance; A = Actual disappearance
NS = Not significant; * = $P<0.05$; ** = $P<0.01$

Calcium hydroxide treatment (by soaking) and sodium hydroxide treatment (by spraying) significantly increased the disappearance of all straws as compared to untreated and water-treated straws (Tables 6.4, 6.5 and 6.6). Generally, sodium hydroxide was more effective in improving the disappearance of both groups of straws, but the positive effects of calcium hydroxide were also obvious. For example, while the average total disappearance of the cereal group and grain legume group was increased about 12 and 10 percentage units respectively following treatment with NaOH, the corresponding values for straws treated with $Ca(OH)_2$ (9%) by the soaking method were about 10.0 and 6.5 percentage units. When the average disappearance (total) of straws treated with 4% NaOH was compared with the values obtained following treating with water (soaking) the differences were 13.3 and 10.5% units for cereal and grain legume groups respectively.

Although, alkali treatment of cereal straws by both calcium hydroxide and sodium hydroxide resulted in higher disappearance values than for grain legume straws, a similar reduction in disappearance of both groups of straw was observed in this study following soaking in tap water (6.7 vs 6.6% units).

The statistical significance of the main effects and interactions in this experiment are shown in Table 6.6. For instance, as already shown, soaking the straws in tap water resulted in lower solubility and disappearance either for cereal straws or grain legume straws, but within each group of straw the reduction rate was not the same for the straws. While this reduction in solubility for wheat straw was about 3.5% units the corresponding value for oat straw was around 10.0% units. Therefore, within each group of straw the solubility and disappearance of straws was independently affected by the experimental treatments.

Generally, because of higher solubility of the straws treated with NaOH, the differences between their actual disappearance and the disappearance of untreated straws were smaller than the corresponding values for $Ca(OH)_2$-treated straws (Tables 6.4 and 6.5).

Discussion of Experiments of 6.3.1, 6.3.2 and 6.3.3

$Ca(OH)_2$:

As expected, calcium hydroxide treatment mainly at higher concentrations and the soaking method improved the dry matter disappearance of both cereal straws and grain legume straws in the rumen. The increases in rumen dry matter disappearance of the straws following treatment with $Ca(OH)_2$ is likely to be related to the increase of mainly soluble carbohydrate liberated by the alkali hydrolysis process (Jackson 1977).

Both solubility and dry matter disappearance of water-soaked cereal and grain legume straws significantly declined, presumably because of losses of readily-soluble organic matter. In a feeding experiment with growing heifers, Roxas *et al.* (1987) soaked rice straw in plain water and then immediately drained it for a few hours. No appreciable change in composition of rice straw due to soaking was found in their experiment. However, there was an important difference between the soaking method used in these Waite Institute studies described in this chapter and the Beckman method. The soaked straws were never washed as recommended for straws treated with NaOH in Beckman method, because it was suggested that washing of $Ca(OH)_2$-treated straws led to more losses of the digestible organic matter compared to unwashed and soaked straws in different suspensions of $Ca(OH)_2$. It has been reported that high calcium content of soaked straw in $Ca(OH)_2$ suspension has no effect on phosphorus utilisation (Djajanegara *et al.* 1985) or mineral balance (Verma *et al.* 1982), therefore the effective $Ca(OH)_2$ treatment of low-quality feeds can be as simple as soaking the materials in the desirable $Ca(OH)_2$ solution and then feeding to animals after draining the feed for a few hours.

Increased digestibility of low-quality roughages following alkali treatment is based on initial levels of digestibility. For example, higher increases in digestibility can be expected following treatment of roughages of low initial digestibility in comparison with roughages of high initial digestibility (Owen 1978). In the Waite Institute studies generally, the increased disappearance values for wheat straw were higher than those for lentil straw, whereas the initial disappearance of lentil straw was higher than wheat straw (47.3 v 36.8).

Although the question as to why wheat straw gave highest disappearance at 12% calcium hydroxide and lentil straw at 9% cannot be clearly explained from the available data in this study it may be related to the different structure of cell walls and probably different contents of protein and calcium. For instance, the calcium content of untreated lentil straw is about 3.5 times more than that for wheat straw (AMETFC 1979). However, more studies are required in order to distinguish and clearly explain these differences.

While total dry matter disappearance of wheat and lentil straw significantly improved by spraying calcium hydroxide, generally this treatment process was less effective compared to the soaking method, probably because of the low solubility of this reagent (Doyle *et al.* 1986). While the disappearance of $Ca(OH)_2$ spray-treated straws followed the very close trend of those treated by soaking in the same alkali, it seems that because of the remaining higher amount of $Ca(OH)_2$ in spray-treated straws, the dry matter disappearances are over-estimated. It is apparent from Figure 6.5 that the ash content of sprayed straws was about two times higher than that for soaked straws: therefore, more calcium has been incubated with sprayed samples than for soaked samples. The calcium hydroxide was finely ground and probably most of its particles were small enough to pass through the pores of nylon bags while in the rumen. The calcium hydroxide that disappeared was regarded as total dry matter disappearance of straw whereas the actual coefficients (Figure 6.2) show that the effectiveness of this alkali by the spray method should be lower than that obtained in this experiment.

In alkali treatment of low-quality roughages with NaOH, it has been pointed out that because reasons such as pollution problems, dry matter losses, heavy end-products and requirement for large amounts of water, dry processes are more convenient and recommended in comparison with the soaking processes (Sundstøl 1988; Castrillo *et al.* 1991). However, calcium hydroxide is a non-polluting, safe and cheaper alkali and with the method which was undertaken in this study probably there is no appreciable loss of dry matter because of soaking (Roxas *et al.* 1987). Also, since calcium is metabolised in a different manner to sodium (Ibrahim 1983), intake of higher amounts of this mineral through feeding roughages treated with $Ca(OH)_2$ by the soaking method has no adverse effects on animals (Djajanegara *et al.* 1985). Therefore, washing of the straws soaked in $Ca(OH)_2$ solution is not required. Most of the above-mentioned problems involved with dip-treating crop residues with NaOH, may not exist for $Ca(OH)_2$, thus treating fibrous feeds with $Ca(OH)_2$ by the soaking method would be a useful procedure. However, in spite of some positive results obtained in this study, the profitability of calcium hydroxide by the spraying method without further processing is in doubt because of the weakness of calcium hydroxide.

The solubility and disappearance values of untreated straws (wheat and lentil) were similar to the corresponding values obtained following spraying with tap water (0% of $Ca(OH)_2$) (Figure 6.2) indicating that water spraying did not significantly change the general feeding value of the straws in this study.

NaOH:

As expected, the NaOH treatment also improved the solubility and dry matter losses of treated straws in the rumen, probably due to solubilisation of hemicellulose, increasing the extent and rate of cellulose and hemicellulose digestion, presumably by swelling (CAN 1983). Similar results in increasing water solubility of rice straw following treatment with alkali (ammonia) were reported by Nakashima and Ørskov (1992).

While the response of low-quality roughages to sodium hydroxide treatments has been extensively studied by *in vivo* and *in vitro* methods (Jackson 1977; Kristensen 1982; Castrillo *et al.* 1991) there is little information in the literature on the effects of alkali treatment on disappearance of straws, especially grain legume straws measured by the *in sacco* procedure.

However, as with other *in vivo* and *in vitro* results (Rexen and Thomson 1976; Klopfenstein 1978) this study also showed that the 4% concentration of sodium hydroxide gave a better result than other levels, indicating the accuracy and relevance of the *in sacco* method.

In an *in vivo* experiment using male calves, Singh and Jackson (1971) reported that in terms of digestible organic matter intake of wheat straw spray-treated with NaOH the desirable level of alkali was 3.3 g per 100 g straw. In their experiment higher concentrations of the alkali were also less effective. However, because of the above-mentioned reason the 4% concentration of NaOH was chosen as the desirable level of alkali for applying to the groups of straw.

It has been reported that the performance of animals fed chemically-treated low-quality roughages was higher than the performance of animals fed untreated materials (Jackson 1977; Ibrahim 1983): however, the practical designs should be investigated in regard to the local conditions (Sundstøl 1988).

As previously discussed, crop residues should be fed to animals during the hot and dry period in the Mediterranean-type climate of southern Australia. It seems that chemical treatment of these residues is likely to be adopted by feedlot operators but further investigation into the local conditions is warranted. The results of this study would suggest that feedlot performance of sheep at maintenance levels can be improved by feeding high levels of alkali-treated straws.

Ash content of the sodium hydroxide treated straws was increased linearly because of the accumulation of sodium. Probably animal health can be adversely affected by feeding NaOH-treated straw with concentrations over 40 g/kg dry matter (Jackson 1977).

Sodium hydroxide treatment was more effective for lentil straw than for wheat straw. For example, the total and actual disappearance of wheat straw increased 9.8 and 0.4 percentage units respectively following treating with 4% NaOH, whereas these values for lentil straw were 13.4 and 11.8% respectively, probably due to higher content of crude protein and differences in cell wall structure. These results suggest that alkali treatment of grain legume leads to better performance in animals than cereal straws: however, more studies are required.

The results of this study (Table 6.4) show that susceptibility of cereal or grain legume straws to water and calcium hydroxide treatment varied widely, indicating that extrapolations from one cereal or grain legume species to another may be misleading. Although it is generally believed that the nutritive value of oat straw is higher than barley and wheat straw (Kjos *et al.* 1987; Reid *et al.* 1988), some exceptions to this conclusion can be found (Cottyn and de Boever 1988; Givens *et al.* 1989). In this study, while the initial dry matter disappearance of oat straw was higher than both barley and wheat straw, its total disappearance response to calcium hydroxide treatment was much lower. However, in addition to unavoidable experimental errors that might occur, weather conditions during the growing season or even after harvesting (Kjos *et al.* 1987), the proportion of leaves and stems (Thiago and Kellaway 1982) and differences in cell wall structure can be responsible for the above-mentioned variations. On the whole, as other reports suggest (Kernan *et al.* 1979, 1981; Ørskov *et al.* 1983), in this experiment the rumen disappearance of barley straw was comparable to oat straw.

While the *in sacco* disappearance of broad bean straw remained unchanged following the water-soaking treatment, the corresponding values for lentil and pea straw were significantly lower than untreated straws. Two suggestions can be made for explaining these differences: (a) The physico-chemical structure of the straws was different and therefore different modes of action by $Ca(OH)_2$ may have occurred. (b) Although all of the straws were ground through the same hammer mill and screen this physical process probably has resulted in different particle sizes between the species. For instance, the proportion of very fine particles for lentil and pea was higher than that for broad bean and it led to higher dry matter losses following dip treatment with water or calcium hydroxide.

Ash determinations showed that more calcium remained in grain legume straws than cereal straws. Generally, the ash content of 12% $Ca(OH)_2$-treated cereal straws was about 5% units higher than that for untreated straws, but for grain legume straws even with a lower level of 9% $Ca(OH)_2$ the increased ash level was about 7% units, indicating that the mass volume of grain legume straws was probably lower than for cereal straws, therefore more insoluble $Ca(OH)_2$ can precipitate into this compact mass.

The response of both cereal and grain legume straws to NaOH-treatment in terms of dry matter losses from the nylon bags was higher than that for $Ca(OH)_2$ presumably because of its higher solubility and alkalinity. Also probably because of these characteristics of sodium hydroxide more improvement in the solubility of the treated straws was obtained in comparison with the same straw treated with calcium hydroxide. Furthermore the solubility and disappearance improvements following treatment with NaOH were higher for cereal straws than those for grain legume straws. Although the real reasons are unclear the results are in agreement with the conclusion of Robards *et al.* (1983) that improved nutritive value of poor-quality straws by treating with NaOH is higher than that for the straws of initially higher quality.

In this Waite Institute study, despite considerable improvement obtained following treatment with NaOH for both cereal and grain legume straws, because of the complex interactions between ruminants and alkali-treated feeds, it is recommended that the optimum levels of alkali and appropriate techniques be further tested in feeding trials and feedlots during the dry period of southern Australia. However, soil pollution, livestock health problems and economical treatment methods are the main issues which must be overcome.

6.4 Alkali treatment of mature medic pods with calcium hydroxide and sodium hydroxide

6.4.1 Introduction

As previously mentioned, mature medic pods are an important component of dry annual pastures during the dry period on millions of hectares of the cereal belt of southern Australia. These pods are a valuable source of nutrients for sheep, mainly during the time that other components of the pasture are in short supply. In one district of South Australia mature medic pods have been harvested for pelleting as a feedstuff for ruminants.

Medic pods are characterised by high contents of crude protein and fibre (Chapter 4). The high fibre content limits usefulness as a component of ruminant diets. It is widely recognised that energy availability to ruminants from fibrous feeds is limited by the close physical and chemical association between structural carbohydrates and lignin (Jackson 1977; Morris and Bacon 1977; Hartly and Jones 1978; Chesson 1981). To increase the utilisation of many fibrous feedstuffs it is necessary to decrease the effect of lignification (Lesoing and Klopfenstein 1981). Many studies have been undertaken to assess the possibility of improving the feeding value of fibrous materials by chemical treatments (Klepfenstein *et al* 1978; Sundstøl *et al.*

1979). Among the many chemical treatments developed up to now, alkali treatments (and in particular sodium hydroxide) have achieved a measure of commercial acceptance (Chesson 1981) and the most profitable in terms of increasing the energy availability and digestibility of crop residues (Ololde *et al.* 1970; Singh and Jackson 1971).

However, fibrous roughages are often deficient in nitrogen (Hunter 1988) whereas legume residues, and in particular mature medic pods, have higher contents of nitrogen: therefore, a considerable increase in the feeding value of medic pods following treatment with alkalis can be expected.

Despite many reports on alkali treatment of cereal straws, there have been few studies on legume residues. Furthermore, no data were found in the literature concerning alkali treatment of mature medic pods. However, considering the high content of protein and special physical form the treatment of mature medic pods with alkalis could lead to greater improvement in feeding value than with cereal straws.

6.4.2 Materials and methods

Medic pods (Sava, Parabinga and Paraggio) were from the same source as described in Chapter 4. The treatments were carried out on whole intact pods without any physical treatment such as the grinding which was applied to cereal straws and grain legume straws. There were 5 experiments. The alkalis, their concentrations and method of application were the same as described for the cereal and grain legume straws in previous parts of this chapter.

In Experiment 1, Sava pods were soaked in tap water with increasing concentrations of $Ca(OH)_2$ (3, 6, 9 and 12% w/w) in order to select the most desirable concentration of alkali for applying in following experiments. In Experiment 2, the effects of different concentrations of calcium hydroxide (3, 6, 9 and 12% w/w) by the spraying method on solubility and disappearance of the Sava pods were studied. In Experiment 3, the optimum method of application and concentration of calcium hydroxide (resulting from Experiment 1) was applied to three lots of annual medic pods i.e. Sava, Parabinga and Paraggio. In Experiment 4, mature Paraggio pods were treated with different concentrations of sodium hydroxide (by spray method) in order to obtain the best level in terms of upgrading the dry matter disappearance or solubility of the treated pods. In the last experiment (Experiment 5), as for Experiment 3, the pods of Sava, Parabinga and Paraggio were treated (spray method) with the optimum concentration of sodium hydroxide resulting from Experiment 4.

To assess the disappearance of treated pods, these were partially dried (at 60°C for 48 h), ground through the 1-mm screen and incubated by the *in sacco* method in the rumen of four fistulated adult Merino wethers. The statistical designs, alkali concentrations, treatment procedures, fistulated sheep, nylon bags and analytical and incubation procedures were the same as those used in section 6.3 of this chapter.

6.4.3 Results

Dry matter disappearance of mature Sava pods either untreated or treated with calcium hydroxide by soaking and spraying are shown in Figure 6.9. Both water solubility and total disappearance of the pods declined following soaking in tap water (0% of $Ca(OH)_2$), whereas the mean values of these variables for the water-sprayed Sava pods tended to be higher than untreated pods.

While water solubility of the mature Sava pods remained nearly steady following treatment with 3% $Ca(OH)_2$ by the soaking method, the corresponding values for the same pods treated by the same alkali and spraying method significantly increased ($P<0.01$). For example, the difference between water solubility of untreated pods and the maximum water solubility of treated pods by the soaking method (obtained following treatment with 12% $Ca(OH)_2$) was only 0.7 percentage unit whereas this value for pods treated by spraying was 9.0 percentage units.

The actual dry matter disappearance of the Sava pods was significantly ($P<0.01$) affected by treatment with $Ca(OH)_2$ applied by the two methods but it is evident from Figure 6.9, that the general increment rate for pods treated by the soaking method was positive whereas for the pods sprayed with similar concentrations of $Ca(OH)_2$ this trend was negative as compared to the untreated pods. Both total and actual dry matter disappearances of the Sava pods treated with $Ca(OH)_2$ by the soaking method and total disappearance of the same pods treated with the same alkali by the spraying method levelled off at approximately 9% of the alkali (w/w). However, as mentioned above, water solubility of the Sava pods treated with $Ca(OH)_2$ by spraying increased up to the highest level of this alkali applied in this study (12% w/w).

Calcium-hydroxide-treated Sava pods, especially by the spraying method, had a considerably higher ash content than the untreated pods (Figure 6.14). Ash content of the pods treated with higher concentrations of $Ca(OH)_2$ by spraying was higher than the corresponding values for the pods treated by soaking. For instance, while the difference between ash content of untreated pods and pods treated with 12% $Ca(OH)_2$ by soaking was 3.5 percentage units, this value for the respective pods sprayed by $Ca(OH)_2$ was 14.2 percentage units.

Data on relationships between the different concentrations of calcium hydroxide (independent variable) and disappearance of the pods (dependent variable) were compared through the orthogonal analyses. The related statistical information and the fitted graphs are shown in Table 6.7 and Figures 6.10 and 6.11. The results clearly demonstrate that relationships between the dependent variables and independent variables mostly follow non-linear regression. Except for water solubility of the $Ca(OH)_2$-sprayed pods, the relationships are between linear and cubic. These relationships are shown in the regression equations of Table 6.7.

The accuracy of the regression equations was tested by comparing the observed values with the estimated disappearance values through the above-mentioned equations (Tables 6.8 and 6.9). The estimated or expected values were very close to the observed mean in the experiments. For example, the estimated disappearance means from the regression equations also confirm that 9% of $Ca(OH)2$ was the best concentration of this alkali for improving the rumen dry matter disappearance of mature whole Sava pods.

It is evident from these data and figures that the application of $Ca(OH)_2$ by both methods resulted in significant improvement in total dry matter disappearance of Sava pods, but soaking was more effective than the spraying procedure. The correlation coefficients of the measured variables presented in Table 6.10 support this finding. This coefficient for all the variables measured on the pods soaked in $Ca(OH)_2$ was positive and higher than the corresponding value for spray-treated pods.

Table 6.7 **Relationships between alkali concentrations and rumen degradability characteristics of mature whole medic pods treated by different methods (Experiments 6.4.1, 6.4.2. and 6.4.4)**

Y	X	r^2	Regression equation
Solubility of Sava whole pods	$Ca(OH)_2$ concentration (0, 3, 6, 9, and 12%) applied by **soaking**	0.873**4	$Y = 11.17 + 72.67 X - 333.33X^2$
Total dry matter disappearance of Sava whole pods	" " "	0.865**	$Y = 43.85 - 61.09 X + 4452.38X^2 - 26697.53 X^3$
Actual dry matter disappearance of Sava whole pods	" " "	0.790**	$Y = 32.80 - 170.69 X + 5666.67X^2 - 31635.80 X^3$
Solubility of Sava whole pods	$Ca(OH)_2$ concentration (0, 3, 6, 9, and 12%) applied by **spraying**	0.969**	$Y = 15.13 + 73.67 X$
Total dry matter disappearance of Sava whole pods	" " "	0.795**	$Y = 48.29 - 174.51 X + 4250.00X^2 - 22299.38 X^3$
Actual dry matter disappearance of Sava whole pods	" " "	0.891**	$Y = 33.18 - 240.86 X + 4043.65X^2 - 21064.82 X^3$
Solubility of Paraggio whole pods	NaOH concentrations (0, 2, 4, 6 and 8%) applied by **spraying**	0.990**	$Y = 12.50 + 144.57 X + 1392.86X^2$
Total dry matter disappearance of Paraggio whole pods	" " "	0.967**	$Y = 42.95 - 103.85 X + 24981.77 X^2 - 513802.08 X^3 + 3092447.92X^4$
Actual dry matter disappearance of Paraggio whole pods	" " "	0.876**	$Y = 30.25 - 310.52 X + 30606.77 X^2 - 690885.42 X^3 + 4342447.92X^4$

Y = dependent variable; X = Independent variable; r^2 = Coefficient of determination;
** = $P<0.01$

Table 6.8 **Mean total dry matter disappearance of Sava pods treated with calcium hydroxide, observed in the experiment and expected from the regression equations (Experiments 6.4.1 and 6.4.2)**

Treatment	Dry matter disappearance (%)	
	Observed	Expected
$Ca(OH)_2$ (soaking)		
0%	43.6	43.9
3%	46.2	45.3
6%	49.1	50.4
9%	55.9	55.0
12%	54.3	54.5
$Ca(OH)_2$ (spraying)		
0%	48.3	48.3
3%	46.2	46.3
6%	48.4	48.3
9%	50.7	50.8
12%	50.0	50.0

Table 6.9 **Mean total dry matter disappearance of Paraggio pods treated with sodium hydroxide, observed in the experiment and expected from the regression equations (Experiment 6.4.4)**

Treatment	Dry matter disappearance (%)	
	Observed	Expected
NaOH (soaking):		
0%	43.0	42.9
2%	47.3	47.2
4%	53.8	53.7
6%	55.8	55.7
8%	58.1	58.0

Table 6.10 Correlation coefficients (r) between the measured variables (Experiments 6.4.1, 6.4.2. and 6.4.4)

Sample	Alkali	Variables (in %)	r
Sava mature whole pods	$Ca(OH)_2$ (Soaking)	Solubility & Total dry matter degradation	0.785**
		Solubility & Actual dry matter degradation	0.650**
		Total dry matter degradation & & Actual dry matter degradation	0.977**
Sava mature whole pods	$Ca(OH)_2$ (Spraying)	Solubility & Total dry matter degradation	0.630**
		Solubility & Actual dry matter degradation	-0.828**
		Total dry matter degradation & & Actual dry matter degradation	-0.122^{NS}
Paraggio mature whole pods	NaOH (Spraying):	Solubility & Total dry matter degradation	0.914**
		Solubility & Actual dry matter degradation	-0.707**
		Total dry matter degradation & Actual dry matter degradation	-0.404^{NS}

** = $P<0.01$; NS = Not significant

The solubility and disappearance data for Sava, Parabinga and Paraggio medic pods following soaking in a suspension of 9% $Ca(OH)_2$ or treating with water (0% $Ca(OH)_2$) are presented in Table 6.11. The differences between solubility and disappearance of different lots of pods were highly significant (Table 6.12). While water-treatment significantly ($P<0.01$) reduced solubility and total dry matter disappearance of Sava and Paraggio pods, the corresponding values for Parabinga pods remained unchanged. However, the disappearance of all lots of pods significantly ($P<0.01$) improved following treatment with calcium hydroxide (Table 6.12). Nevertheless, the disappearance values of untreated and treated Parabinga pods were considerably lower than those for Sava and Paraggio pods. Similar results were reported previously in this thesis (Chapter 4). Responses of pods to calcium hydroxide treatment were in the following order: Sava> Parabinga> Paraggio.

Mean values for the dry matter disappearances of untreated and treated whole mature pods of Paraggio barrel medic with NaOH when suspended in the rumen or washed under running tap water are given in Figure 6.12. Water solubility of the pods tended to decline following spraying with water (0% of NaOH) and then sharply increased by increasing the level of the alkali (2,4,6 and 8%). For example while the water solubility of untreated pods was about 13.3% on average, it reached 32.7% after treatment with 8% sodium hydroxide, an increase of more than 245%.

The dry matter disappearance of the Paraggio pods, as for solubility, declined following the application of 0% alkali but thereafter by increasing the level of sodium hydroxide the disappearance also was increased. However, as will be reported later, the general trend was not completely linear. The actual dry matter disappearance of the pods slowly increased up to an application of 4% sodium hydroxide and significantly ($P<0.05$) reduced thereafter.

Although ash content of the treated pods remained unchanged following treatment with 0% NaOH, the ash content for the other levels of this alkali sharply increased (Figure 6.14). For instance, the ash content of pods treated with 8% NaOH, increased 10.1 percent above that for untreated pods.

Table 6.11 Percent dry matter disappearance of mature medic pods when untreated or treated with calcium hydroxide by soaking and sodium hydroxide by spraying (Experiments 6.4.3 and 6.4.5)

Treatment	Medic pods								
	Sava			Parabinga			Paraggio		
	S	T	A	S	T	A	S	T	A
$Ca(OH)_2$									
Untreated	14.6	46.8	32.2	13.7	35.5	21.8	13.3	45.2	31.9
Water-treated	11.5	44.2	32.7	13.7	35.5	20.8	10.6	41.0	30.4
$Ca(OH)_2$-treated	14.9	55.7	40.8	15.1	43.3	28.2	14.7	50.5	36.8
NaOH									
Untreated	14.2	47.0	32.8	12.9	35.6	22.7	12.9	44.5	31.6
Water-treated	14.9	48.6	33.7	13.2	35.0	21.8	12.6	43.6	31.0
NaOH-treated	23.2	60.2	37.0	19.4	48.5	29.1	21.0	53.5	32.5

S = Solubility; T = Total; A = Actual

Table 6.12 Summary of analyses of variance of medic pods either untreated or treated with two alkalis (Experiment 6.4.5)

Source of variation	component		
	S	T	A
	Significance level		
$Ca(OH)_2$ (Soaking)			
Type of pods	**	**	**
Type of treatment	**	**	**
Type of pods x Type of treatment	NS	NS	**
NaOH (Spraying)			
Type of pods	**	**	**
Type of treatment	**	**	**
Type of pods x Type of treatment	**	**	**

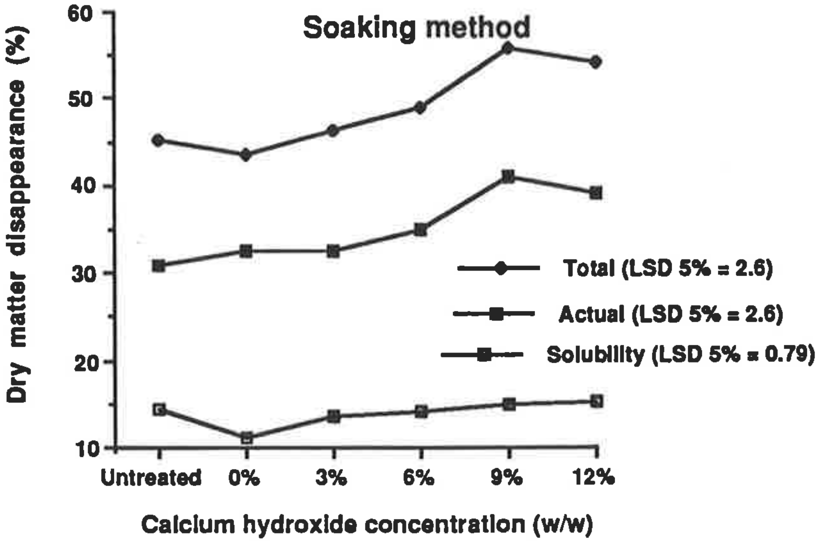
S = Solubility; T = Total; A = Actual; ** = $P<0.01$; NS = Not significant

Along with data following treatment of Sava pods with calcium hydroxide, the regression equations for Paraggio pods treated with NaOH are given in Table 6.7. The relationship between these variables is also shown graphically in Figure 6.13. Although in the orthogonal comparison of the solubility data the F-value for both linear and quadratic comparisons was significant, the sum of squares for linear comparison was 1044.5 whereas this value for the quadratic comparisons was only 17.8. For this reason, it appears that the dependent variable (solubility) is linearly related to the independent variable (different concentrations of sodium hydroxide) as shown in Figure 6.13.

In general, total dry matter disappearance of the pods increased following treatment with all levels of sodium hydroxide (2, 4, 6 and 8%) but, as is evident from Figure 6.13, the incremental rate up to 4% alkali was much higher than the rates thereafter. The actual disappearance of the treated Paraggio pods was negatively correlated to the corresponding solubility. Similar trends in correlation between solubility and actual disappearance of the same pods resulted following treatment with $Ca(OH)_2$ by spraying (Table 6.10).

Table 6.11 sets out the mean values of total dry matter disappearance of pods either untreated or treated with NaOH. The expected means which were estimated through the regression equations were the same as the observed values. The results of Experiment 5, are summarised in Tables 6.11 and 6.12. Both solubility and dry matter disappearance of the Sava, Parabinga and Paraggio mature pods significantly ($P<0.01$) increased following treatment with 4% NaOH. While the dry matter disappearance of the untreated pods and pods treated with either NaOH (4%) or $Ca(OH)_2$ (9%) was in the order: Sava> Paraggio> Parabinga, the overall improvement of the above-mentioned pods following treatment with these alkalis was in this order Sava> Parabinga> Paraggio.

No great change in solubility and disappearance of the Sava, Parabinga and Paraggio pods occurred following spraying pods with tap water. The interactions Type of pods x Type of treatment for solubility and disappearance data were significant (Table 6.12).



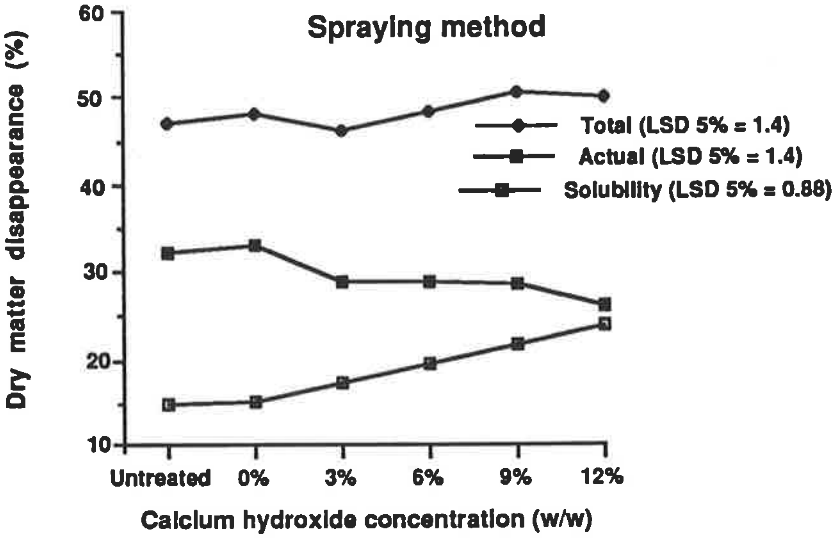


Figure 6.9 Dry matter disappearance of untreated Sava pods and Sava pods treated with calcium hydroxide by two methods (Experiments 6.4.1 and 6.4.2)

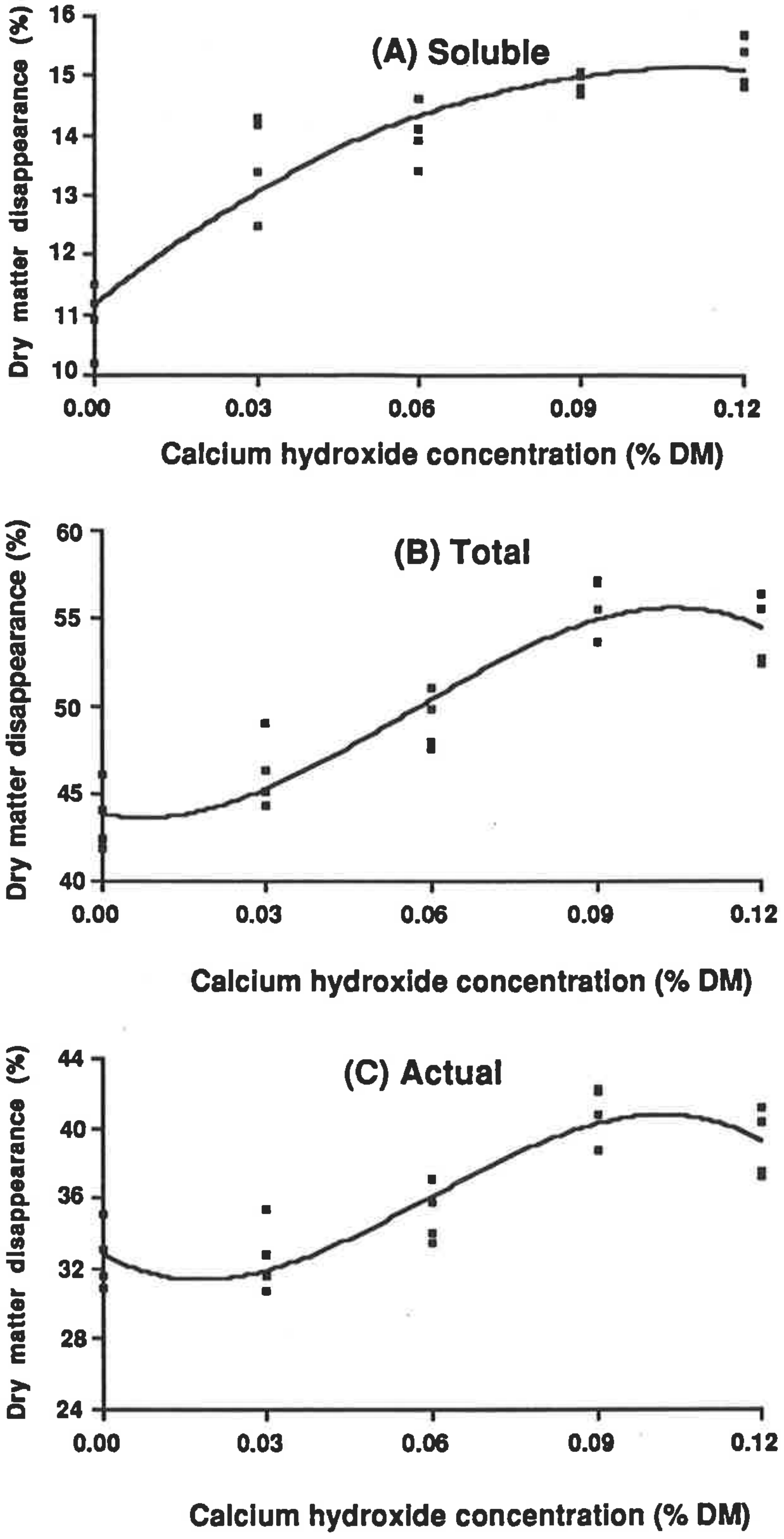


Figure 6.10 Regression (polynomial) of dry matter disappearance of Sava pods on calcium hydroxide concentrations applied by soaking (Experiment 6.4.1)

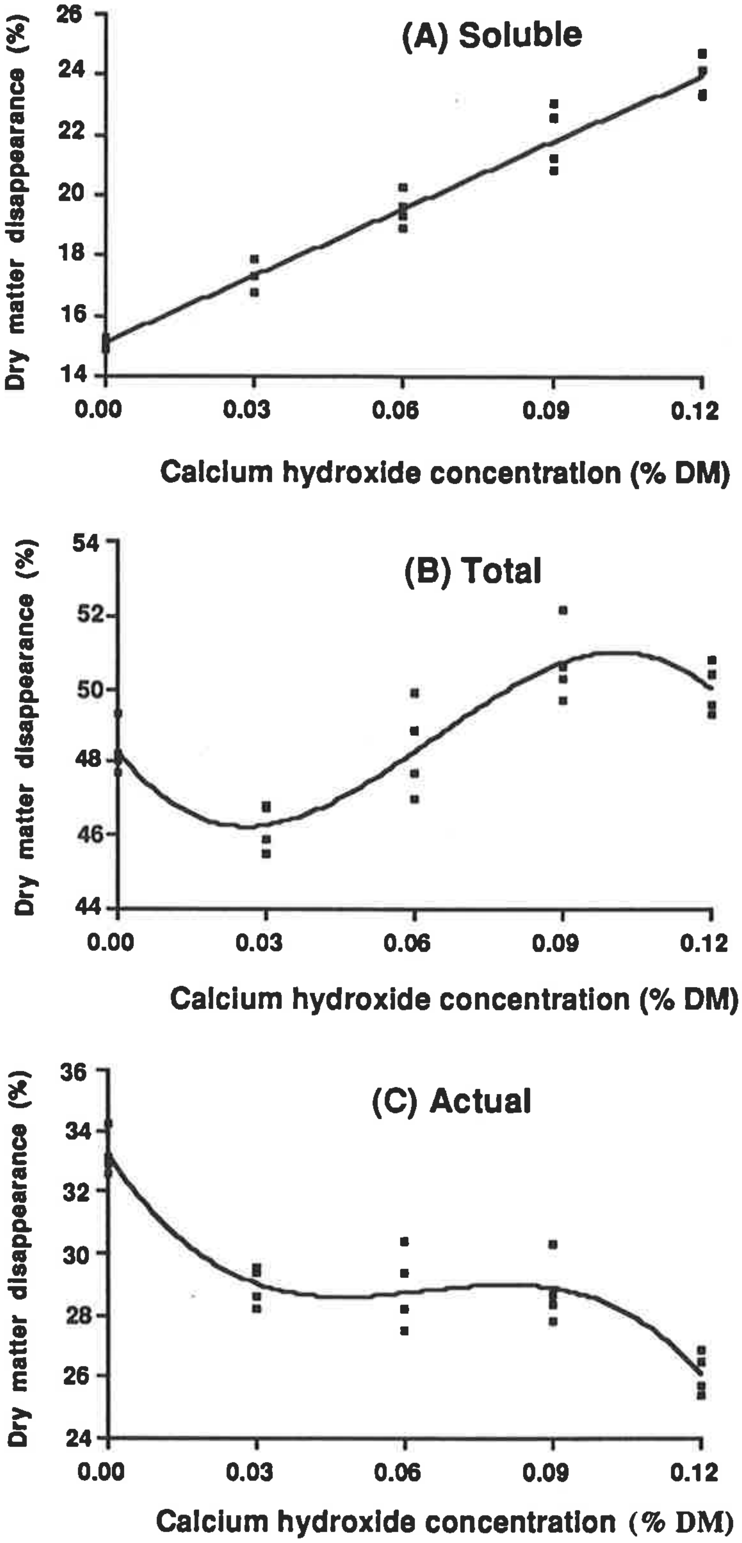


Figure 6.11 Regression (polynomial) of dry matter disappearance of Sava pods on calcium hydroxide concentrations applied by spraying (Experiment 6.4.2)

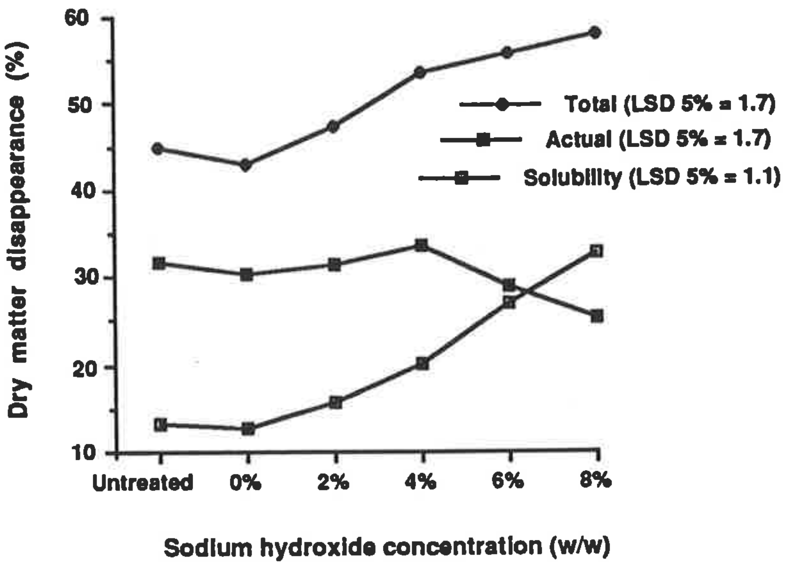


Figure 6.12 Dry matter disappearance of untreated Paraggio pods and Paraggio pods treated with sodium hydroxide by the spray method (Experiment 6.4.4)

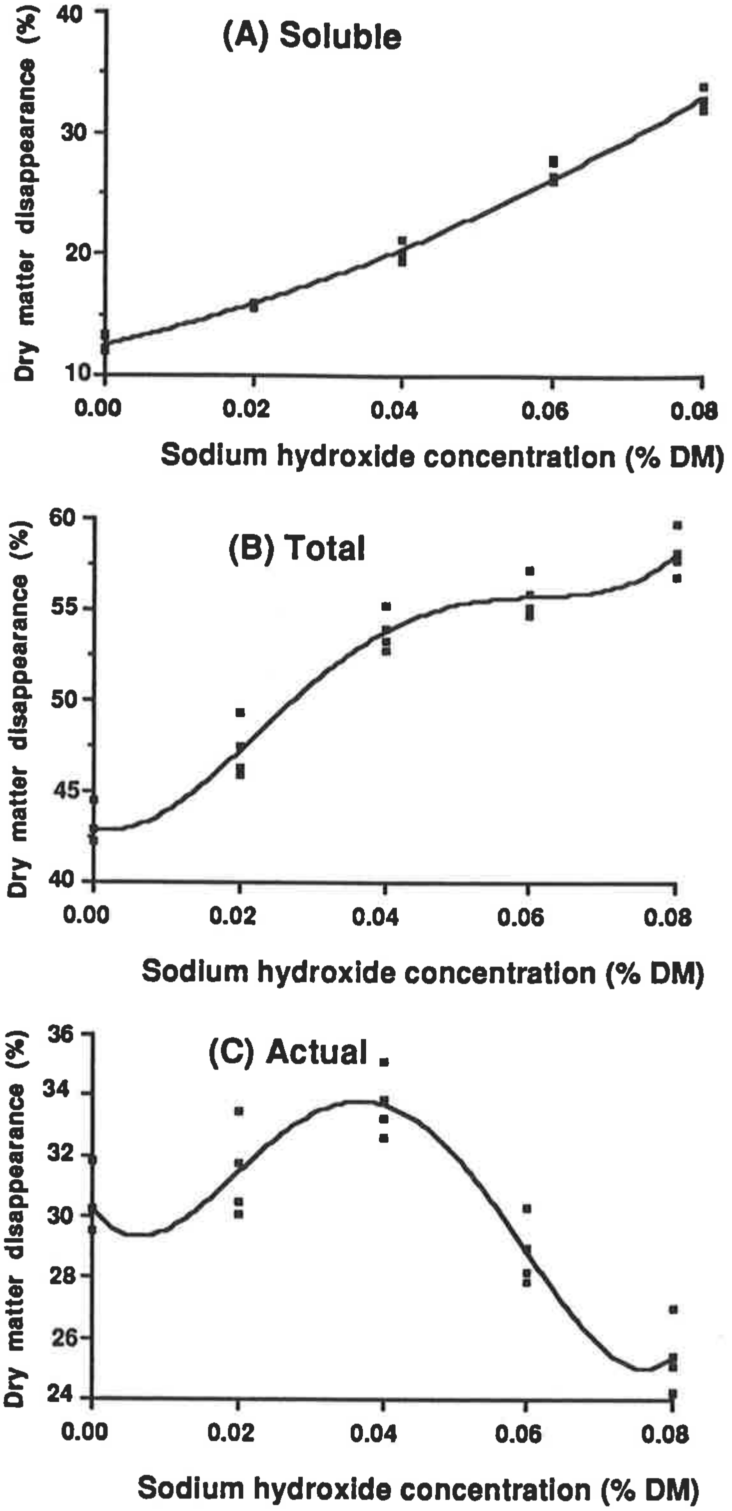


Figure 6.13 Regression (polynomial) of dry matter disappearance of Paraggio pods on sodium hydroxide concentrations applied by spraying (Experiment 6.4.4)

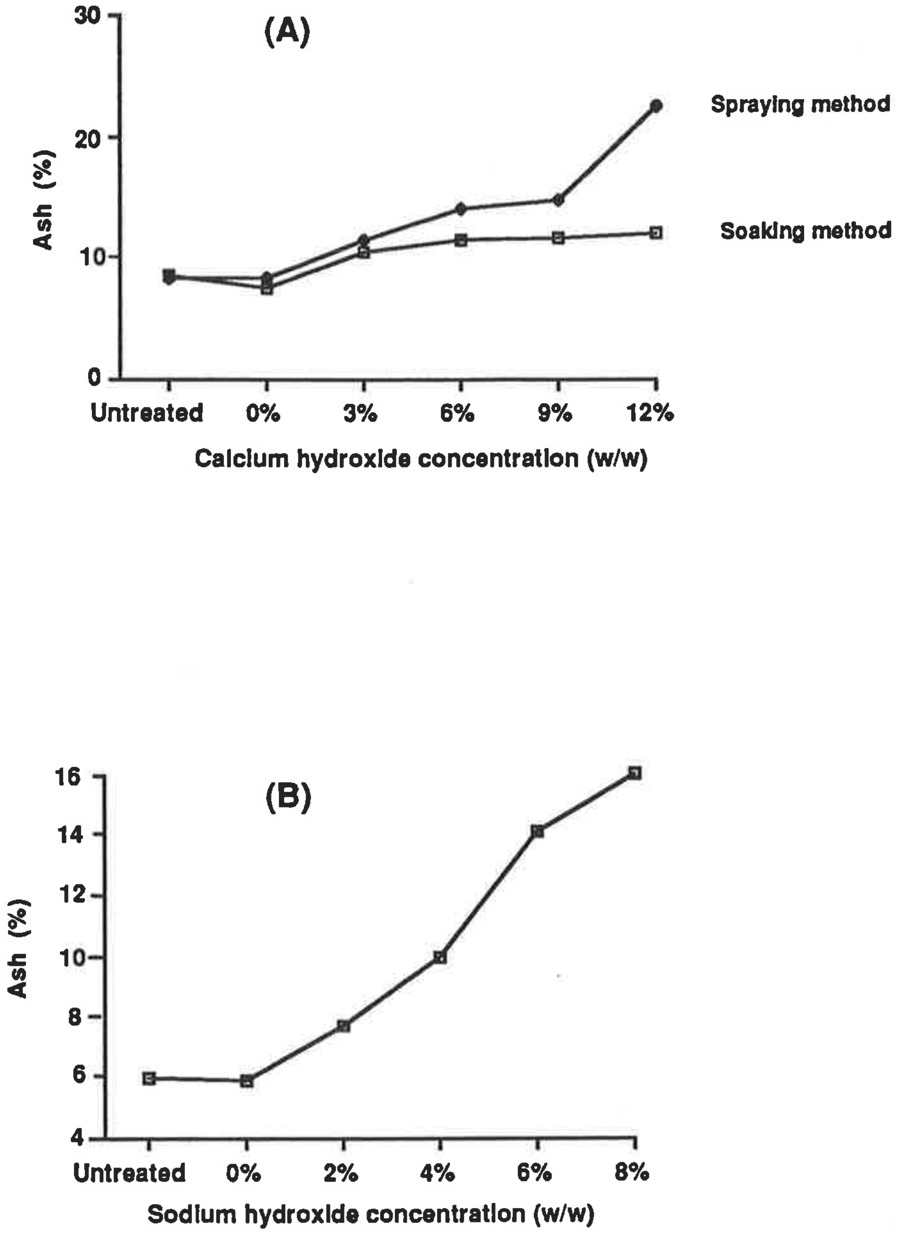


Figure 6.14 Ash content of treated and untreated medic pods with alkalis (A) Sava with calcium hydroxide, (B) Paraggio with sodium hydroxide (Experiment 6.4.4)

6.4.4 Discussion

There is very little information on the chemical treatment of legume residues to improve feeding value. Most published data refer to perennial forage legumes such as lucerne and grain legume residues such as soybean straw (Felix *et al.* 1990). No data were found in the literature concerning the impact of alkali on disappearance of annual medic residues such as mature pods, probably because on a world scale the mature medic pods have been quantitatively unimportant as a feed for ruminants compared with other fibrous feed resources such as cereal stubbles, straws or different types of hay. However, mature medic pods are important in southern Australia and other Mediterranean-type environments during the dry period of summer and autumn. Furthermore these medic pods can be upgraded to support levels of ruminant livestock production above maintenance.

In spite of poor solubility in calcium hydroxide, significant improvement in the disappearance of the mature medic pods was obtained in this study. The effects of this chemical by soaking were much better than by the spraying procedure, presumably because of its weak solubility in water. It has been reported that application of this alkali by soaking procedures has upgraded the *in vivo* digestibility of cereal straws (Lesoing *et al.* 1981; Djajanegara *et al.* 1985).

The total dry matter disappearance of Sava pods following treatment with calcium hydroxide applied by soaking reached a maximum of 55.9% after treatment with 9% $Ca(OH)_2$. Therefore an improvement of 10.6 percentage units was achieved compared to untreated pods. This difference between untreated and treated Sava pods with the same alkali but a different spraying procedure was less than 4.0 percentage units. Despite this big difference in total dry matter disappearance of the pods treated with $Ca(OH)_2$ by different procedures, an important difference also existed between levels of water solubility. The differences between water solubility of untreated pods and pods treated with 12% $Ca(OH)_2$ applied by soaking and spraying procedures (Figure 6.9) were 0.1 and 9.0 percentage units respectively. This big difference in solubility does not mean that the spraying procedure has been more effective in improving solubility of the pods: rather this difference is due to addition of the considerable amount of calcium by the spraying procedure. As evident from Figure 6.14, similar differences existed between ash contents of untreated pods and pods treated with $Ca(OH)_2$ applied by different methods. In this regard the effects of $Ca(OH)_2$ by the spraying method on dry matter disappearance of Sava pods have been minimal. However, many unavoidable errors are involved with measuring disappearance of feeds by incubation in rumen. For example, no doubt during the rumen incubation samples confined in nylon bags are extensively colonised by rumen microorganisms which all cannot be removed by washing the bags with water (Varvikko *et al.* 1983). In this situation the degraded materials will be regarded as undegraded samples and the final results are lower estimations of real disappearance. The presence of large amounts of calcium presumably can increase the effects of this type of error: however, in this study the significances of these kinds of errors on the results were not assessed.

The small effects of $Ca(OH)_2$ by the spraying procedure in this study could be related to the short time of treatment. The experiments carried out by Gharib *et al.* (1975) showed that ensiled poplar bark treated with $Ca(OH)_2$ for a longer period resulted in digestibility levels as high as those given by NaOH.

In contrast to the spraying procedure, application of $Ca(OH)_2$ by soaking even in a treatment of 24 h was highly effective. The positive effects of this alkali by the same procedure (soaking) on intake and digestibility of wheat straw has been reported by Djajanegara *et al.*(1985). The effects of Ca(OH)2 on disappearance of medic pods by the soaking procedure are considerable and comparable to the effects of sodium hydroxide. Although no data were found on this subject in the literature, data related to alkali treatment of crop residues suggest that, in general, alkali treatment of fibrous materials dissolves lignin, silica and hemicellulose and reduces the strength of the intermolecular bonds (Jakson 1977). Accessibility of cell wall polysaccharides for microbial enzyme attack in the rumen is the main reason for the increased digestibility of straw and other lignocellulosic materials (Anna Nikolic 1982). On the other hand, composition and characteristics of polysaccharides vary greatly among roughages and type of cell wall (Van Soest 1982). Therefore the composition and linkages between the structural carbohydrates and lignin of cell walls of mature medic pods may differ to some extent and because of this have shown good response to calcium hydroxide in this study.

In spite of some controversy in the available literature about the effectiveness of calcium hydroxide treatment, the positive effect of sodium hydroxide on digestibility of fibrous materials has been known for a long time. Treatment of medic pods with NaOH resulted in higher total dry matter disappearance and also extensive solubilisation in water. For example, the solubility of Paraggio pods treated with 8% NaOH was 2.5 times greater than that for untreated pods. Achievement of solubilisation of roughages with high content of crude fibre is the primary step in enhancing digestibility and feeding value for ruminants (McManus and Choung 1976).

Although no attempt was made in this study to determine the cell wall composition of the pods before and after treatment with alkalis, for the other fibrous feeds it has been reported that alkali treatment solubolises the lignin and its extent greatly differs between plant materials and species (Chesson 1988). It seems that response of mature medic pods to sodium hydroxide treatment in terms of solubolisation is higher than this response for cereal roughages, probably because the cell walls of the Gramineae and Leguminoseae roughages behave differently on alkali treatment (Hartley and Jones 1977). However, there is no information about the nature of the lignin-polysaccharide complex of mature pods of annual medics.

The actual dry matter disappearance of Sava pods treated with higher concentrations of NaOH, declined compared to untreated pods probably because of their higher water solubilisation. As described earlier, the actual figures for disappearance in these experiments were obtained by subtracting the solubility from total disappearance. The correlation coefficient between these variables (Table 6.10) was negative: therefore, in view of intensive solubilisation following NaOH-treatment, the actual disappearance must be reduced, but the final result will be more digestion and absorption of the treated pods. In terms of improving disappearance the best responses were obtained following treatment of medic pods with 4% NaOH and 9% $Ca(OH)_2$. Such results in *in vivo* studies for cereal straws have been reported in the literature (Klopfenstein 1978; Djajanegara *et al.* 1985).

The chemical treatments described in this chapter were carried out on whole, mature medic pods on a laboratory scale: it is likely that, application of these treatments for ground medic pods and *in vivo* trials lead to different results. Also, effectiveness of calcium hydroxide and sodium hydroxide on medic pods can be maximised by increasing the temperature or pressure i.e. during pellet-making processes.

The higher ash content of the alkali-treated mature medic pods in these studies are in agreement with the results of other workers (Greenhalgh 1980; Adebowale and Nakashima 1992) and Meeske *et al.* (1993) who reported that chemical treatment of wheat straw resulted in higher content of ash as compared to untreated straw.

The differences in response of the three lines of pods to alkalis could be related to the differences in physical structure and the formed linkages between the main components of their cell walls. Previously it was mentioned (Chapter 4) that there were no considerable differences in proximate chemical composition of the three lots of pods.

Although, great variation in the dry matter disappearance (digestibility) of different varieties and species of cereal straw have been reported by other workers (Kernan *et al.* 1984; Ramanzin *et al.* 1986), our understanding of the nature and form of cell walls of medic pods is very poor and more research is needed to give appropriate answers to the variation in feeding value.

7.0 LOT-FEEDING MERINO WETHERS FOR MAINTENANCE

7.1 Introduction

In Australia, sheep obtain most of their feed requirements from pasture (Cottle 1991). In the Mediterranean-type environment of southern Australia there is a marked seasonal fluctuation in the quantity and quality of feed available from the pasture (Allden 1959; Carter 1977; Puckridge and French 1983; Purser *et al.* 1987). The climatic pattern of winter rainfall and usual summer drought provides a wide range of feed resources for grazing animals, ranging from high quality herbage in the wet and rainy season to dry and low-quality mature pasture residues during the hot, dry period in summer and early autumn (Donald and Allden 1959; Purser 1980). Weather variation is a major problem for most of the world's farmers and it may seriously affect animal production systems in Australia because animals are kept at pasture throughout the year.

In areas of southern Australia with Mediterranean-type climate, pasture availability is often a major limitation to sheep production during late summer and early autumn (Doyle *et al.* 1989). A shortfall in feed supplies during drought periods is also a common feature of the Australian sheep industry (Cottle 1991). Continuous grazing, especially with high stocking rates, during this period makes paddocks bare, causing soil erosion and pasture deterioration mainly through the loss of annual legumes.

Carter (1981a) reported that pasture production and annual medic regeneration can be severely affected by heavy grazing during the dry period in summer and autumn. Carter (1981a) and de Koning and Carter (1989) observed that in annual medic and subterranean clover, pastures seed reserves were significantly depleted by excessive grazing of sheep on dry pasture residues. Carter (1981a) showed that Merino wethers consumed 1 tonne/ha of medic seed in 8 weeks while de Koning and Carter (1989) showed that 2/3 tonne of subterranean clover seed was eaten in 10 weeks.

Drought is part of the environment of South Australia (Jefferies and Nash 1989), therefore appropriate drought feeding and managements must be chosen by farmers, to cope with recurring droughts and reducing sheep damage to annual pasture seed reserves and soil.

Various management strategies such as culling can be adopted by farmers and sheep producers during droughts and summer feed shortages. An alternative strategy that has been proposed by research workers (Carter *et al.* 1993), livestock advisers and successfully used by some farmers (Morbey and Ashton 1990; Rodda 1992) is lot-feeding or hand feeding sheep in a confined area during these periods.

As mentioned in Chapter 2, lot-feeding can be practised with sheep of different physiological states, such as maintenance, pregnancy etc. At production levels there are economical considerations in applying this management strategy. However, lot-feeding at maintenance level or drought feeding of sheep during the dry months is often a last resort for farmers in southern Australia and conventional economics is generally replaced by considerations of least-cost.

Sheep lot-feeding for most farmers is new (Fels 1980) and its bases, such as suitable yard layouts and facilities, available feedstuffs, biological and behavioural factors, intensive feeding management and formulation of the appropriate low cost ration must be understood for this practice to be effective.

The following study was undertaken to provide much-needed information in two main areas of direct relevance to the Iranian sheep industry, viz, layout and management and nutritional management including the use of mature medic pods in rations.

The aims were: (i) to establish a simple, economical and applicable feedlot and (ii) to compare the effects of feeding cereal straw with legume straw and lucerne hay with medic pods.

7.2 Materials and methods

Feedlot location and design: The experiment was conducted at the Faculty of Agricultural and Natural Resource Sciences, Waite Campus, The University of Adelaide, South Australia, Lat 34° 58′ S., Long. 138° 38′ E. at an altitude of 122.5 m above sea-level. Four existing yards with firm ground, good drainage and suitable access to an animal holding and weighing shed were chosen. The selected site was free from dust and away from sources of frequent disturbance. The layout of the feed-lot is shown in Diagram 7.1. The yards allowed an average c. 3.5 m^2 per sheep.

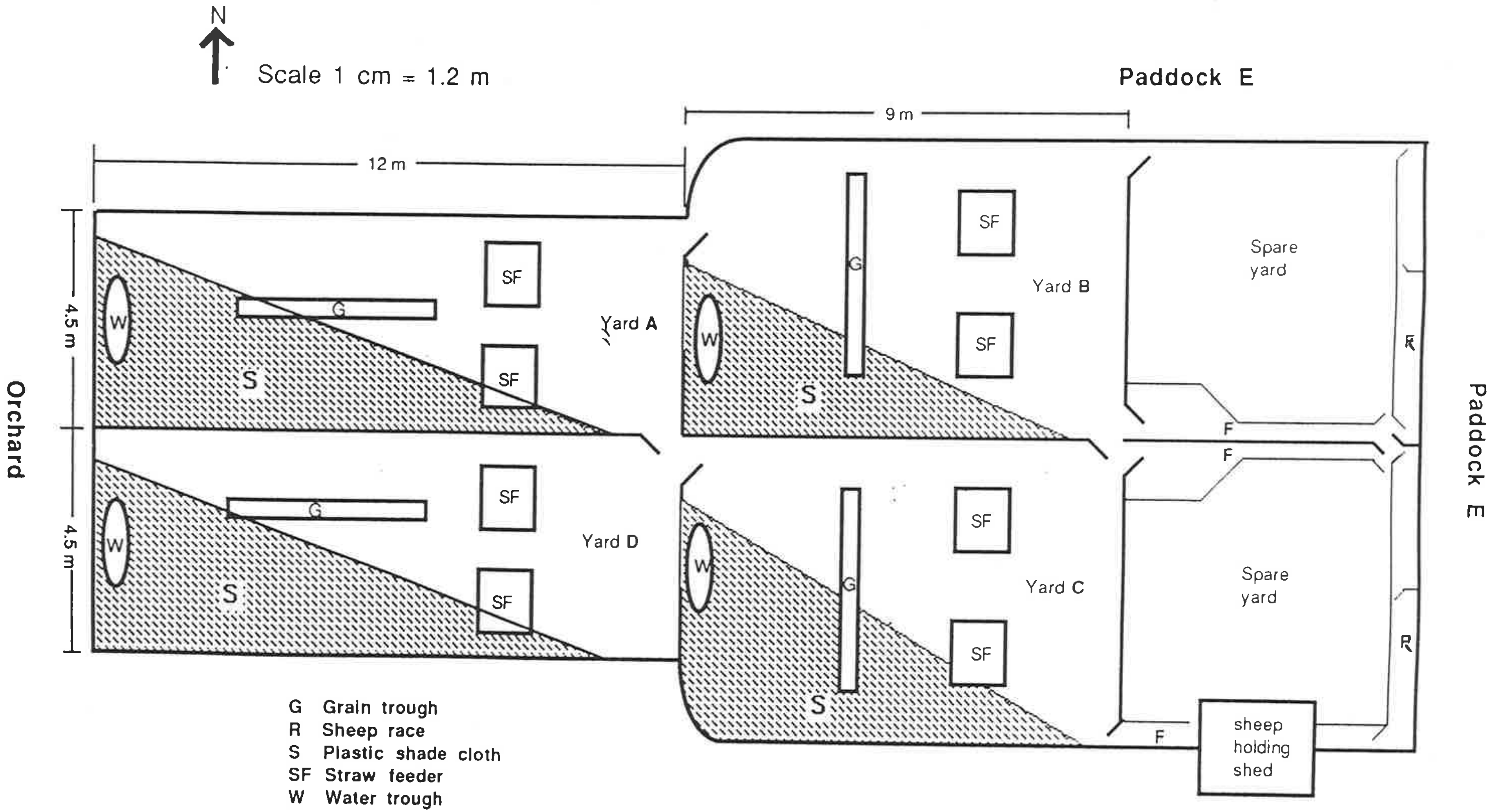


Diagram 7.1 Feedlot design for sheep

Lot-feeding of sheep started on 3 March 1992 and ended on 12 May 1992. The mean maximum and minimum daily temperatures and total rainfall during this period of 71 days were; 22.0°C, 14.6°C and 119.0 mm respectively. It should be noted that the 62 year mean maximum and minimum daily temperatures and total rainfall during March, April and May in this area are 21.6°C and 13.0°C and 159 mm respectively.

Animals: Sixty South Australian adult (about three years old) Merino wethers plus four spares averaging 63 kg body weight were selected from the Waite Institute wether flock. These were vaccinated against enterotoxaemia and drenched for internal parasites. Wethers were divided into four groups by stratified randomisation based on body weight.

Statistical design and dietary treatments: A completely randomised design (CRD) with four treatments and 15 sheep replicates was used. The dietary treatments were full rations made from the following feeds: barley grain (cv. Schooner), barley straw (cv. Galleon), mature medic pods (cv. Paraggio), pea straw (cv. Alma) and lucern hay (cv. Hunterfield). Treatments comprised:

(A) Barley grain + barley straw

(B) Barley grain + barley straw + mature medic pods

(C) Barley grain + pea straw+ mature medic pods

(D) Barley grain + barley straw + lucerne hay

Block licks of trace minerals and salt were freely provided for all groups. Barley grain as the main source of energy was selected because it is the grain most commonly fed to ruminants in South Australian feedlots (Bell *et al.* 1991a). Pea straw, a common legume straw in this state, was chosen to be compared with cereal barley straw.

Mature whole medic pods have a crude protein content around 20%, therefore supplementation of sheep rations containing mainly cereals with a small amount of these pods can provide additional nitrogen for the rumen microorganims. Lucerne hay was selected as a standard hay and for comparison with the other feed sources.

Ration formulation: Many methods have been introduced for ration formulation of farm animals (Crampton and Harris 1969). Linear programming techniques are the most accurate and there is world-wide used of programs for formulation of least-cost rations for both ruminant and non-ruminant animals (Shaw and Thornton 1974). Numerous publications are available on computer-based, least-cost ration formulation for farm animals (Hughes *et al.* 1983; Savvant *et al.* 1983).

The South Australian Department of Primary Industries has developed a computer program for formulation of least-cost rations for sheep and cattle. The program which is known as TAKE-AWAY calculates the least-cost rations by using the metabolizable energy (ME), rumen-degradable protein (RDP), undegraded protein (UDP) and several macro minerals such as calcium (Ca) and phosphorus (P). A complementary program (RUMNUT) provides data of the minimum daily nutrient requirements for both sheep and cattle based on the data of ruminant nutrition research provided by the United Kingdom Ministry of Agriculture, Fisheries and Food in 1980 and 1984. The energy system in this program has been adopted by the Australian Standing Committee on Agriculture (SCA 1990). TAKE-AWAY and RUMNUT programs have been employed to estimate the daily nutrient requirement of experimental sheep at the maintenance level (Table 7.1) and formulation of the least-cost rations for these animals.

Formulated rations, costs and nutrient contents are summarised in Tables 7.2, 7.3, and 7.4. In practice, it is impossible to compound rations (even with computer programs) meeting exactly the nutrient requirements of pre-defined classes of animals. Different individual performances between the animals, variation in nutrient contents of feedstuffs, feeding management and environmental factors such as heat or cold stress are the important factors that can affect the animal responses to the computer-based balanced rations. In this study the first set of rations which were balanced by the TAKE-AWAY program could not maintain the experimental sheep at the defined body weight. For this reason during the feeding period of 71 days another two sets of rations (# 2 and 3) were formulated in order to maintain sheep body weight (Table 7.2).

Table 7.1 Minimum daily nutrient requirements of South Australian adult Merino wethers at maintenance level (from RUMNUT computer program)

Body weight (kg)	Nutrient per animal				
	DMI (kg)	ME (MJ)	CP (g)	Ca (g)	P (g)
65	1.00	8.00	62.10	1.53	1.52

Table 7.2 Composition of rations used

Sheep groups	Feedstuff	Rations		
		1	2	3
		Composition (% DM basis)		
A	Barley grain	38	48	58
	Barley straw	62	52	42
B	Barley grain	30	40	50
	Barley straw	65	50	35
	Medic pods	5	10	15
C	Barley grain	30	40	50
	Pea straw	65	50	35
	Medic pods	5	10	15
D	Barley grain	30	40	50
	Barley straw	65	50	35
	Lucerne hay	5	10	15

Feeding technique: The total experimental period of 71 days was divided into five sub-periods of 12, 10, 14, 14 and 21 days respectively. During all of the periods sheep were given loose baled straw (barley and pea straws) *ad libitum* using modified wool packs supported by stable welded steel frames (Figure 7.1). Straw residues were collected periodically in order to calculate daily straw intake.

Sheep were gradually introduced to the barley grain to minimise the risk of grain poisoning. During the introductory period (first period) sheep were first given 50 g barley grain for two days and this was slowly increased up to the levels which were calculated by the TAKE-AWAY program. These levels were continued during the second period. The medic pods and chopped lucerne hay were fed with the barley grain. In the third period the grain, medic pods and lucerne hay were given every other day.

The initial rations did not maintain body weight. Therefore, the second set of rations including 10% extra barley grain, and 5% medic pods or lucerne hay were formulated and fed to the sheep under the same feeding management (every other day) in the fourth period. At the end of this period it was found that sheep had lost weight and had a lower fat score than at the beginning. Because of this the third set of rations was formulated by increasing barley grain by 10% and medic pods or lucerne hay by 5%. In the final period barley grain, medic pods and lucerne hay were given daily.

Measurements:

Sheep weighing: All sheep were weighed when they entered the feedlot and then weekly at the same time of day until the end of the experiment. They were also weighed after grazing green pasture for nine weeks following the feeding experiment.

Fat scoring technique: Every week (before weighing) the sheep, standing in a relaxed state, were fat scored by the following method (Jefferies 1961; Russle *et al.* 1969).

The total tissue depths of the three indicator areas on the sheep's body was felt by balls of thumbs and fingers.

> **Short ribs:** The areas between the end of short ribs and the start of the hind legs on both sides of the backbone.
>
> **Backbone:** The prominence of the backbone between and around the bones and the ends of short ribs and the start of the hind legs.
>
> **Tail bones:** Fat tissues around the backbone in the tail area.

The sheep were scored on a scale of 1 to 5 according to the categories outlined in Table 7.5.

Table 7.3 Nutrients supplied by different rations formulated by TAKE-AWAY program

Sheep groups	Ration No.	Daily intake (kg/d) as fed	ME (MJ/d)	CP (g/d)	Ca (g/d)	P (g/d)
A	1	1.1	8.7	65.2	2.5	1.9
	2	1.1	9.5	72.7	2.2	2.2
	3	1.1	10.3	80.3	2.0	2.5
B	1	1.1	8.1	68.2	2.6	1.7
	2	1.1	8.8	84.8	2.2	2.1
	3	1.1	9.6	101.4	1.8	2.5
C	1	1.1	8.5	81.7	6.7	1.7
	2	1.1	9.2	95.2	5.3	2.1
	3	1.1	9.8	108.6	4.0	2.5
D	1	1.1	8.2	65.7	3.0	1.7
	2	1.1	9.1	79.7	3.0	2.1
	3	1.1	10.0	93.8	3.3	2.5

Table 7.4 Daily feed costs (cents per sheep per day)

Sheep groups	Formulated by TAKE-AWAY program			Observed in practice		
	Rations			Rations		
	1	2	3	1	2	3
A	13.3	13.9	14.5	13.6	13.3	14.3
B	13.2	14.2	15.2	13.1	15.4	16.0
C	14.6	15.3	16.0	13.2	15.6	16.6
D	14.2	16.2	18.2	14.7	16.7	18.7

Wool growth measurement: An aqueous solution of 0.8% (w/v) Durafur Black R was prepared. Immediately prior to use 0.4 gram of Durafur Black R was dissolved in 50 ml of distilled water. Firstly, a paste of Durafur Black R and water was made and then during stirring the rest of the water was added. The solution was periodically stirred until the flakes of the chemical completely dissolved. Finally 0.4 ml of Hydrogen peroxide (30 percent (v/v) strength) was added.

Application of dye solution: Wool growth over the short periods of time can be estimated by dye-banding the wool staples at intervals of more than three weeks (Chapman and Wheeler 1963). Fleece dye-banding may be employed at regular intervals throughout the different seasons (Williams and Chapman 1966). The amount of wool production in the dye-band intervals is estimated by removing the dye-banded staples in conjunction with total fleece weights (Chapman and Wheeler 1963; Williams and Chapman 1966; Langlands and Wheeler 1968).

The mid-right side of the sheep was chosen to dye-band. The fleece was gently parted and along a line of approximately 10 cm at the skin level adequate dye solution was applied to moisten the emergent part of the fibres by a fibre-glazed pasteur pipette. The excess solution of Durafur Black R on the skin surface was removed with the pipette and discarded (Chapman and Wheeler 1963; Williams and Chapman 1966).

The surface of the wool at the dye-band site, was marked by a weather-resistant stock marker spray. Dye solution was applied at the beginning and the end of lot-feeding.

Dye-banded wool removal: The mid-side dye-banded part of the fleece was cut close to the skin immediately before shearing. Weight of all greasy wool including the dye-banded samples was recorded at shearing time. In the laboratory two staples were taken from the dye-banded samples and accurately weighed. One end of the staples was attached by a spring-clip, dipped and fully-immersed into degreasing solvent (Shell X 55) at least 10 times. A second clip was attached to the other end of the staples and, after removing the first clip, dipped and immersed in the solvent another 10 times. This process was repeated in a second container (beaker) of clean solvent.

Table 7.5 Description of fat-scoring

Score No.	Tissue depth (mm)	Indicator points **Short ribs**	 **Backbone**	 **Tail**
1 (Very lean)	0-5	Short ribs have square ends. Space between them can be easily felt.	Bones are prominent and sharp. Fingers can easily feel between them.	Bones are sharp with little or no fat over.
2 (Lean)	6-10	Short ribs have rounded ends. Space between them can be felt with a little pressure.	Bones are raised with smooth and rounded ends. Space between them can be felt with a little pressure.	Bones are only just covered. Edges are rounded.
3 (Medium)	11-15	Short ribs have well-rounded ends. It is not possible to press between them.	Bones are raised a little. Still able to feel but not possible to press between them.	Detectable bones are well covered.
4 (Fat)	16-20	The ends of only one or two bones nearest to the rib cage may be felt	The ends of some bones may still be felt. Skin begins to float as on fluid.	It is difficult to feel any bone.
5 (Very fat)	21-25	Bones cannot be felt.	Backbone recessed in fat is difficult to feel.	It is impossible to feel any bone.

The visible vegetable matter was removed by forceps from the degreased staples. These staples were left under a fume hood for a few hours then accurately weighed after the solvent evaporated. Total clean wool percentage was calculated using the following equations:

$$\text{Clean wool (\%)} = \frac{\text{Staple weight after degreasing}}{\text{Staple weight before degreasing}} \times 100$$

$$\text{Total clean wool production} = \text{weight of all wool} \times \text{\% clean wool}$$

Staples were cut along the bottom of the dye-bands with sharp scissors. These sections were accurately weighed. By using the following equations, wool growth per day for each sheep was obtained:

Amount of clean wool growing during the period between two successive dye-bands = Weight of the staple between two dye-bands/Total weight of the clean staple x Total clean wool

Amount of wool growth per day = Clean wool production during the period/No. of days between two successive dye-bands

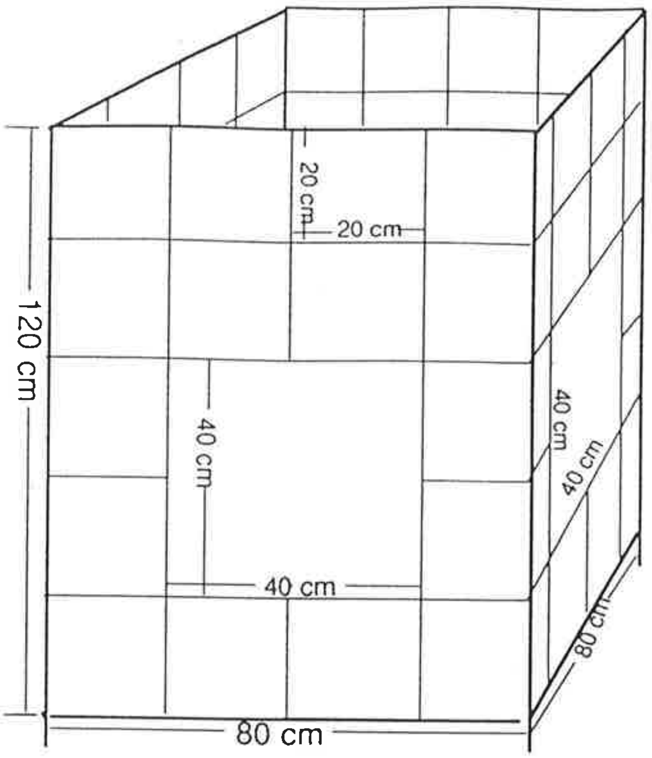
Feed measurement and sampling: All feeds including straws, barley grain, medic pods and lucerne hay were weighed prior to feeding. Straws were offered *ad libitum* and other feeds were given at 0900 hr. Feed residues were collected and weighed for estimation of daily dry matter intake.

Feeds were sampled twice weekly throughout the experiment in order to determine chemical composition and *in vitro* digestibility. The methods used for chemical analyses and *in vitro* digestibility have been described in previous chapters.

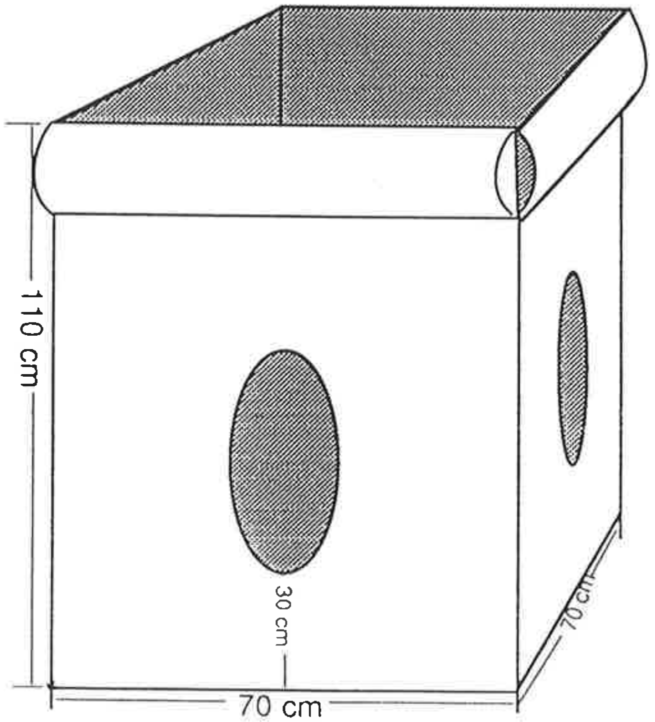
Feedlot facilities

Straw feeders: In order to minimise the fouling and wastage of straw by sheep, wind or rain, straw feeders were made from polypropylene wool packs suspended inside a square frame made of 20 cm x 20 cm concrete reinforcing mesh. Four holes (40 cm x 40 cm) were made in the sides of steel frames with the bottom of the hole 50 cm above the ground (Figure 7.1). Wool packs were stitched firmly to the frames around the hole and the wool pack slit to allow sheep to feed on the straws. The top of the straw feeders was covered by folding the flaps of the wool packs over it (Plate 7.1). Two of these frames were provided for each group of sheep.

Grain troughs: Galvanised grain troughs were used for each group of sheep (Figure 7.2). Sheep had access to both sides of these troughs (Plate 7.2). The troughs were anchored to the ground by tent pegs.



(a)



(b)

Figure 7.1 Straw feeder frame (a) and fitted sack (wool pack) (b)

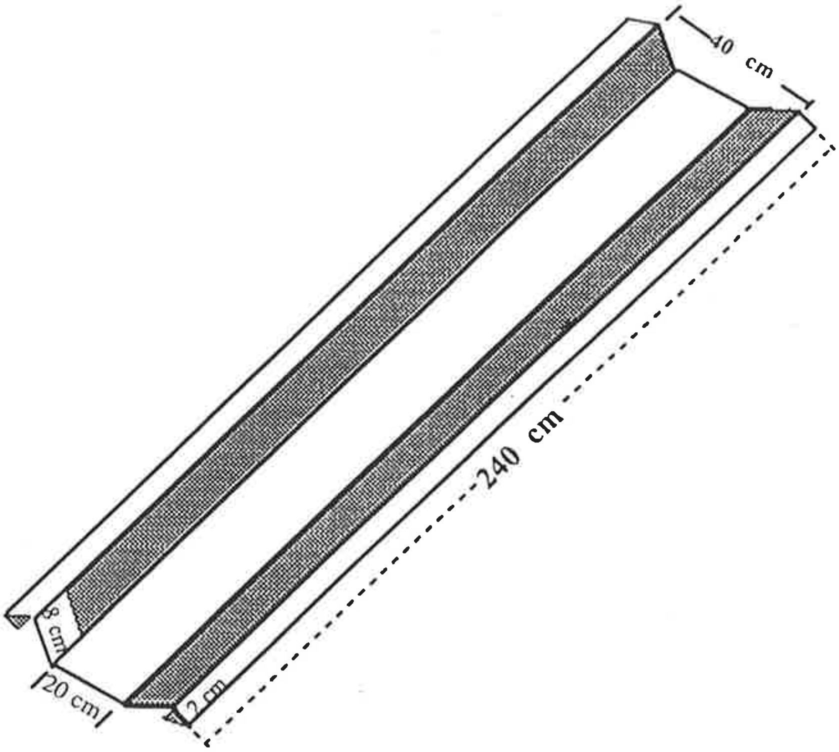


Figure 7.2 Grain trough and its dimensions

Plate 7.1 General views of straw feeders used in the feedlot experiment.

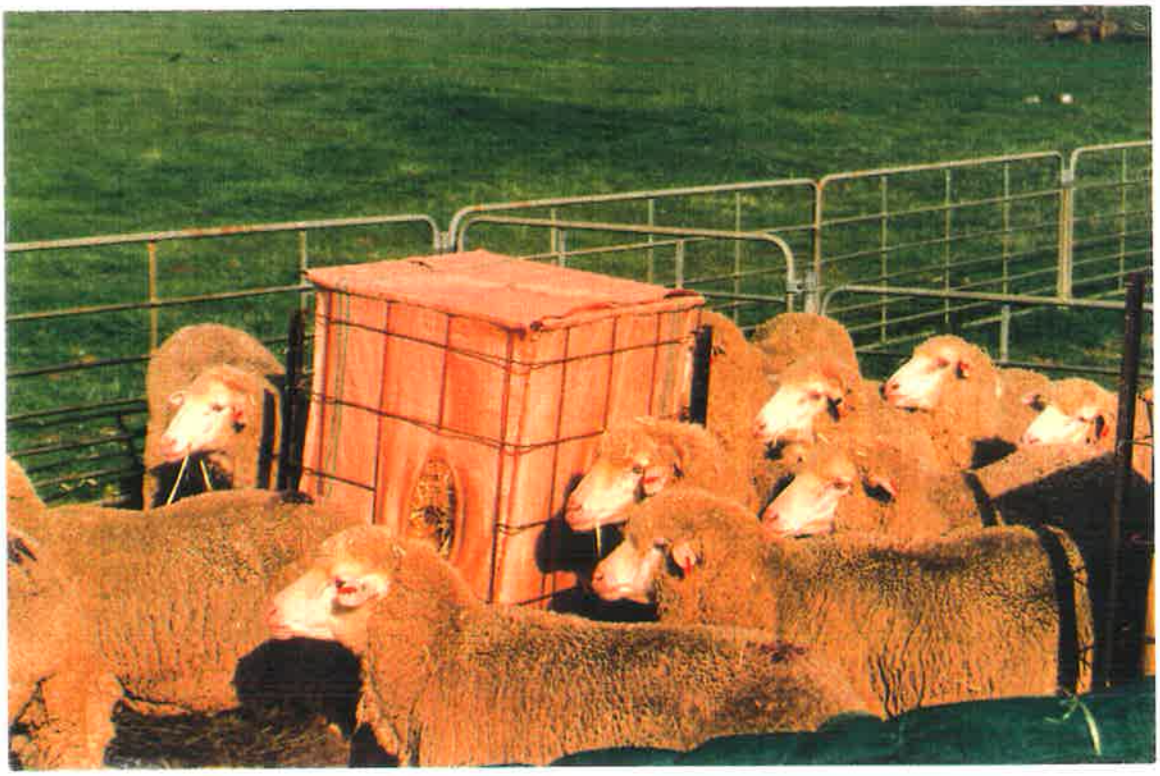


Plate 7.2 General view of the feedlot (upper), grain trough and shade (lower).

Water troughs: Fresh and clean water was provided through galvanised troughs. These were installed about 50 cm above ground level and close to the fences to avoid contamination of water with faeces.

Shade: Shade cloth (1 m^2/sheep) which reduced incident radiation by 60% was provided in each yard.

Daily management: Feedlot conditions were checked daily. Troughs including feed troughs and water troughs were cleaned on a regular basis. Sheep health and behaviour were observed daily to detect and solve any problem promptly.

Release of sheep: At the end of the feedlot experiment (71 days) sheep were weighed and dye-banded. They were fed mainly with roughage for a few days and released from the feedlot to graze green pasture for 63 days then re-weighed.

7.3 Results

Dry matter intake: Data on dry matter intake of the whole rations and individual feedstuffs are given in Tables, 7.6 and 7.7 also Appendix 7.1. These data are also presented graphically for each treatment throughout the experimental period in Figures 7.3, 7.4, 7.5 and 7.6. Total dry matter intake during Week 1 of the experiment for all of the groups was lower than the dry matter intake observed during the subsequent weeks. This is because during the first two weeks of the experiment the sheep were gradually introduced to barley grain. During this time sheep were also adapting to the feedlot conditions. Total dry matter intake of all treatments increased in Week 2 as the animals adapted to the grain and feedlot conditions and it was nearly constant throughout the following weeks (Figure 7.3). The mean dry matter intake of groups did not significantly differ in this experiment. Average dry matter intake as the percentage of body weight was 1.9, 1.9, 1.8 and 1.8 percent for treatment A, B, C and D respectively. The overall daily dry matter intakes were 1.1, 1.1, 1.0 and 1.1 kg/sheep/d for the respective treatments, A, B, C and D. These intakes also are similar to the values predicted by RUMNUT computer program (Table 7.1) of South Australian Department of Primary Industries.

Despite the constant total dry matter intake of all the treatments throughout the feedlotting period, voluntary intake of both barley straw and pea straw decreased markedly with advancing time in the feedlot. For example, in treatment D voluntary intake of barley straw reduced from 36/kgW$^{0.75}$/d in the first two weeks of doing lot-feeding to 20 g/kgW$^{0.75}$/d in the last two weeks of the experiment (Table 7.6), a reduction equal to 44%. Similar patterns were observed for the other treatments.

Generally, voluntary intake of pea straw was lower than barley straw (Table 7.6), but there was no significant difference between weekly intakes of these two types of straw. The voluntary intake of these straws declined following the introductory period probably due to increasing amount of readily-available energy source (barley grain). For example, the average voluntary intake of barley straw for groups A, B and D and pea straw for group C based on metabolic body weight was 28, 29, 28 and 25g/kg W$^{0.75}$/d respectively.

As mentioned in the Materials and methods section, in order to maintain sheep body weight and condition the rations were re-formulated three times using the TAKE-AWAY program. The predicted daily intakes of both barley and pea straws by this computer program are given in conjunction with the observed intake values Figure 7.7 and Table 7.8. There was a significant correlation between the predicted and observed intake values for the straws ($r = 0.91^{**}$). These significant correlations show the accuracy and validity of both TAKE-AWAY and RUMNUT programs.

Figure 7.6 shows that barley grain consumption was the same for treatments B, C and D but higher for treatment A. This is because one of the main objects of ration formulation was to create rations balanced for both energy and protein as well as macro minerals such as calcium and phosphorus. In treatment A with only two ingredients (poor and moderate in protein content) it was not possible to use the same amount of barley grain as for the other treatments.

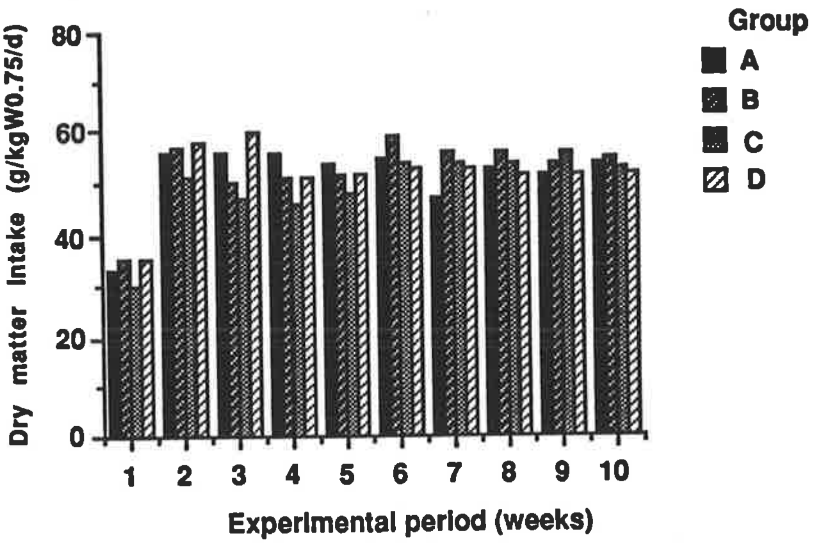


Figure 7.3 Average daily dry matter intake of whole rations by sheep

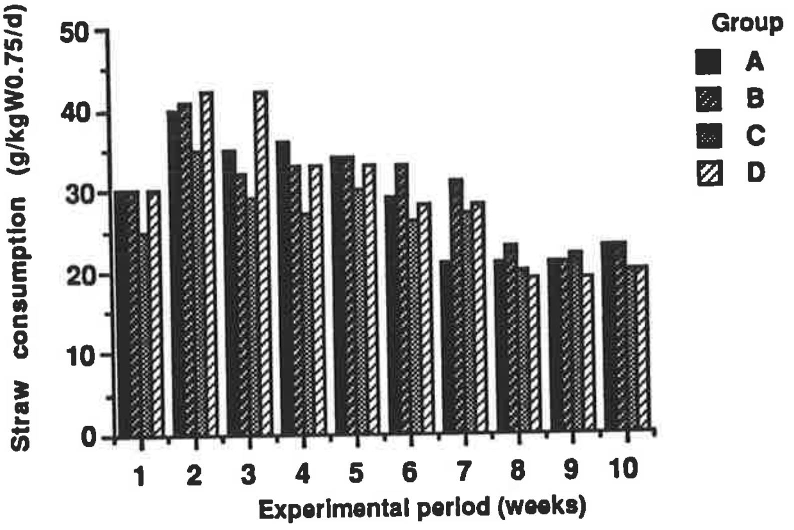


Figure 7.4 Voluntary straw consumption by sheep in feedlot

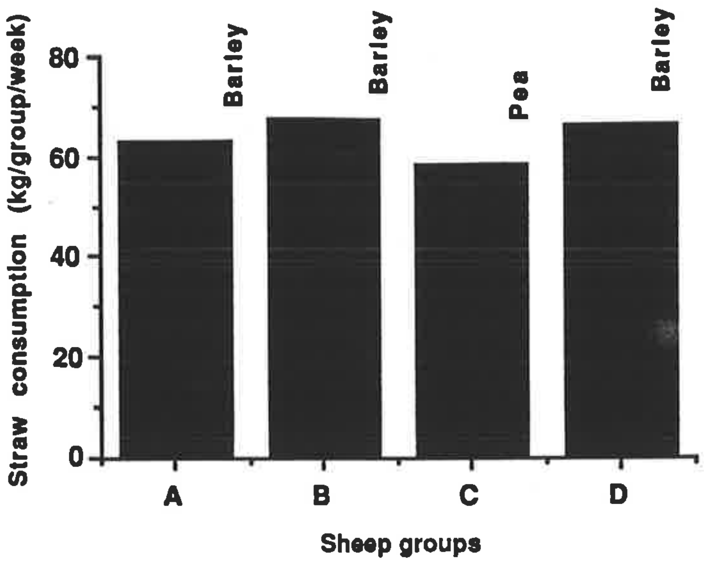


Figure 7.5 Average weekly straw consumption by the individual groups of sheep

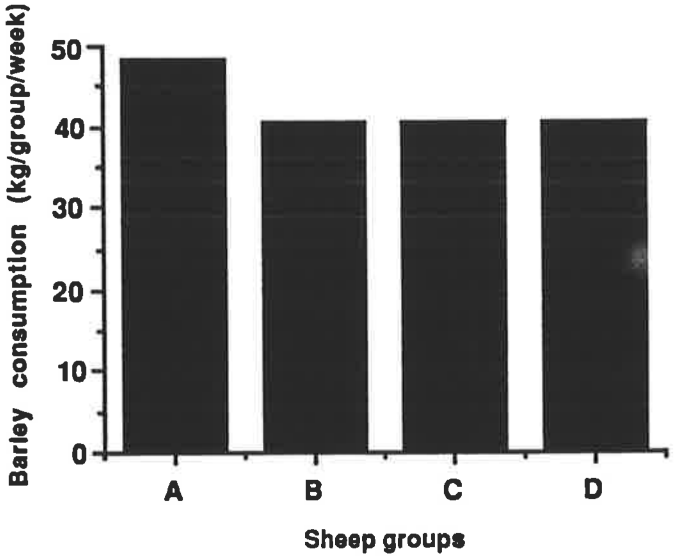


Figure 7.6 Average weekly barley grain consumption by the individual groups of sheep

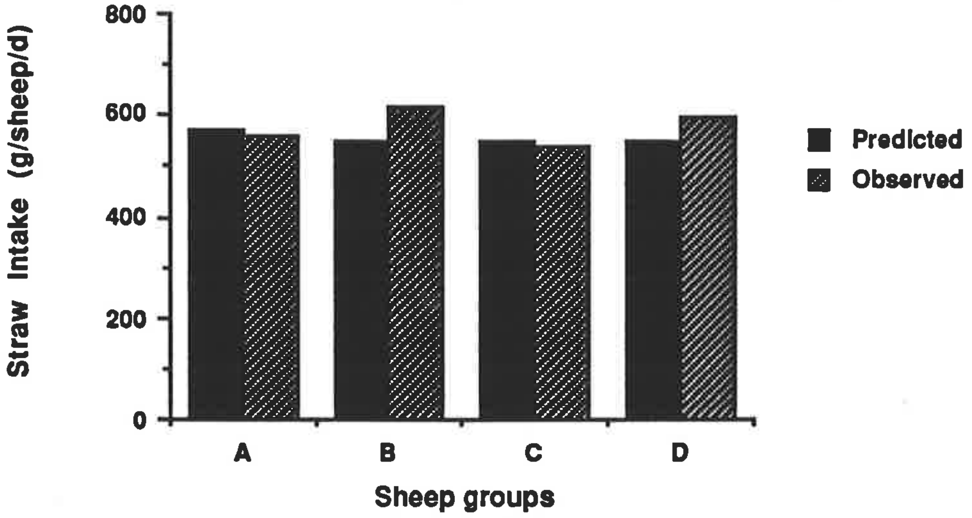


Figure 7.7 Average voluntary intake of straws during the experiment against the predicted values (from TAKE-AWAY program)

Table 7.6 Average daily dry matter intake and voluntary straw consumption of sheep

Experimental period (weeks)	Voluntary intake (g/kg $W^{0.75}$/d)							
	Dry matter				Straw			
	A	B	C	D	A‡	B‡	C†	D‡
1	33	35	30	35	30	30	25	30
2	56	57	51	58	40	41	35	42
3	56	50	47	60	35	32	29	42
4	56	51	46	51	36	33	27	33
5	54	52	48	52	34	34	30	33
6	55	59	54	53	29	33	26	28
7	47	56	54	53	21	31	27	28
8	53	56	54	52	21	23	20	19
9	52	54	56	52	21	21	22	19
10	54	55	53	52	23	23	20	20
Mean	53 ± 2	53 ± 2	49 ± 2	52 ± 2	29 ± 2	30 ± 2	26 ± 1	29 ± 3

‡ = Barley straw; † = Pea straw

Table 7.7 Average intake (kg/sheep/week) of different ration ingredients over the whole experiment (Data show means ± SE on air-dry basis)

Sheep group	Ration ingredients					
	Barley grain	Barley straw	Lucerne hay	Medic pods	Pea straw	Whole ration
A	3.25 ± 0.39	4.21 ± 0.05	_	_	_	7.44 ± 0.04
B	2.71 ± 0.34	4.47 ± 0.04	_	0.69 ± 0.11	_	7.87 ± 0.05
C	2.71 ± 0.34	_	_	0.69 ± 0.11	3.87 ± 0.03	7.27 ± 0.05
D	2.71 ± 0.34	4.41 ± 0.05	0.69 ± 0.11	_	_	7.81 ± 0.04

Table 7.8 **Daily amount of straw predicted by TAKE-AWAY program and actually consumed by the experimental sheep (g/d)**

Sheep groups	Ration No.	Straw utilisation	
		Predicted	Observed
A	1	682	721
	2	572	514
	3	462	441
B	1	715	703
	2	550	675
	3	385	473
C	1	715	601
	2	550	580
	3	385	435
D	1	715	766
	2	550	594
	3	385	431

Body weight change: The weekly mean body weight of sheep during the experiment is summarised in Figures 7.8 and 7.9. In all treatments sheep rapidly lost body weight during the first two weeks of the experiment, because adaptation to the feedlot system takes time. Also during this period sheep were introduced to the barley gradually, therefore the energy concentrations (MJ/kg DM) in the daily rations during early weeks were significantly lower than in following weeks: however, the differences in body weight of the four groups of sheep were not significant during the early weeks (Appendix 7.2).

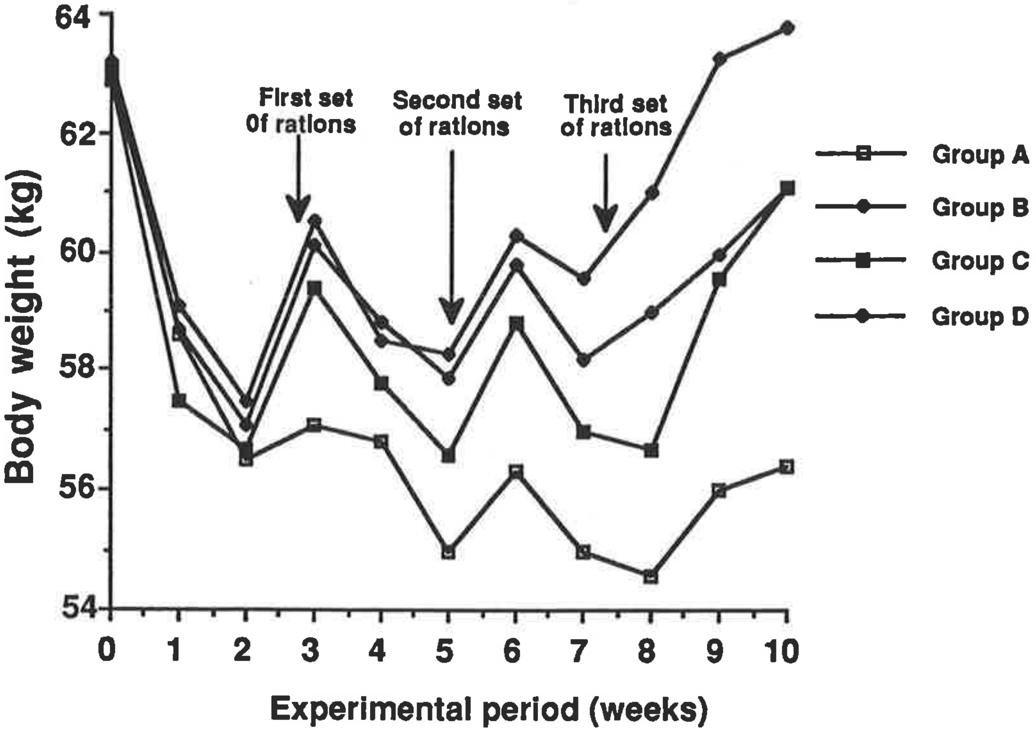


Figure 7.8 Mean body weight of the four groups of sheep

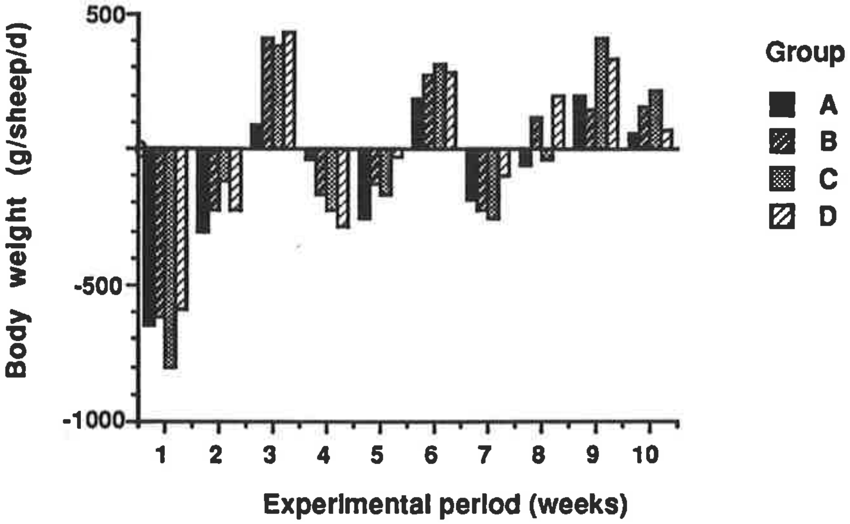


Figure 7.9 Body weight changes of the four groups of sheep

All sheep increased in weight in Week 3 in comparison with Week 2, but at different rates. Mean group body weight in treatments B, C and D were close together but significantly (P<0.05) higher than treatment A (fed only with barley straw and barley grain).

Although the differences between body weights during the following weeks became highly significant (P<0.01), the major difference was between treatment A (barley straw and barley grain) and the other treatments (barley straw or pea straw, barley grain plus a source of CP). The highest mean body weight occurred in treatment D (barley straw, barley grain and lucerne hay) and the lowest in treatment A (barley straw and barley grain).

Throughout the whole experiment individual mean body weight changes were: -6.72, -1.89, -2.03 and +0.63 for treatments A, B, C and D respectively, although short-term body weight changes were considerably greater than these values (Figures 7.8 and 7.9).

The sheep were weighed nine weeks after releasing them on green pasture. It was suggested that the pasture availability (feed on offer) could compensate the body weight losses and maintain sheep in acceptable condition: therefore, no supplementary feed was given in the paddock after releasing the experimental sheep. All the sheep recovered their lost weight and were heavier than their initial weight at the beginning of feeding (Appendix 7.2). In fact, the sheep from treatment A (only barley straw and barley grain) showed "compensatory growth" and weighed the same as those in other treatments.

Fat score: The mean weekly fat scores of experimental sheep are shown in Figure 7.10. It is clear from the data presented in these figures and Appendix 7.3 that there was no significant difference between mean group score values obtained in weeks 1, 2, 3 and 4. During the following weeks significant differences (P<0.01) between fat score data resulting from different experimental rations were detected. The general trend of mean fat scores for groups of sheep was similar to body weight changes (Figures 7.8 and 7.9). The fat score of the sheep given dietary treatment A (barley straw and barley grain) was significantly lower than that of the other treatments. It is also apparent from an analysis of the data that there were no differences between the fat score means of treatments B, C and D (Appendix 7.3).

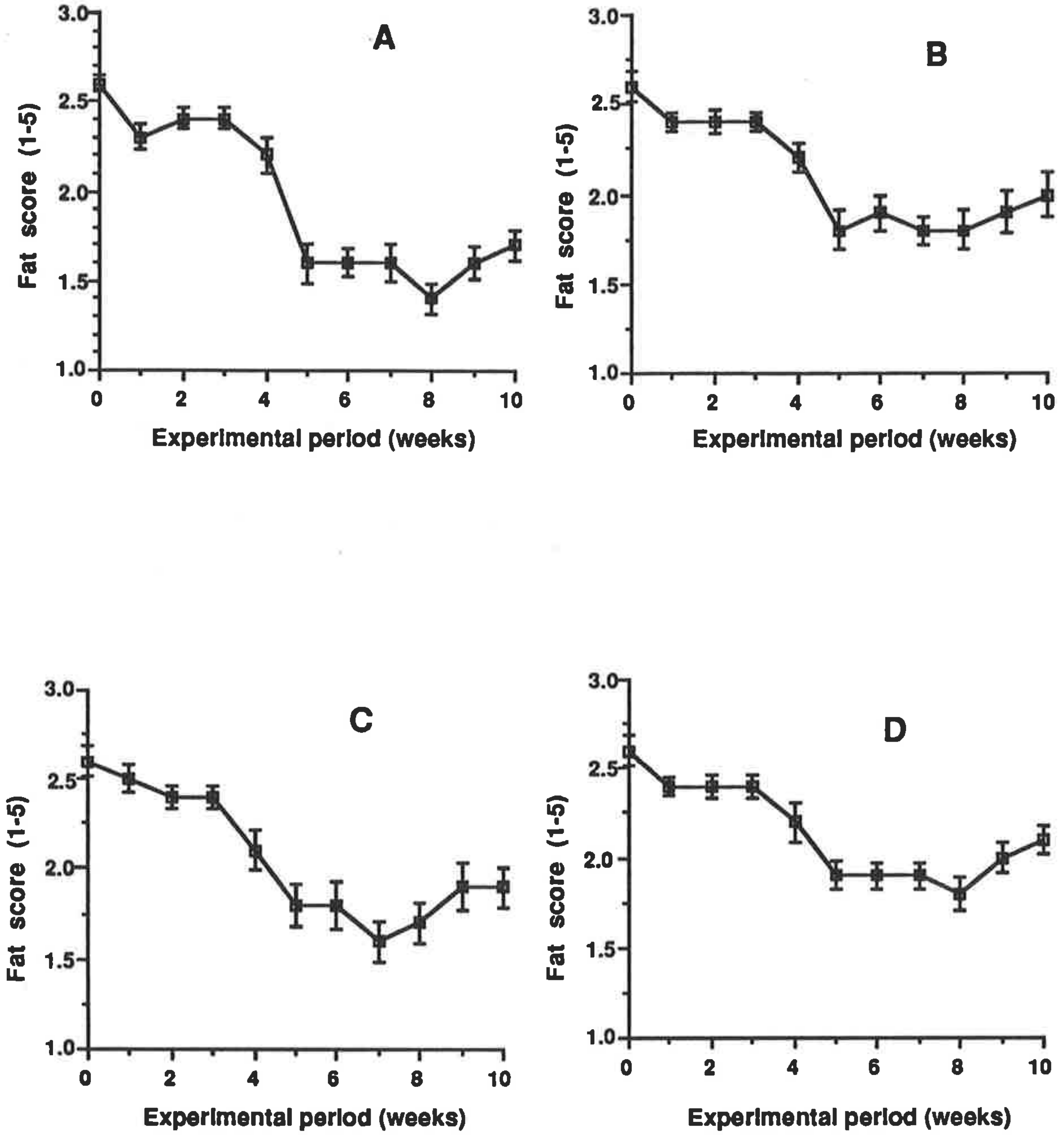


Figure 7.10 Mean fat score of the four groups of sheep

A decline in fat scores occurred despite an increase of more than 20% in the barley grain content of the ration over the minimum recommended level for maintenance. However, this trend in fat score did not affect the recovering ability of the feedlot sheep when on the pasture. All groups of sheep including those sheep that were given only barley straw and barley grain in the feedlot recovered their condition on green pasture (Appendix 7.3).

Wool growth: There were no significant differences between the feeding treatments in any wool measurements (Table 7.9). The average wool growth for all groups of sheep was approximately six grams clean wool per head per day. Apparently, body weight changes and the dietary regimes did not significantly affect the wool growth of the four groups of sheep in this experiment. However, it should be mentioned that in spite of the lack of treatment effects on wool growth, there was considerable variation between individual sheep from as low as 4.1 g/d per day to as high as 9.1 g/d of clean wool.

Table 7.9 Wool growth measurements

Component	Sheep groups				Significance
	A	B	C	D	level
Greasy wool (kg/sheep/10 months)	4.7 ± 0.2	4.6 ± 0.1	4.9 ± 0.2	4.7 ± 0.1	NS
Clean wool (%)	75.4 ± 1.2	74.2 ± 1.3	73.9 ± 1.1	78.1 ± 1.3	NA
Clean wool (kg/sheep/10 months)	3.5 ± 01	3.4 ± 01	3.7 ± 01	3.7 ± 0.1	NS
Clean wool (g/sheep/d)	6.0 ± 0.2	5.9 ± 0.3	6.8 ± 0.4	6.6 ± 0.3	NS

NS = Not significant; NA = Not measured

Chemical composition and digestibility: The chemical composition and *in vitro* digestibility of the feedstuffs which were fed to sheep in this experiment are given in Table 7.10. Barley straw and pea straw had similar contents of crude fibre but crude protein content of pea straw was about double that of barley straw (5.7% v 3.2%).

With medic pods three main nutrients should be considered i.e. crude protein, crude fibre and ether extract (fat). The crude protein content of medic pods was about 21% which compares favourably with excellent lucerne hay and grain legumes such as peas. As was discussed in an earlier chapter the high crude fibre content (equal to straw) has limited the nutritive value of medic pods, although their crude protein and lipid contents can be digested at higher levels (Chapter 4).

Both dry matter and organic matter digestibilities of barley straw and pea straw were similar but lower than corresponding values for lucerne hay. Digestibility of medic pods was even lower than the straws, probably due to high content of indigestible fibre.

The metabolizable energy content (ME/kg DM) of animal feedstuffs can be predicted with some equations in relation to dry matter and organic matter digestibility. SCA (1990) has employed the following equations:

$$\text{ME/kg DM} = 0.17\ \text{DMD\%} - 2.0$$

$$\text{ME/kg DM} = 0.16\ \text{OMD\%} - 1.8$$

(DMD = Dry matter digestibility; OMD = Organic matter digestibility)

The approximate metabolizable energy (MJ/kg DM) contents of the feeds used here and derived from the above equations were 13.0, 5.8, 6.9, 4.4 and 5.7 for barley grain, barley straw, lucerne hay, medic pods and pea straw respectively. The values are slightly higher than the values which were used by the TAKE-AWAY computer program used to formulate the rations.

Health conditions: There were no sheep deaths during the experiment. Only one sheep was affected by Pinkeye (likely caused by sharp ends of the straw particles, dust and flies) during the first week. This sheep was treated with an antibiotic eye ointment for a few days and recovered.

No shy feeders were detected among the sheep, probably due to provision of enough troughs and feeders and applying appropriate sheep management.

Table 7.10 Chemical composition and *in vitro* digestibility of different feeds in feedlot rations (DM basis)

Component	Barley grain	Barley straw	Lucerne hay	Medic pods	Pea straw
Chemical composition					
Dry matter	89.0	88.0	87.0	89.0	86.0
Organic matter	97.2	91.1	91.7	94.5	93.7
Crude protein	9.8	3.2	18.8	21.1	5.7
Crude fibre	5.0	36.8	34.4	35.6	39.6
Ether extract	2.3	0.8	1.6	4.3	0.7
Nitrogen-free extract	80.1	50.3	36.9	33.5	47.7
***In vitro* digestibility**					
Dry matter	88.0	45.9	52.6	37.5	45.2
Organic matter	88.7	47.5	54.7	40.1	46.4

7.4 Discussion

The major expense in lot-feeding and any other intensive animal production system is the cost of the feed required to achieve a satisfactory performance level. Therefore, it is important to feed balanced rations in order to obtain best results with minimum cost. Computer programs that provide least-cost ration formulation based on linear programming are excellent tools in this context. These programs are only as good as the data input. Most of the time it is impossible for the exact predicted values to be achieved. Therefore, their inputs and outputs must be understood and interpreted by animal nutritionists.

In this experiment, although all rations were formulated by a computer program for least-cost rations, the first and second sets of rations could not maintain sheep condition in relation to body weight or fat score. According to the data generated by this program, the nutrients supplied were considerably in excess of sheep requirements (Figures 7.11 a and b) but, in spite of this, sheep lost weight during the time that these rations were fed. The possible reasons may be as follows.

(a) The nutrient requirement values in the computer package are the minimum values: therefore, formulation of the ration based on these values may not provide the optimum performance. In another words the sheep requirements were higher than the levels provided.

(b) Real feeding values of ration ingredients probably were lower than the values used by the program.

(c) Feeding sheep with rations containing mainly roughages could have resulted in considerable body weight losses, particularly when these are given separately (Aitchison 1988). Digestion and absorption processes of these roughages require more energy in comparison with the better-quality feeds. In spite of higher rates of heat increment the resultant net energy is low, thus these sorts of variations following feeding low-quality materials can be expected.

(d) Feedlot conditions are unnatural for sheep: therefore, feed requirements may be increased compared to the natural conditions.

(e) It seems that longer-term feeding is required to achieve stable conditions in feedlots. Generally, it is not possible to provide the sheep nutrient requirements from the beginning of lot-feeding because an adaptation period is required.

Voluntary intake: Voluntary consumption of both barley and pea straw while introducing sheep to the barley grain (first two weeks) were close to the values reported by Göhl (1981) for pea straw and Capper *et al.* (1986) for barley straw. Although it has been emphasised in the literature (ICARDA 1991) that the voluntary intake of grain legume straw in generally higher than that of cereal straw, in this experiment no significant difference in the intake of barley straw and pea straw was found. This may be attributed to dust in the pea straw or the presence of some kind of anti-nutritional factors in the chemical composition of pea straw. Frequently it has been reported that some legumes may contain phenolic compounds such as tannins that could adversely affect their quality and nutritive value (Francis 1973; Mcleod 1974; Capper 1988). In spite of the importance of the effects of these anti-quality factors on the feeding value of legume straw, there have been no investigations in this area (Capper 1988). However, no adverse effects of pea straw were found in this study.

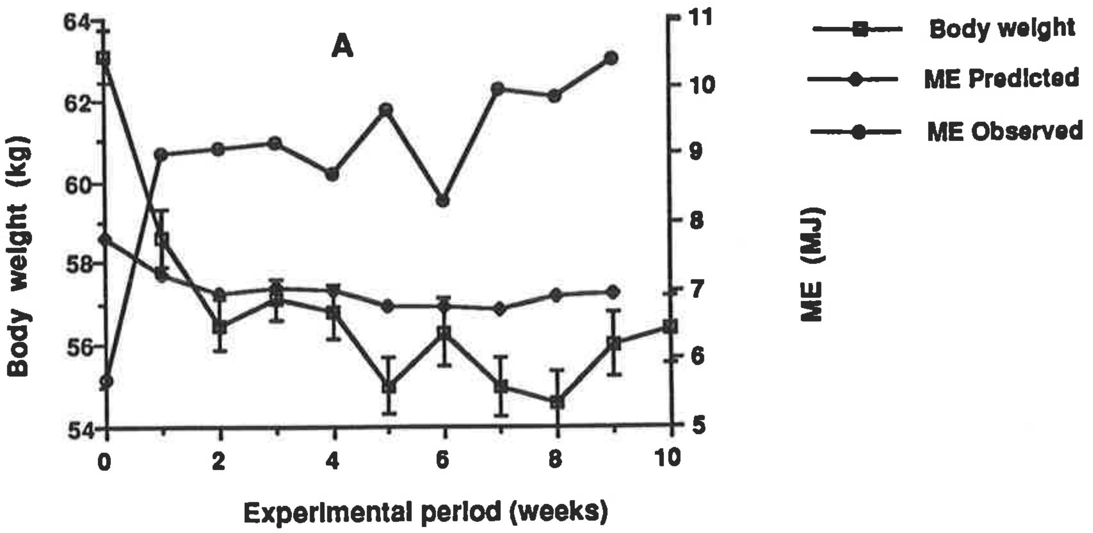
Apparently, increasing the amount of energy-rich barley grain has depressed the voluntary intake of straw in all the experimental groups. This adverse effect of energy-rich concentrates has been reported elsewhere (Dixon 1986).

Average dry matter intakes as the percentage of the body of sheep in this experiment are in agreement with the estimated values by Feeding Standards for Australian livestock (SCA 1990). Also the total dry matter intake of all treatments is very close to the values predicted by the RUMNUT computer program. Therefore, this program appears to provide a reliable tool for farmers interested in lot -feeding.

Chemical composition and digestibility: The chemical composition and *in vitro* digestibilities of the feedstuffs were comparable to those of AFIC.(1982, 1987); ICARDA (1984, 1985a, 1985b, 1991); AMETFC (1979); Capper (1988); NRC (1988) and Parr *et al.* (1988). The lower digestibility of medic pods and straw was most likely associated with their higher contents of indigestible crude fibre.

From the chemical composition point of view, medic pods are an exceptional feed for ruminants. According to the International Classification of Animal Feedstuffs (AFIC 1987), feeds containing more than 18% crude fibre are classified as roughages and feeds containing less than 20% crude protein and 18% fibre as energy feed. Feeds with more than 20% protein are classified as protein supplements. Therefore, as far as protein is concerned medic pods could be classified as protein supplements but their fibre content is as high as the first group (roughages). Thus, there is no defined class of feedstuff covering medic pods.

Body weight and fat score changes: Despite similar dry matter intake of experimental rations, weekly body weight values differed significantly especially after Week 4. The main difference was between treatment A (only barley straw and barley grain) and other treatments.



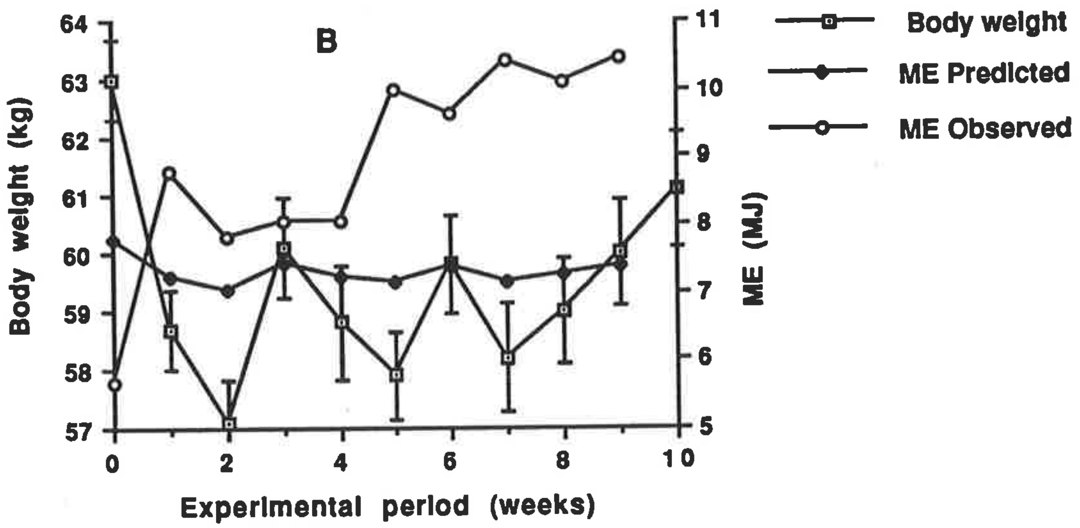
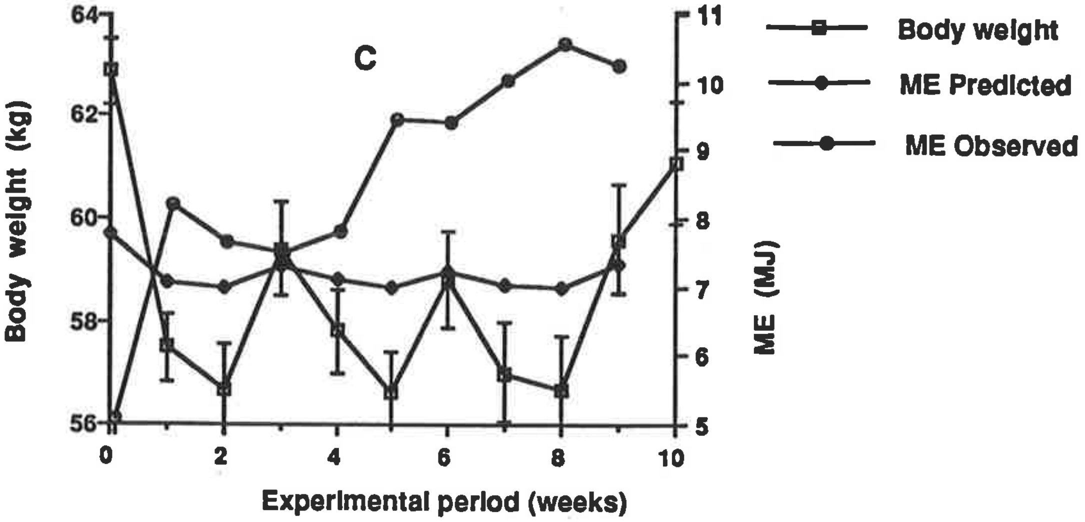


Figure 7.11a Mean body weight of the experimental groups of sheep in relation to metabolizable energy intake (groups A and B)



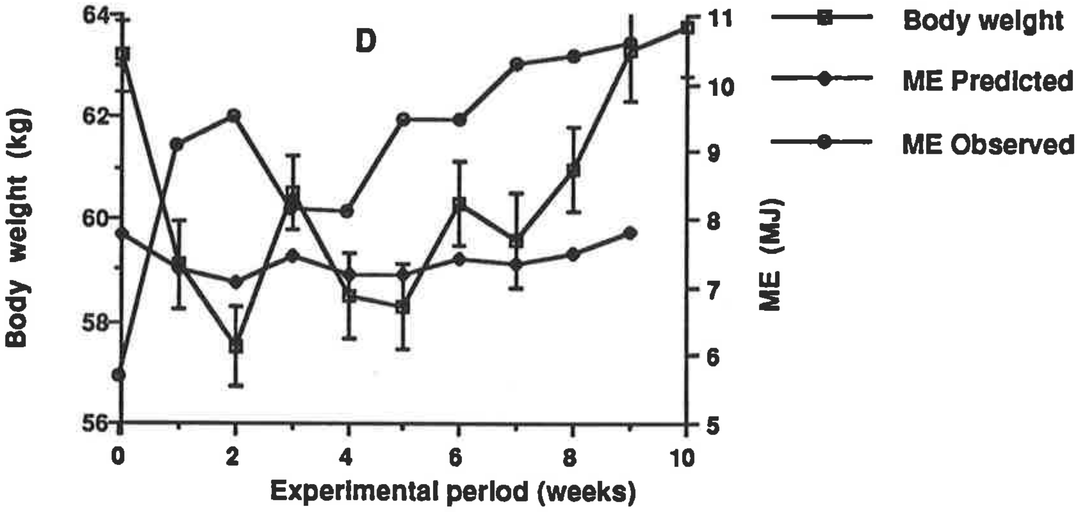


Figure 7.11b Mean body weight of the experimental groups of sheep in relation to metabolizable energy intake (groups C and D)

All the rations were balanced for energy content: but using medic pods (21% CP) in treatment B and C and lucerne hay (18% CP) in treatment D meant that the total amount of crude protein in these rations was considerably higher than for treatment A. This could provide one explanation for the significant differences in sheep body weights between treatments A and other treatments (B,C and D).

Energy and protein are the most important essential nutrients.(McDonald *et al.*1988). Furthermore, Leng (1991) noted that the feed utilisation or production efficiency was affected by the ratio of protein to energy (P/E). The only differences between treatment A and other treatments were the small amounts of either medic pods or lucerne hay which were added at a level of not more than 15%. However, the P/E ratio of treatment A was considerably lower than other treatments (Figure 7.12).

The differences between body weight changes and fat scores could not be attributed to differences in mineral nutrition because macro and trace mineral blocks were provided to all groups. Neither the differences could be the result of environmental factors because all sheep were kept under the same conditions. Differences in rumen-degradable or undegraded protein and P/E ratios are the most likely reasons. It appears from Figures 7.11a and b that ME was used better in rations B and C compared with ration A and best of all in ration D. It is also apparent from the above figures that excess of ME applied over ME required was about the same for all rations. However, body weight changes seem to indicate that ME was best used in ration D (best body weight response) and worst in ration A (worst body weight response) with rations B and C in between. This makes management difficult and critical in intensive ruminant nutrition.

Straw utilisation: All ruminants need some source of roughage in their daily diets and for drought-affected sheep and lot-feeding at maintenance levels maximising straw intake can often be the most cost-effective feeding method.

In this experiment it was found that, by increasing the amount of barley grain, voluntary intake of both barley straw and pea straw was reduced. Ample evidence is available to suggest that the excesses of energy-rich concentrates can adversely affect intake and utilisation of low-quality roughages (i.e. substitution feeding). In an *in vivo* experiment with sheep Henning *et* *al.* (1980) found that straw intake declined linearly from 1178 g/day to 825 g/day as the proportion of maize grain added to the diet rose from 0 g/kg to 393 g/kg straw. It was suggested that in this situation, reduction in the number of cellulytic bacteria in the rumen was responsible for declining straw utilisation rather than changes in rumen pH. However, Raymond (1969) suggested that both low rumen pH and the number or activity of the fibre-digesting bacteria are the main factors that could reduce intake of roughages when supplemented with large amounts of concentrates containing readily-fermentable carbohydrates. It has been concluded that when the amount of low-quality roughage in the ruminant diets exceeds 30 to 40% of the roughage-concentrate diets they could be of value to the animals mainly when the roughages have to be fed or upgraded (Doyle 1983). On the other hand, Haque and Dolberg (1983) noted that inclusion of small amounts of concentrate (10-20%) to a basal diet containing treated or untreated straw tended to cause an increase in the intake of straw.

The minimum percentage of straw in the final set of rations (calculated by TAKE-AWAY program) given to group A and other groups of sheep was 42% and 35% respectively (Table 7.2). However, in spite of this, voluntary intake of straw declined, probably because of the presence of the readily-fermentable energy source (barley grain). The TAKE-AWAY program predicted the changes in intake with the changes in ration composition. Table 7.7 and Figure 7.6 show the observed values of straw intake throughout the experiment for all treatments and these were very close to the corresponding predicted values.

Wool growth: The quality and quantity of the wool produced by sheep is affected by the genotype, environmental and dietary factors (Brown 1976b; Allden 1979; Hynd 1982). The amounts of wool growth in this experiment are in agreement with the conclusion by Aitchison (1988) who reported that during late summer and autumn wool growth of sheep grazing dry and low-quality roughages can be reduced to around five to six grams clean wool per sheep per day. The experiment was conducted during the dry autumn period in South Australia and sheep were fed largely fibrous feeds. Therefore, low rates of wool growth were expected.

Allden (1979) found that feed intake is the major determinant of wool growth and Wuliji (1990) reported that wool characteristics were affected by feed intake. However, as mentioned earlier, there were no significant differences in total feed intake by the four sheep groups and that may be the main reason for the lack of differences in wool growth in this study.

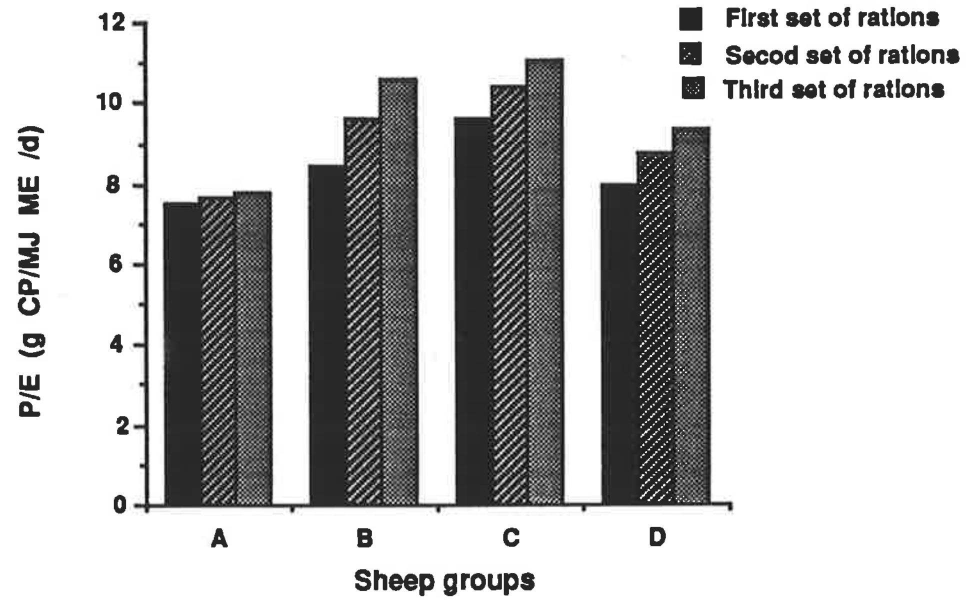


Figure 7.12 Ratio of crude protein to metabolisable energy supplied by different rations

8.0 GENERAL DISCUSSION AND CONCLUSIONS

The experimental results and appropriate interrelationships have already been reviewed and discussed in separate sections of this thesis. This chapter summarises and interprets the main points of the various sections of this thesis together with proposals for further research.

Annual legume pastures have made major contributions to Australian crop and livestock production in the cereal-sheep zone (Carter 1981a; Halse and Wolfe 1985; Carter 1987). Therefore, the persistence of annual legumes is a key factor in this zone. The main indicator of sustainability and productivity of annual pasture legumes is the seed bank and pasture availability throughout the year mainly during the summer-autumn period (Carter 1993).

The most important tool which can greatly affect both annual legume persistence and animal production in the pastures is stocking intensity (Archer 1989; Carter 1989). As was evident from the Korunye grazing experiment reported in this thesis, the disappearance of dry residues was highly correlated with stocking densities. Although the availability of both mature medic pods and dry residues (without pods) on all experimental plots declined as grazing continued, the disappearance rate of dry residues (excluding pods) mainly in the area under high stocking density was much faster than that for mature pods. This indicates that grazing by sheep at high stocking density during the dry season can damage the pod and seed reserves of this type of medic pasture rapidly soon after introducing the sheep to the pasture residues. The extent of this damage undoubtedly will depend on the type of medic, the initial availability of dry pasture residues and pods, and stocking density. Therefore, grazing the dry medic pastures over the summer and autumn period should be carefully monitored.

The grazing experiment also showed that sheep firstly selected large pods containing more seed and larger seeds. Similar results were reported on grazed dry medic pastures by Carter (1981a). From these results it can be suggested that when continuously grazing medic pastures over the summer-autumn period, especially at high stocking densities, the smaller pods containing less seeds also will be depleted by sheep. In this situation the medic cultivars which produce large pods are likely to lose more pods and seeds over summer-autumn due to grazing. The efficiency of sheep in harvesting the larger seeds of other annual legumes (clovers) has been reported by other workers (de Koning and Carter 1989; de Koning 1990; Squella 1992). Nevertheless, it was concluded from the *in sacco* studies reported in this thesis that harvesting the larger pods by sheep is more related to ease of prehension with consequent ecological effects rather than the higher feeding value of larger pods and seeds.

The survival of medic seeds following ingestion by sheep measured in the grazing experiment (Chapter 3) and pen feeding studies (Chapter 4 *in vivo* study) indicates that the regeneration of seedlings from sheep faecal pellets is unlikely to contribute greatly to the overall regeneration of medic pasture. Germinating seed excreted with faeces normally die through desiccation. The average seed survival of a medic cultivar such as Paraggio (that produces smaller seeds than Sava) was less than 2.5%. From the statistical point of view this value is not very significant in the total seed-seedling dynamics of grazed pasture. While sheep can distribute annual legume seeds over grazing areas through their faeces this is insufficient for medic cultivars like Sava, Parabinga and Paraggio but the distribution in sheep faeces of small-seeded *Medicago* spp. and *Trifolium* spp. is important (Carter *et al.* 1989).

In addition to this direct damage to the pasture legume seed bank by sheep grazing, the progressive grazing of dry pasture residues with higher stocking densities also increased the exposure of medic pods and seeds to the natural diurnal variation of temperature at the soil surface. Dry pasture residues reduce the effects of direct sunlight by insulating seeds during the dry and hot period of the year. Soil surface temperature can be markedly affected by the quantity of dry pasture residues (Quinlivan 1965; Taylor *et al.* 1984; Quigley and Carter 1985). Hence, with the decline of dry pasture residues through grazing, the rate of hard seed breakdown will be increased, especially when the medic pasture is under heavy grazing. It was shown in the grazing experiment (Chapter 3) that the percentage of bare ground (or dry residue disappearance) in the plot under high stocking density reached a level around 45% at the end of a three week grazing as compared to 0% at the start of grazing. Thus high stocking densities over the summer-autumn period not only reduce the seed bank by ingestion but also increase the percentage germination of seed and emergence of seedlings from the surviving seed reserve to an undesirable extent. Such results recently have been reported by Carter (1982) for barrel medic, also Carter and Lake (1985), de Koning (1990) and Squella (1992) for subterranean clover. Nevertheless, de Koning concluded that increases in germination and emergence of subterranean clover following summer-autumn grazing were due to breakdown of physiological dormancy rather than of hard seed breakdown.

Persistence of annual medic pastures can be improved by many factors such as selecting and introducing better genotypes. However, it seems that grazing management factors are of the greatest concern in this context. Management can improve persistence of annual medics by ensuring adequate seed production and avoiding excessive depletion of pod and seed reserves from the pastures during the dry season.

It is widely accepted that after initial sowing of medic seeds and satisfactory seed production the level of seeds in the pasture seed reserve is adequate in subsequent years following a cropping sequence because of medic hard seeds. Consequently, as a general practice, farmers do not resow medics. Nevertheless, heavy grazing of medic pasture as employed in the Korunye grazing experiment reported in Chapter 3, can severely reduce the medic seed bank and require resowing of medics (Carter 1981a, 1982). A technique has been developed by Carter *et al.* (1989) and further reported by Carter and Porter (1992) to predict the need for sowing additional legume seed following a cropping sequence. The seriousness of the problem can be significantly reduced by optimising the utilization of the pasture by attention to stocking density during the dry season. The depletion of medic seed reserves is a special problem on hard-setting soils in the cereal-pasture-livestock zone where sheep can easily ingest medic pods.

The studies reported in Chapter 4 indicate that mature medic pods are an important component of dry pasture residues and a valuable source of nutrients for sheep, mainly when other feed resources are in short supply. Although the medic pods varied widely in physical characteristics, voluntary intake and digestibility, generally all of them comprised about 30% seed and 70% hull.

The medic pods were rich in both crude protein and crude fibre. Crude protein content of the whole pods ranged from 16% for Sava snail medic to over 20% for Paraggio barrel medic. The crude fibre contents of these cultivars were about 39 and 35 percent respectively. The quantity of these two major nutrients in the composition of the mature medic pods makes them an atypical feed resource for ruminants in comparison with the traditional animal feeds. According to international classification, the animal feedstuffs with crude fibre content more than 18% are grouped as dry forages and roughages and the feeds with crude protein content of 20% and more are classed as protein supplement (AFIC 1987). Thus, from the crude fibre point of view, medic pods can be considered as a roughage, but with regard to crude protein they are a protein supplement. Hence, there is not a clear group for these types of feeds.

The results of the experiments described in Chapter 4, indicate that mature medic pods can be important as protein supplements for sheep in the summer-autumn period, when dead pastures or crop residues may contain as little as 4-6% crude protein (Dove 1990). The high content of crude protein with high digestibility confirms this conclusion. While the apparent dry matter digestibility of whole mature pods of Sava, Parabinga and Paraggio was 37, 27 and 33 percent, respectively, the corresponding coefficients for crude protein were 66, 62 and 65 percent.

Crude fibre content of the pods was also high (Table 4.2) but in contrast to crude protein, the digestibility of crude fibre was low (Table 4.6). Probably this fraction of mature medic pods is made of lignin and other compounds which are less available to the rumen microbes. Therefore, it seems that the major limiting factor to the nutritive value of mature medic pods is their fibre fraction. Due to this component, the digestibility and utilisation of the energy was largely reduced. As discussed in Chapter 4, the ratio of crude protein to metabolisable energy in medic pods is much higher than other livestock feeds such as alfalfa hay, barley grain etc. Nevertheless a crude protein/metabolisable energy ratio equal to 37 g CP/ME (MJ) for mature barrel medic pods shows the high content of crude protein and also indicates the deficiency of the pods in readily-available energy.

The *in vitro* and *in sacco* digestibility coefficients of mature medic pods were highly correlated to the values obtained by the total collection method (*in vivo*): these methods are therefore reliable techniques for estimation of the feeding value of this type of ruminant-livestock feed and the information is collected at much lower cost. Furthermore, as the whole mature medic pods have two parts, seed and hull, evaluating digestibility of both pod fractions by *in vivo* techniques is almost impossible, whereas the digestibility coefficient of any feed or individual component can simply be measured by the *in vitro* or *in sacco* methods.

It was evident from the *in vitro* study of residual pods (pods refused in pen-feeding study with pure pod diet) that both dry matter and organic matter digestibilities were lower than the original pods (as fed). This indicates that, as for grazing situations (Carter 1980; de Koning and Carter 1989), sheep first selected the largest pods with larger seeds. The results of *in sacco* studies also showed that the size of the medic pods was an important factor for selection by sheep in the field with consequent ecological effects on the subsequent pasture.

According to the *in sacco* studies reported in Chapter 4, while the disappearance of ground hulls of mature medic pods in the rumen generally was less than 25%, the corresponding coefficients for the ground seeds were over 90%. These different coefficients indicate that the feeding value of medic pods is dependent on the actual seed : hull ratio.

Generally, rumen disappearance of whole pods, seeds and hulls in both physical forms (ground and unground) increased linearly up to 48 h incubation and further incubation was ineffective in maintaining the same rate of fermentation. Therefore, for these types of studies and feeds, *in sacco* incubation of feed samples in the rumen for 48 h can give the best and the most reliable coefficients.

There was evidence from *in sacco* studies reported in Chapters 4 and 5 to suggest that breakdown of whole pods and seeds by chewing is the most important factor influencing seed digestion and survival following ingestion by sheep. Such conclusions have been reported for annual legumes by other workers (Carter *et al.* 1989; Jones and Carter 1989; Squella 1992). The *in sacco* studies with pure intact medic seeds indicated that soft seeds were highly susceptible to the digestive enzymes secreted by the rumen microorganisms. Germination of seeds following incubation in the rumen was severely reduced. Apparently some hard seeds were digested in the rumen following seed softening but this was of minor importance.

Incubation of intact medic seeds in the rumen severely affected seed germination but as reported by Yamada and Kawaguchi (1971) for goats, Simao Neto and Jones (1987) for cattle and Squella (1992) for sheep, hard seeds were hardly digested in the rumen, probably due to the impervious cuticle which is more resistant to microbial digestion. However, the breakdown of pods and seeds is an unavoidable action during the ingestion and digestion processes hence hard seeds will also be scarified or broken then digested, and as previously-mentioned the quantity of seeds surviving passage through the gut in grazing situations is so low that these cannot make significant contributions to regeneration of the grazed pasture.

The results of *in vivo* experiments presented in Chapters 4 and 5 of this thesis showed that voluntary intake of Paraggio barrel medic pods (P-Paraggio) harvested following a poor growing season was considerably lower than that for the cultivars Parabinga and Sava. When the intake of P-Paraggio pods was compared with the intake of another line of Paraggio pods (G-Paraggio) harvested following a good season, a large difference was found in intake. The voluntary intake of G-Paraggio pods was about five times greater than the intake of P-Paraggio pods (1837 g v 343 g). No data were found in the literature showing such a big difference in voluntary intake between samples within a cultivar and no other reports are available of such a high intake of mature medic pods as that recorded for the G-Paraggio pods.

It was concluded that low intake of the P-Paraggio pods can be related to the presence of some anti-nutritional factors similar to those reported for other legumes (Howarth 1988; Li *et al.* 1992). Contamination of the pods with fungal residues was another possibility, although in terms of type of fungi present no difference was found between the two lines of Paraggio pods.

The environmental factors that vary from year to year and season to season can cause unexplained and unexpected differences in feed quality (Meyer and Jones 1962; Marten *et al.* 1988). Therefore, the poor intake of P-Paraggio pods may be partially attributed to the adverse effects of the poor season. However, the possibility of involvement of other factors such as poisonous chemicals introduced by man (Reid 1973) or differential weathering (especially following rain) of the pods heaped in the field cannot be entirely eliminated.

It is clear that undesirable fodder conservation methods can influence feeding value. In many districts of South Australia, farmers dump the harvested medic pods to form stacks in the field often with no cover or unsuitable covers without the required ventilation. Following summer rains it is likely that harmful fungi grow on these pods and produce some kind of toxins which may reduce palatability, taste or, in general, voluntary intake of the pods. However, these problems can be minimised by following appropriate harvesting and storage procedures.

In the subsequent *in vivo* experiment (Chapter 5) various treatments other than molasses, not only failed to overcome the intake problem of the P-Paraggio pods but also they had a synergistic effect in combination with the factors responsible for low intake. However, molasses-treatment doubled the intake of P-Paraggio pods, thus it seems that the factor(s) responsible for low intake, initially affected the taste, odour or sensory selection by sheep. The important conclusion from the studies in this thesis is that there are potentially-large differences in feeding value to sheep of medic pods of the same cultivar.

The data presented in Chapter 6 indicate that both calcium hydroxide and sodium hydroxide were effective alkalis in increasing solubility and rumen digestibility of cereal straws, grain legume straws and mature annual medic pods. Application of calcium hydroxide for treatment of these fodders by soaking methods led to more improvement than by the spray method. Perhaps this was because of low solubility of this alkali: thus the method of treatment of fibrous feeds with calcium hydroxide appears to be the key factor in determining its ability to improve the feeding value. It has been reported that calcium content of low-quality roughages soaked in $Ca(OH)_2$ suspension has no effect on mineral balance and utilisation (Verma *et al.* 1982; Djajanegara *et al.* 1985), thus the effective calcium hydroxide treatment of low-quality feeds can be as simple as soaking the materials in the desirable $Ca(OH)_2$ solution and then feeding to livestock after draining for a few hours.

The greatest rumen disappearance of wheat and lentil straws occurred following treatment with 12% and 9% calcium hydroxide by the soaking method respectively. This variation in response may be related to the different structure of cell walls and probably different contents of protein and calcium.

In the studies reported in Chapter 6, generally, the increment in dry matter disappearance of wheat straw was higher than that for lentil straw following treatment with calcium hydroxide, probably because the initial disappearance of lentil straw was greater than for wheat straw. This is in agreement with the conclusion of Owen (1978) that greater increases in digestibility can be expected following treatment of roughages with low initial digestibility.

As expected, the NaOH-treatment of the cereal and grain legume straws and mature medic pods significantly improved their rumen digestibility. The 4% concentration of sodium hydroxide gave a better result than other levels. Although little information on the effects of alkali treatment on the disappearance of straws, especially grain legume straws (measured by *in sacco* procedure), was found in the literature, the effective level of NaOH was similar to that used *in* *vivo* and *in vitro* experiments reported elsewhere (Klopfenstein 1978), indicating the accuracy and importance of the *in sacco* method for this type of research.

Generally, the response of both cereal and grain legume straws to NaOH-treatment was greater than that for $Ca(OH)_2$, probably due to its high solubility and alkalinity. In spite of poor solubility of $Ca(OH)_2$, significant improvement in the disappearance of the mature medic pods was obtained in the studies presented in Chapter 6. The total dry matter disappearance of Sava pods following treatment with $Ca(OH)_2$ applied by the soaking procedure reached a maximum of 55.9% after treatment with 9% $Ca(OH)_2$ (w/w). The desirable level of calcium hydroxide for improvement of the rumen digestibility of mature medic pods, as for lentil straw, was 9%. The average rumen disappearance of Sava pods treated with 9% $Ca(OH)_2$ by the soaking method was 2.65 times greater than the corresponding disappearance obtained by the same alkali and concentration but applied by the spraying method. The effects of $Ca(OH)_2$ by the spraying procedure on mature medic pods also could be related to low alkalinity and short time of treatment.

Treatment of the pods with NaOH resulted in higher total dry matter disappearance and extensive solubilisation in water. Achievement of solubilisation of low-quality roughages is the primary step in enhancing digestibility and feeding value for ruminants (McManus and Choung 1976).

Fibrous feeds are often deficient in nitrogen (Hunter 1987) whereas legume residues and, in particular, mature pods have a higher content of nitrogen: therefore, a considerable increase in feeding value of medic pods following treatment with alkali can be expected (Chapter 6). For efficient utilisation of fibrous residues by ruminants it is essential that the rate of microbial digestion be maximised. Usually N and energy are the limiting factors (Dixon 1986). While the energy availability of fibrous feeds can be increased by alkali treatment, generally N deficiency remains as an important limiting factor for cereal straw residues. The crude protein content of grain legume residues and mature medic pods is equal to or even greater than the level which is required for sheep maintenance. Therefore, it seems that alkali treatment of these residues is likely to give satisfactory improvement and be adopted by feedlot operators during the dry period of Mediterranean-type climatic areas of southern Australia. However, there is no doubt that the nutritive value of the above-mentioned feeds varies over a wide range due to the genetic make-up and environmental conditions, thus further investigations under local conditions are warranted.

In areas of southern Australia that have a Mediterranean-type climate with regular summer dry months and periodic droughts, the appropriate drought feeding management has to be adopted by farmers, to cope with recurring droughts, thus reducing sheep damage to annual pasture seed reserves and soil. A recommended management is lot-feeding or hand feeding sheep in a confined areas during late summer and early autumn. The study reported in Chapter 7, was an attempt in this direction.

The general approach, facilities, feed ingredients, ration formulation, feeding procedures and management, and the results reported in Chapter 7 were consistent with the results of a survey conducted over the agricultural districts of South Australia. The survey questionnaire (Appendices 8.1 and 8.2) was sent to 31 District Livestock Officers and District Agronomists. Over 75% of the responding Livestock Officers and Agronomists, mainly from the Central Region, recommended lot-feeding as a management strategy for reducing the effects of short-term and long-term drought on sheep and pastures, avoiding soil erosion, securing the newly emerged seedlings following the break of season and finally maintaining an adequate medic pod and seed reserve of annual legumes. Some 90 percent recommended lot-feeding during late summer-early autumn period. Most of the responding Livestock Officers and Agronomists stated that farmers had started this practice since 1982 (a very dry year), although some pointed out that sheep lot-feeding in their districts started in 1970's.

The survey showed that farmers in various districts have lot-fed all types of sheep including dry and pregnant ewes, wethers, hoggets and lambs but more attention had been paid to the dry sheep rather than prime lambs and pregnant ewes. According to the information provided by the survey the size of a feedlot flock varied between 100 and 650 sheep. The percentage of sheep that had been lot-fed each year varied widely over the different districts. For example, in Eyre Region this figure was over 30%, in the Central Region between 0 and 100% and in South East Region this percentage was very low and insignificant. The survey confirmed that lot-feeding was important in the cereal-livestock zone where both soils and pastures are most prone to damage by excessive grazing in summer and autumn.

According to the information provided by the survey, the average death rate in the feedlots was between 1 and 6%. The most common causes of death were grain poisoning and shy feeders. The major feedlot problems recognised by the officers were the high cost of feed and the fact that the new management required a high labour input against lower sheep returns, also the need for balanced rations and the scarcity of land i.e. non-erodable ground in some districts.

However, from the results presented in Chapter 7 and the district survey information it can be concluded that lot-feeding of sheep during the dry period of southern Australia (late summer and early autumn) can be successfully established with simple and inexpensive facilities at the farm level. The provision of adequate (but not expensive) facilities such as feed troughs and straw feeders can greatly reduce the number of shy feeders.

Hand feeding of sheep requires careful feed selection, ration formulation and appropriate feeding management. Computer formulation of least-cost rations (such as TAKE-AWAY ration formulation developed by the South Australian Department of Primary Industries) are excellent tools in this regard, in order to achieve maximum benefit at minimum cost.

Straws, particularly grain legume straws, can be fed to sheep in considerable amounts (over 40% of the required dry matter) with cereal grain, mainly at maintenance or drought-feeding levels. These sheep may lose considerable body weight but weight can be recovered very soon after releasing sheep onto green pastures. Ashton (1990) demonstrated that the feeding value of barley straw was more than 70% the value of oaten hay for ewes in a feedlot. Furthermore, sheep lost more body weight on rations containing hay than on rations containing straw. However, the low crude protein content of cereal straw can reduce its feeding value by restricting the normal microbial activity in the rumen (ICARDA 1991). In such circumstances feeding ruminants with legume straws can improve the nitrogen retention and dry matter digestibility of the whole ration. These were the main reasons for choosing pea straw as a feed in this Waite Institute study. Supplementation of straw-based diets with small amounts of protein supplements, or inclusion of around 10% lucerne hay or medic pods, could probably maintain sheep body weight and health.

A feedlot manager must be prepared to adjust feeding management in line with changes in sheep condition and realise that scientific data on nutrient requirements needs to be used as an initial, not final, basis for feeding.

The practical implications and suggested future work as a result of the studies reported in this thesis can be summarised as follows:

(1) Grazing of annual medic pastures over the summer-autumn period is inevitable, but should be carefully managed and optimised, in order to reduce the dramatic damage of heavy grazing on pod (seed) reserves and the soil. In practice, the optimum stocking density is difficult to determine because pasture availability and acceptability to the sheep can vary enormously with different species, growing season, rainfall and management skills. The optimum stocking density and the ideal stage at which sheep should be removed from the dry medic pastures has to be determined in every district or even every farm. Different medic cultivars and lines may well show different responses to excessive grazing: therefore, study on these responses is recommended. It is well known that medic species and cultivars with large pods are most prone to depletion by overgrazing. This is especially a problem on hard-setting soils where sheep may prehend virtually all pods, hence study is required on this aspect.

(2) Differences in seed survival of the medic cultivars studied in this thesis was not statistically significant, as almost all of the seeds were lost in the digestive tract of sheep, thus the very limited number of seeds excreted in sheep faeces may not significantly contribute to regeneration of the grazed pasture. More studies are needed.

(3) Medic pods can provide adequate crude protein for all types of sheep but they are deficient in readily-available energy: therefore, this feed source should be supplemented with energy supplements such as cereal grain or molasses. In areas where these pods are produced in commercial quantities, for best utilisation pods should be ground, mixed and pressed by other ingredients of a complete ration in a pellet-making process. However, this involves costs. Chemical treatment of medic pods can also give better results than for other crop residues. Again costs are involved. More *in vivo* studies are required on this subject.

(4) In a region like southern Australia where short-term and longer-term drought is a natural part of the environment and valuable medic pastures are under threat of heavy grazing during the dry season, crop residues which are available in large quantities should be considered as a feed source or a supplement to the pastures. Chemical treatment of residues is promising for both short-term and long-term needs. It seems that the utilisation of crop residues will become more attractive and eventually dominate as grain and other feed prices rise. If crop residues have to be used, it is desirable that feeding value be increased by genetic manipulation or by applying appropriate physical or chemical treatments. Thus more detailed and practical information is required on the effectiveness of different treatments and animal performance following feeding with treated crop residues.

(5) Measuring the voluntary consumption of mature medic pastures is difficult and sometimes impractical. In such instances the indigestible fibre fraction of the pasture residues can be used as internal markers. Although no data were found in the literature on this subject, at least it can be recommended as a method complementary to the traditional pasture sampling methods for research in the field of evaluation of the intake of dry pasture residues.

(6) The variable voluntary intake of mature medic pods of cv. Paraggio resulting in several experiments reported in this thesis, reveals that some species or lines of annual legumes may contain particular substances that can significantly reduce voluntary intake. However, when medic pastures are under threat of heavy grazing during the dry season, the low intake of medic pods may lead to longer-term stability of the pastures and grazing systems. Under these conditions growing medic cultivars that inherently produce mature pods with lower palatability and consequent lower intake are a possible way of saving the pastures. The studies on this subject are very limited and further work using more species, cultivars and lines grown under various environmental conditions are needed to test this hypothesis.

(7) Lot-feeding of sheep during the dry period enables farmers to save their pastures and sheep numbers without risk of severe wind erosion on exposed soils. This management can be economical and practical for most farmers, but more studies on cost-effective designs, facilities and ration formulation are required. More research is required on lot-feeding of different types of sheep especially dry and pregnant ewes and the impact on their subsequent performance.

Appendix 3.1 Availability of total dry pasture residues (g) harvested from circular areas of 0.064 m^2 during the grazing period at Korunye

	Stocking density											
	Low				Medium				High			
Sample	Grazing period (days)				Grazing period (days)				Grazing period (days)			
No.	0	7	14	21	0	7	14	21	0	7	14	21
1	23.5	19.8	23.0	19.8	23.9	23.0	21.0	18.5	24.2	21.3	15.8	11.5
2	21.4	23.2	17.2	20.3	21.7	19.3	14.8	15.5	19.6	18.7	14.4	13.8
3	23.3	23.9	23.0	19.7	20.6	19.2	20.2	17.8	24.8	17.2	19.9	11.1
4	20.3	16.8	21.7	19.2	20.7	23.1	14.8	10.4	18.9	13.6	12.6	13.3
5	23.4	22.9	17.1	16.6	24.2	27.1	22.6	20.7	23.2	18.2	15.9	14.4
6	23.0	21.9	17.9	23.0	20.0	18.3	18.3	15.0	19.9	21.0	16.8	12.3
7	24.6	17.6	18.3	19.0	23.6	21.7	19.0	13.4	24.0	17.3	15.9	11.4
8	23.1	20.6	22.1	15.9	22.4	18.6	16.4	19.0	24.0	22.5	16.2	14.4
9	21.8	25.4	19.6	17.0	26.7	20.5	22.1	16.4	24.1	17.6	16.2	14.6
10	19.4	19.9	20.9	19.5	24.1	18.9	18.5	15.5	21.6	25.3	16.8	15.1
Sum	223.8	212.2	200.6	190.0	227.9	210.7	187.6	162.1	224.2	192.8	160.4	132.0
Mean	22.4	21.2	20.0	19.0	22.8	21.0	18.8	16.2	22.4	19.3	16.0	13.2
S.E.	0.5	0.9	0.7	0.7	0.7	0.9	0.9	0.9	0.7	1.0	0.6	0.5
C.V.(%)	7.2	13.0	11.8	11.0	9.1	13.6	14.9	18.4	10.0	17.1	11.6	11.4

Appendix 3.2 **Availability of dry pasture residues without pods (g) harvested from the circular areas of 0.064 m^2 during the grazing period**

	Stocking density											
	Low				Medium				High			
Sample	Grazing period (days)				Grazing period (days)				Grazing period (days)			
No.	0	7	14	21	0	7	14	21	0	7	14	21
1	9.9	7.6	10.7	8.9	10.4	9.8	12.1	7.3	10.3	9.3	6.4	3.7
2	8.5	8.5	6.2	10.0	8.0	6.9	6.0	6.6	9.5	9.1	4.9	3.9
3	10.9	11.0	10.9	9.4	9.8	6.8	9.1	7.5	10.9	6.1	8.0	4.1
4	9.0	9.0	8.1	7.7	8.6	10.0	5.0	2.1	9.2	5.7	6.5	5.3
5	10.5	9.8	7.5	6.7	11.8	13.1	10.1	12.8	10.7	8.7	6.5	3.5
6	9.7	9.7	7.2	10.6	8.2	8.2	7.6	4.8	7.8	9.1	7.1	4.1
7	11.0	6.4	8.9	6.8	11.3	8.5	6.9	3.2	9.2	6.7	4.5	3.2
8	10.1	7.5	9.10	4.3	9.4	9.1	5.4	8.8	9.4	8.9	5.2	6.0
9	9.4	11.6	9.1	6.1	11.1	8.1	10.2	4.4	10.7	6.5	5.4	4.2
10	8.2	8.2	8.9	10.6	9.7	7.9	6.9	8.5	8.9	9.5	6.5	4.3
Sum	97.1	91.5	86.4	81.3	98.2	88.5	79.4	66.0	96.4	79.6	60.9	42.4
Mean	9.7	9.1	8.6	8.1	9.8	8.8	7.9	6.6	9.6	8.0	6.1	4.2
S.E.	0.3	0.6	0.5	0.7	0.4	0.6	0.7	1.0	0.3	0.5	0.3	0.3
C.V.(%)	9.9	22.1	17.1	26.2	13.4	20.9	29.5	47.4	10.2	19.0	17.5	19.5

Appendix 3.3 Availability of mature pods (g) harvested from circular areas of 0.064 m^2 during the grazing period

	Stocking density											
	Low				Medium				High			
Sample	Grazing period (days)				Grazing period (days)				Grazing period (days)			
No.	0	7	14	21	0	7	14	21	0	7	14	21
1	13.6	12.1	12.3	10.8	13.5	14.1	8.9	11.2	13.9	11.9	9.4	7.7
2	13.0	11.0	11.0	10.3	13.7	12.4	8.8	8.9	10.1	9.6	9.5	9.9
3	12.4	12.9	12.1	10.3	10.9	12.4	11.1	10.3	13.9	11.1	11.9	7.0
4	11.3	9.4	13.6	11.5	12.1	13.1	9.7	8.3	9.7	7.9	6.1	8.0
5	12.9	13.2	9.6	9.8	12.4	13.9	12.5	8.0	12.6	9.6	9.4	10.9
6	13.3	12.3	10.7	12.4	11.8	10.1	10.7	10.1	12.1	11.9	9.7	8.2
7	13.6	11.2	9.4	12.2	12.3	13.3	12.1	10.2	14.8	10.6	11.4	8.2
8	13.0	13.1	13.0	11.5	13.1	9.5	11.0	10.1	14.6	13.6	11.0	8.5
9	12.4	13.7	10.6	10.9	15.5	12.4	11.9	12.0	13.4	11.1	10.8	10.5
10	11.2	11.8	12.0	8.9	14.4	11.0	11.6	7.0	12.7	15.8	10.3	10.8
Sum	126.6	120.7	114.2	108.7	129.7	122.2	108.3	96.1	127.8	113.2	99.5	89.6
Mean	12.7	12.1	11.4	10.9	13.0	12.2	10.8	9.6	12.8	11.3	9.9	9.0
S.E.	0.3	0.4	0.4	0.3	0.4	0.5	0.4	0.5	0.6	0.7	0.5	0.4
C.V.(%)	6.7	10.8	12.2	9.9	10.6	12.9	12.0	16.0	13.7	19.5	16.1	15.7

Appendix 3.4 Pod density obtained from the circular areas of 0.064 m^2 (each) during the grazing period

	Stocking density											
Sample No.	Low				Medium				High			
	Grazing period (days)				Grazing period (days)				Grazing period (days)			
	0	7	14	21	0	7	14	21	0	7	14	21
1	150	151	146	134	149	154	129	121	153	130	126	100
2	148	134	140	123	153	149	123	114	128	120	130	109
3	149	143	130	135	147	161	142	132	154	145	144	104
4	140	142	151	140	143	155	142	116	128	97	86	110
5	145	141	135	131	148	158	143	126	148	124	126	136
6	152	131	149	139	138	128	145	118	129	135	127	116
7	154	151	123	145	150	152	145	125	165	122	135	124
8	149	150	149	124	144	112	131	115	162	145	139	124
9	144	145	136	148	171	137	126	129	155	144	120	132
10	145	143	131	122	161	136	144	116	152	180	128	137
Sum	1474	1431	1390	1341	1504	1442	1370	1212	1474	1342	1261	1192
Mean	14 8	14 3	13 9	13 4	15 0	14 4	13 7	12 1	14 7	13 4	12 6	11.9
S.E.	1.3	2.1	3.0	2.9	3.0	4.9	2.7	2	4.4	6.9	5.1	4.2
C.V.(%)	2.8	4.7	6.9	6.8	6.3	10.8	6.3	5.3	9.5	16.3	12.7	11.2

Appendix 4.1 Characteristics of the pellets[†] fed to the penned sheep (Moisture-free basis)

(A) Feed ingredients

Ingredients	(%)
Oat hulls	40
Oats (grain)	39
Triticale (grain)	15
Bentonite	2
Salt	1
Limestone	2
Urea	0.5
Vitamin and minerals	1

(B) Composition of the vitamin and minerals

Vtamin and mineral	IU/kg	mg/kg	Active ingredient
Vitamin A	8250	–	–
Vitamin D3	1650	–	–
Iron	–	93	(Ferrous sulphate)
Manganese	–	48	(Manganous oxide)
Zinc	–	52	(Zinc oxide)
Cobalt	–	1	(Cobalt sulphate)
Molybdenum	–	0.4	(Sodium molybdate)
Iodine	–	0.6	(Potassium iodide)

(C) Chemical composition

Nutrient	KJ/kg	(%)
Digestible energy	9.4	–
Crude fibre	–	17.00
Crude protein	–	7.80
Calcium	–	0.66
Phosphorus		0.24

[†] Australian Feed Services Pty. Ltd., South Australia.

Appendix 5.1 Active constituents of the mineral-blend, salt block provided for the sheep during pen feeding experiments[†]

Constituent	(%)	
	Min.	Max.
Salt (NaCl)	53.00	54.20
Molasses	5.00	-
Calcium (Ca)	13.50	-
Phosphorus (P)	0.60	-
Sulphur (S)	0.80	-
Copper (Cu)	0.10	
Cobalt (Co)	0.01	-
Magnesium (Mg)	0.02	-
Ferrous Iron (Fe++)	0.14	-
Iron (Fe+++)	0.07	-
Fluorine (F)	-	0.09
Bentonite	0.50	-

[†] Olsson Industries Pty. Ltd., Angle Park, South Australia.

Appendix 7.1 Dry matter intake (g/d) of different feedstuffs and rations by four experimental groups of sheep

Experimental group	Feedstuff	Experimental period(weeks)									
		1	2	3	4	5	6	7	8	9	10
A	Barley straw	657	841	733	743	686	590	438	429	419	475
	Barley grain	64	329	418	418	418	528	528	638	638	638
	Total	721	1170	1151	1161	1104	1118	966	1067	1057	1113
B	Barley straw	652	862	681	714	714	697	652	481	448	489
	barley grain	64	281	330	330	330	440	440	550	550	550
	Medic pods	55	55	55	55	55	110	110	165	165	165
	Total	771	1198	1066	1099	1099	1247	1202	1196	1163	1204
C	Pea straw	538	719	600	581	621	583	576	405	467	433
	Barley grain	64	281	330	330	330	440	440	550	550	550
	Medic pods	55	55	55	55	55	110	110	165	165	165
	Total	657	1055	985	966	1006	1133	1126	1120	1182	1148
D	Barley straw	648	881	890	705	702	593	595	414	429	450
	Barley grain	64	281	330	330	330	440	440	550	550	550
	lucerne hay	55	55	55	55	55	110	110	165	165	165
	Total	767	1217	1275	1090	1087	1143	1145	1129	1144	1165

Appendix 7.2 Body weight (kg) of sheep in feedlot and after 9 weeks on pasture (Data show means ± SE)

Period (weeks)	Experimental group A	B	C	D	Significance level
In feedlot					
0	63.1 ± 0.7	63.0 ± 0.7	63.1 ± 0.7	63.2 ± 0.7	NS
1	58.6 ± 0.7	58.7 ± 0.7	57.5 ± 0.7	59.1 ± 0.9	NS
2	56.5 ± 0.6	57.1 ± 0.7	56.7 ± 0.8	57.5 ± 0.8	NS
3	57.1 ± 0.5	60.0 ± 0.9	59.4 ± 0.9	60.5 ± 0.7	*
4	56.8 ± 0.6	58.8 ± 1.0	57.8 ± 0.8	58.5 ± 0.8	NS
5	55.0 ± 0.7	57.9 ± 0.8	56.6 ± 0.9	58.3 ± 0.8	*
6	56.3 ± 0.8	59.8 ± 0.8	58.8 ± 1.0	60.3 ± 0.8	*
7	55.0 ± 0.7	58.2 ± 0.9	57.0 ± 1.0	59.6 ± 0.9	*
8	54.6 ± 0.8	59.0 ± 0.9	56.7 ± 1.1	61.0 ± 0.8	**
9	56.0 ± 0.8	60.0 ± 0.9	59.6 ± 1.2	63.3 ± 0.9	**
10	56.4 ± 0.8	61.1 ± 1.0	61.1 ± 0.7	63.8 ± 1.0	**
On Pasture					
19	66.6 ± 0.5	66.7 ± 0.8	67.2 ±	66.8 ± 0.8	NS

NS = Not significant; * = P<0.05; ** = P<0.01

Appendix 7.3 Average weekly fat score of experimental sheep in feedlot and after 9 weeks on pasture

(Data show means ± SE)

Period (weeks)	Experimental group				Significance level
	A	B	C	D	
0	2.6 ± 0.05	2.6 ± 0.09	2.6 ± 0.08	2.6 ± 0.08	NS
1	2.3 ± 0.07	2.4 ± 0.05	2.5 ± 0.08	2.4 ± 0.05	NS
2	2.4 ± 0.06	2.4 ± 0.07	2.4 ± 0.07	2.4 ± 0.07	NS
3	2.4 ± 0.06	2.4 ± 0.05	2.4 ± 0.07	2.4 ± 0.07	NS
4	2.2 ± 0.10	2.2 ± 0.08	2.1 ± 0.11	2.2 ± 0.11	NS
5	1.6 ± 0.11	1.8 ± 0.11	1.8 ± 0.12	1.9 ± 0.08	*
6	1.6 ± 0.08	1.9 ± 0.10	1.8 ± 0.13	1.9 ± 0.07	*
7	1.6 ± 0.10	1.8 ± 0.08	1.6 ± 0.11	1.9 ± 0.07	*
8	1.4 ± 0.09	1.8 ± 0.11	1.7 ± 0.11	1.8 ± 0.09	**
9	1.6 ± 0.09	1.9 ± 0.12	1.9 ± 0.13	2.0 ± 0.09	**
10	1.7 ± 0.08	2.0 ± 0.13	1.9 ± 0.11	2.1 ± 0.08	**
19	2.8 ± 0.08	2.7 ± 0.11	2.8 ± 0.09	2.8 ± 0.10	NS

NS = Not significant; * = $P<0.05$; ** = $P<0.01$

Appendix 8.1 Questionnaire relating to sheep lot feeding management

30 June, 1993

QUESTIONNAIRE ON LOT FEEDING OF SHEEP DURING SUMMER AND AUTUMN

Reza Valizadeh, a Ph D student in the Faculty of Agricultural and Natural Resource Sciences, is researching sheep lot feeding involving feeding of annual medic residues including pods and various crop residues. In particular, he has been assessing the impact of sheep grazing on dry medic pasture residues, evaluating feeding value of mature medic pods and crop residues for sheep, and lot feeding at maintenance level using least cost rations.

To help verify that the above-mentioned research is applicable and relevant to the needs of farmers, we would be very grateful if you could complete the attached questionnaire as far as you are able, and return the questionnaire by post. Our best address is c/- Waite Agricultural Research Institute, Glen Osmond, S. Aust. 5064.

Your sincerely,
E. D. Carter
E.D. Carter
Visiting Research Fellow

Enquiries: E.D. Carter (08) 30 37213
R. Valizadeh (08) 30 37414

QUESTIONNAIRE ON LOT FEEDING OF SHEEP

Name:

Position:

Office Address:

Please provide the following detail on sheep lot feeding in your district.

1. When (which year) did farmers start lot-feeding sheep in your district?

2. What were the main reasons for lot-feeding sheep in that year?

3. In which month is lot feeding started and finished in recent times?

   Started..Finished...............

4. What type of sheep (ewes, wethers, etc.) are being lot feed?

5. What percentage of sheep are usually lot fed each year?

6. How many sheep are generally put in each fedlot?

7. What rations are fed to the sheep ? Please state the main ingredients and costs.

8. What is the average death rate in the fedlots?

9. What is the major cause of death?

10. Do you recommend lot feeding as part of normal management?

11. What are the main problems in this management?
12. What kind of information do you most require from research on lot-feeding?

Please write any other comments you wish to make.

E.D. Carter
R. Valizadeh

Appendix 9.1 List of Papers Arising from Research Undertaken for this Thesis

CARTER, E.D., PORTER, R.G., ABABNEH, M.H., SQUELLA, F., MUYEKHO, F.N. and VALIZADEH, R. (1992). The production and management of annual pasture legumes in ley farming systems of South Australia. *Proc. 6th Aust. Agron. Conf.* Armidale, Australia. pp. 418-421.

CARTER, E.D., CHAICHI, M.R., GRIERSON, I.T., PORTER, R.G. and VALIZADEH, R. (1993). The potential for lot feeding of sheep on cereal farms to protect medic seed reserves and surface soil. *Proc. 7th. Aust. Agron. Conf.* Adelaide. p. 440.

VALIZADEH, R., CARTER, E.D. and YATES, N.G. (1992). Intake, *in vivo* and *in vitro* digestibilities, and seed survival following ingestion of annual medic pods by sheep. *Proc. 6th Aust. Agron. Conf.* Armidale, Australia. p. 536.

VALIZADEH, R., CARTER, E.D. and YATES, N.G. (1993). Voluntary intake and rumen degradation by sheep of mature pods of *Medicago truncatula* cv. Paraggio. *Proc.XVII Int. Grassld. Cong.*, New Zealand and Queensland, Australia. pp. 564-565.

VALIZADEH, R., YATES, N.G., and CARTER, E.D. (1993). The nutritive value of medic pods following treatment with sodium hydroxide or supplementation with molasses. *Proc. 7th. Aust. Agron. Conf.* Adelaide, Australia. pp. 132-135.

VALIZADEH, R., YATES, N.G., and CARTER, E.D. (1993). Nutritive value of cereal straws and grain legume residues. *Proc. 7th. Aust. Agron. Conf.* Adelaide, Australia. p. 447.

VALIZADEH, R., YATES, N.G., and CARTER, E.D. (1993). Nutritive value of mature medic pods for sheep. *1st. Iranian Agron. Cong.* Mashhad, Iran. (In press).

VALIZADEH, R. (1994). Legume residues call for more attention. *Farming Ahead with the Kondinin Group.* Australia's Farm Improvement Group. Western Australia. 25: 48.

10 BIBLIOGRAPHY

ABABNEH, M.H. (1991). The ecology and productivity of annual medic genotypes. Ph. D. Thesis, The University of Adelaide, Australia. 265p.

ABARE (1992). ABARE's Commodity Statistical. Bulletin. Australian Bureau of Agricultural and Resource Economics.

ADEBOWALE, E.A. and NAKASHIMA, Y. (1992). Rumen degradation of some *Leguminosae* and *Graminae* roughages: Effect of chemical pre-treatment with or without cellulase preparation on dry matter and cell wall disappearance. *Anim. Feed. Sci. Techol.* 38: 219-235.

ADEBOWALE, E.A., ØRSKOV, E.R. and HOTTEN, P.M. (1989). Rumen degradation of straw. 8. Effect of alkaline hydrogen peroxide on degradation of straw using either sodium hydroxide or gaseous ammonia as source of alkali. *Anim. Prod.* 48: 553-559.

AFIC (Australian Feeds Information Centre) (1982). Composition of animal feedstuffs in Australia. Leche, T.F., Groenendyk, G.H., Westwood, N.H. and Jones, M.W. (Eds.). CSIRO, Sydney, Australia. 241p.

AFIC (Australian Feeds Information Centre) (1987). Australian feed composition tables. Ostrowski-Meissner, H. (Ed.). CSIRO, Sydney, Australia. 447p.

AITCHISON, E. (1988). Cereal straw and stubble for sheep feed. *J. Agric. West. Aust.* 29: 96-101.

AITCHISON, E.M., MURRAY, P.J. and ROWE, J.B. (1986). Improving the nutritive value of round bales of oat straw by treatment with urea or by supplementation with lupins. *Proc. Aust. Soc. Anim. Prod.* 16: 123-126.

ALEXANDER, B.W., GORDON, A.H., LOMAX, J.A. and CHESSON, A. (1987). Composition and rumen degradability of straw from three varieties of oilseed rape before and after alkali, hydrothermal and oxidative treatment. *J. Sci. Food Agric.* 41: 1-15.

ALLDEN, W.G. (1959). The summer nutrition of weaner sheep. The relative roles of available energy and protein when fed as supplements to sheep grazing mature pasture herbage. *Aust. J. Agric. Res.* 10: 219-236.

ALLDEN, W.G. (1979). Feed intake, diet composition and wool growth. In "Physiological and environmental limitations to wool growth". Black, J.L. and Reis, D.J. (Eds.) CSIRO, Sydney, Australia. pp. 61-77.

ALLDEN, W.G. (1979). Nutritional studies on grain legume crops for grazing livestock. Biennial Report, 1978-79, Waite Agricultural Research Institute, The University of Adelaide. pp. 53-56.

ALLDEN, W.G. (1981). Problems of animal production from Mediterranean Pasture. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham, Royal, UK. pp. 45-65.

ALLEN, R.E. (Ed.). (1984). The pocket Oxford dictionary. Clarendon Press, Oxford. London. p. 651.

AMAN, P. and GRAHAM, H. (1990). Chemical evaluation of polysaccharides in animal feeds. In "Feedstuff evaluation". Wiseman, J. and Cole, D.J.A. (Eds.). Butterworths. London. pp. 161-178.

AMETFC (Arab and Middle East Tables of Feed Composition. (1979). International Feedstuffs Institute. Utah, USA and the Arab Centre for Studies of Arid Zones and Dry Lands. Damascus, Syria. 554p.

AMOR, R.L. (1965). Barrel medic (*Medicago tribuloides* DESR) in the Australian wheat belt. *J. Aust. Inst. Agric. Sci.* 31: 25-35.

ANDREW, W.D. (1962). Behaviour of annual species of *Medicago* introduced into a *Medicago minima* (L.). Bart.-Dominant disclimax community. *Aust. J. Agric. Res.* 13: 212-219.

ANDREW, W.D. and HELY, F.W. (1960). Frequency of annual species of *Medicago* on the major soil groups of the Macquarie region of New South Wales. *Aust. J. Agric. Res.* 11: 705-714.

ANNA NIKOLIC, J. (1982). Some factors influencing the effect of alkali treatment on crop residues. *J. Agric. Sci. Camb.* 99: 115-122.

AOAC (Association of Official Analytical Chemists). (1984). Official methods of analysis of the Association of Official Analytical Chemists. Williams, S. (Ed.).Arlington, Virginia, USA. pp: 152-166.

AOAC (Association of Official Analytical Chemists). (1990). Official methods of analysis of the Association of Official Analytical Chemists. Helrich, K. (Ed.).Arlington, Virginia, USA. pp: 69-83.

ARC (Agricultural Research Council). (1980). The nutrient requirement of ruminant livestock. Commonwealth Agricultural Bureaux, Slough, UK. 351p.

ARC. (1984). Report of the protein group on the ARC working party on the nutrient requirements of ruminants. Commonwealth Agricultural Bureaux, Slough, UK.

ARCHER, K. (1989). Managing pastures for better utilisation and animal production. *Proc. 4th. Annual. Conf. Grassl. Soc. NSW.* pp. 34-41.

ARCHER, K., READ, J. and MURRAY, G. (1993). Pasture decline-real or imagined?. *Proc. 8th. Annual. Conf. Grassl. Soc. NSW.* pp. 8-13.

ARMSBY, H.P. (1917). The nutrition of farm animals. The Macmillan Company. NY. 743p.

ARNASON, J. (1979). Results from Norwegian experiments with treated straw as feed for ruminants. In "Straw decay and its effect on disposal and utilisation". Grossbard, E. (Ed.). John Wiley and Sons.. London. pp. 199-205.

ARNOLD, G.W. (1981). Grazing behaviour. In "World Animal Science, B1, Grazing animals". Morley, F.H.W. (Ed.). Elsevier Sci. Pub. Company. pp. 79-104.

ARNOLD, G.W., and CHARLICK, A.J. (1976). The use of sweet lupins in pastoral systems with breeding ewes. *Aust. Soc. Anim. Prod* 11: 233.

ARNOLD, G.W., WALLACE, S.R. and de BOER, E.S. (1977). Effects of lupin grain supplements on lamb birth weight and growth rate and on milk production of Merino ewes. *Aust. J. Exp. Agric. Anim. Husb.* 17: 915-919.

ASADPOUR, P. and KLOPFENSTEIN, T.J. (1979). Calcium and ammonium hydroxide treatment of wheat straw. *J. Anim. Sci.* 49: 105 A.

ASHTON, B. (1984). Lot-feeding sheep through a drought. Fact Sheet., No. FS 3/84. Dept. Agric. South Australia. 4p.

ASHTON, B. (1986). Lot-feeding of lambs. Fact Sheet, FS 126/76. Dept. Agric. South Australia. 4p.

ASHTON, B. (1989). Feedlots have lots to offer. In Farmer and Stockowner. 29: p. 26.

ASHTON, B. (1990). The use of straw in sheep feedlots. Fact sheet, FS 3/90. Dept. Agric., South Australia. 4p.

ASHTON, B.L. and KING, A.E. (1990). The value of cereal straw in drought rations for lotfed ewes. *Proc. Aust. Soc. Anim. Prod.* 18: 449.

AUSTRALIAN BUREAU of STATISTICS (ABS) (1992a). Livestock and Livestock Production Australia. Castles, I. (Ed.). No. 72210. Commonwealth Government Printer, Canberra, Australia. 21p.

AUSTRALIAN BUREAU of STATISTICS (ABS) (1992b). South Australia, Yearbook. No. 26. Rogers, R.J. (Ed). ABS South Australian Office. pp. 170-194.

AUSTRALIAN BUREAU of STATISTICS.(ABS) (1994). Yearbook Australia. Commonwealth of Australia, Canberra. No. 76. pp. 457-484.

AWC (1989). The Australian wool industry. Australian Wool Corporation. Melbourne.

BACON, J.S.D. (1988). Structure and chemistry. In "World Animal Science, B4. Feed science". Ørskov, E.R. (Ed.). Elsevier Sci. Pub. Company. pp. 23-50.

BAE (1983). Australian agricultural and grazing industries survey 1979-80. Bureau of Agricultural Economics. Canberra, Australia. 146p.

BAE (1984). Wool situation and outlook. Bureau of Agricultural Economics. Canberra, Australia. 35p.

BAKER, A.J., MOHAUPT, A.A. and SPINO, D.F. (1973). Evaluating wood pulp as feedstuff for ruminants and substrate for *Aspergillus famingatus*. *J. Anim. Sci.* 37: 179-182.

BALASUMBRAMANYA, R.H. and BHATAWDEKAR, S.P. (1980). Semi-solid microbial fermentation of rice and wheat straw for protein enrichment and increased digestibility. *Indian. J. Agric. Sci.* 50: 965-970.

BALCH, C.C. and CAMPLING, R.C. (1962). Regulation of voluntary food intake in ruminants. *Nutr. Abst. Rev.* 32: 669-686.

BALCH, C.C. and JOHNSON, V.W. (1950). Factors effecting the utilisation of food by dairy cows. 2. Factors influencing the rate of break down of cellulose in the rumen of the cow. *Br. J. Nutr.* 4: 389-394.

BARBER, A.A. (1990). TAKE-AWAY: A ruminant nutrition software package. *Proc. Aust. Soc. Anim. Prod.* 18: pp. 136-139.

BARRY,T.N. and DUNCAN, S.J. (1984). The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. *Br. J. Nutr.* 51: 485-491.

BARTON II, F.E. (1988). Chemistry of lignocellulose: Methods of analysis and consequences of structure. *Anim. Feed Sci. Technol.* 21: 279-289.

BECKMANN, E. (1922). Conversion of grain straw and lupins into feeds of high nutrient value. *Chem. Abst.* 16: 765.

BEGG, J.E. and PEACOCK, W.J. (1990). Modern genetic and management technologies in Australian agriculture. In "Agriculture in the Australian economy". Williams, D.B. (Ed.). Sydney University Press., Australia. pp. 68-81.

BELL, A., SIMPSON, I. and GILBERT, D. (1986). Lamb lot-feeding budget sheet. Ag. Fact. A. 3.5.2. (Agdex 431/55). Dept. Agric. NSW.

BELL, A., SIMPSON, I. and GILBERT, D. (1991a). Watch hidden lot-feeding costs. In "Kondinin Group Talk", Australia's National Farm Improvement Group. pp. 11-12.

BELL, A., SIMPSON, I. and GILBERT, D. (1991b). Finishing off with a good start. In "Kondinin Group Talk", Australia's National Farm Improvement Group. pp. 15-16.

BEN-GHEDALIA, D., and MIRON, J. (1981). Effect of sodium hydroxide, ozone and sulphur dioxide on the composition and *in vitro* digestibility of wheat straw. *J. Sci. Food Agric.* 32: 224-228.

BEN-GHEDALIA, D., and MIRON, J. (1983). The response of wheat straw varieties to mild sulphur dioxide treatment. *Anim. Feed Sci. Technol.*10: 269-276.

BEN-GHEDALIA, D., and MIRON, J. (1984). The digestibility of wheat straw treated with sulphur dioxide. *J. Agric. Sci. Camb.* 102: 517-520.

BEN-GHEDALIA, D., MIRON, J., EST, Y. and YOSEF, F. (1988). SO_2 treatment for converting straw into a concentrate-like feed: A, growth study with lambs. *Anim. Feed Sci. Technol.*19: 219-229.

BEN-GHEDALIA, D., SFHEFET, G. and MIRON, J. (1980). Effects of ozone and ammonium hydroxide treatments on the composition and *in vitro* digestibility of cotton straw. *J. Sci. Food Agric.* 13: 1337- 1342.

BEN-GHEDALIA, D., SHEFET G., MIRON, J. and DROR, Y. (1982). Effect of ozone and sodium hydroxide treatments on some chemical characteristics of cotton straw. *J. Sci. Food Agric.* 33: 1213-1218.

BEN-GHEDALLA, D. and RUBINSTEIN, A. (1986). The response of screened manure fibre to ozone and sodium hydroxide treatments. *Anim. Feed Sci. Technol.* 15: 47-55.

BISHOP, A.H. and KENTISH, T.D. (1966). The effects on live weight and wool production of autumn deferment with hay feeding. *Proc. Aust. Soc. Anim. Prod.* pp. 164-168.

BLAXTER, K.L. (1960). The utilisation of the energy of grassland products. *Proc. XIII. Int. Grassld. Cong.* pp. 479-484.

BLAXTER, K.L. and WILSON, R.S. (1962). Voluntary intake of roughages by steers. *Anim. Prod.* 4: 351-358.

BODA, K. (Ed.). (1990). Non-conventional feedstuffs in the nutrition of farm animals. Elsevier, Amsterdam. pp. 13-87.

BOWDLER, T.M. and LOWE, K.F. (1980) Forage production from irrigated oats or ryegrass grown with annual legumes or nitrogen in south-eastern Queensland. *Queensland J. Agric. Anim. Sci.* 37: 133-140.

BRAMAN, W.L. and ABE, R.K. (1977). Laboratory and *in vivo* evaluation of the nutritive value of NaOH-treated wheat straw. *J. Anim. Sci.* 46: 496-505.

BRAND, T.S., CLOETE, S.W.P., de VILLIERS, T.T. and FRANCK, F. (1991). Nutritive value of *Medicago truncatula* (cv. Jemalong) pasture for sheep. 1. Seasonal influences on the chemical composition and digestibility of pasture. *J. Anim. Sci.* 21: 88-94.

BRANSBY, D.I. and CONRAD, B.E. (1985). Relating profit to quantity of standing herbage in grazing intensity studies. *Proc. XV Int. Grassld. Cong.*. 1151-1152.

BROOM, D.M. and ARNOLD, G.W. (1986). Selection by grazing sheep of pasture plants at low herbage availability and responses of the plants to grazing. *Aust. J. Agric. Res.* 37: 527-538.

BROWN, T.H. (1976a). Effect of deferred autumn grazing and stocking rate of sheep on pasture production in a Mediterranean-type climate. *Aust. J. Exp. Agric. Anim. Husb.* 16: 181-188.

BROWN, T.H. (1976b). The effect of stocking rate and deferred autumn grazing of pasture on live weight and wool production of Merino wethers in a Mediterranean-type climate. *Aust. J. Exp. Agric. Anim. Husb.* 16: 189-196.

BROWN, T.H. (1977). A comparison of continuous grazing and deferred autumn grazing of Merino ewes and lambs at 13 stocking rates. *Aust. J. Agric. Res.* 28: 947-961.

BRUHN, H.D. (1955). Pelleting grain and hay mixtures. *Agricultural Engineering*. 36: 330-331.

BRUHN, H.D. (1957). Engineering problems in pelletised feed. *Agricultural Engineering*. 38: 322-325.

BRYANT, T.H. (1983). National lamb marketing and production conference "Industry Overview". In "Implications of developments in meat science, production and marketing for lamb production systems. Thatcher, L.P. and Harris, D.C. (Eds.). Paper No. 2. Vic. Dept. Agric. and NSW Dept. Agric., Australia.

BUCKLE, A.E. and SCUDAMORE, K.A. (1990). The occurrence, detection and significance of mycotoxins in animal feeding stuffs. "Feedstuff evaluation". Wiseman, J. and Cole, D.J.A. (Eds). Butterworths. U.K. pp: 411-428.

BUDGET BOOKS (1988). Webster's dictionary. Budget books Pty. Ltd. Melbourne Australia. p. 322.

BUNTING, L.D., RICHARDSON, C.R. and TOCK, R.W. (1984). Digestibility of ozone-treated sorghum stover by ruminants. *J. Agric. Sci. Camb.* 102: 747-750.

BURNS, J.C. (1981). Integration of grazing with other feed resources. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham Royal, UK. pp. 455-471.

BURROWS, I., SEAL, K.J. and EGGINS, H.O.W. (1979). The biodegradation of barley straw by *Coprinus cinereus* for the production of ruminant feed. In "Straw decay and its effect on disposal and utilisation". Grassbard, E. (Ed.). John Wiley & Sons. London. pp. 147-154.

BUTLER, J.L. and McCOLLY, H.F. (1959). Factors affecting the pelleting of hay. *Agricultural Engineering*. 40: 442-446.

CAB (Commonwealth Agricultural Bureaux) (1980). The nutrient requirements of ruminant livestock. The Gresham Press, Surrey, UK. 351p.

CALLOW, C. (1992). The New South Wales feedlot industry: An overview. Yanco. Institute, NSW. 82p.

CAMPLING, R.C, FREER, M. and BALCH, C.C. (1963). Factors affecting the voluntary intake of food by cows. 6. A preliminary experiment with ground-pelleted hay. *Br. J. Nutr.* 17: 263-272.

CAMPLING, R.C. and FREER, M. (1966). Factors affecting the voluntary intake of food by cows, 8; experiment with ground pelleted roughages. *Br. J. Nutr.* 20: 229-244.

CAN (Committee on Animal Nutrition) (1983). Underutilised resources as animal feedstuffs. Board on Agriculture, Natural Research Council. Washington DC., USA. 253p.

CAPPER, B.S. (1988). The role of food legume straw and stubble in feeding livestock. In "The role of legumes in the farming systems of Mediterranean areas". Klower Academic Pub. pp. 151-162.

CAPPER, B.S., THOMSON, E.F. RIHAWI, S., TERMANINI, A. and MACRAE, R. (1986). The feeding value of straw from different genotypes of barley when given to Awassi sheep. *Anim. Prod.* 42: 337-342.

CARTER, E.D. (1965) Some relationships between superphosphate use and consequent animal production from pasture in South Australia. *Proc.* IX *Int. Grassld. Cong.*, Sao Paulo, Brazil. pp. 1027-1032.

CARTER, E.D. (1968a). Changes in seed supply of an annual pasture grazed continuously by sheep at five stocking rates. *Proc. Aust. Grassld. Conf.*, Perth, 1: pp 7-10 (Sect. 1b).

CARTER, E.D. (1968b). The effect of stocking rate on the production and utilisation of annual pasture and on wool production. *Proc. Aust. Grassld. Conf.*, Perth. 1: pp. 9-11 (Sect. 1a).

CARTER, E.D. (1975). "The potential role of integrated cereal-livestock systems from southern Australia in Increasing food production in the Near East and North African Region". UNDP/FAO Regional Project on Improvement and Production of Field Food Crops : Regional Meeting - Lahore-Peshawar-Karachi, Pakistan. 35p.

CARTER, E.D. (1977). Stocking rate and the ecosystem: some soil-plant-animal interrelationships on annual pastures in South Australia. *Proc. XIII Int. Grassld. Cong.*, Leipzig, GDR. pp: 348-354.

CARTER, E.D. (1978). A review of the existing and potential role of legumes in farming systems of the Near East and North African Region. A report to ICARDA. Waite Agricultural Research Institute. 120p.

CARTER, E.D. (1980). The survival of medic seeds following ingestion of intact pods by sheep. *Proc. Aust. Agron. Conf.* Lawes, Queensland. p. 178.

CARTER, E.D. (1981a). Seed and seedling dynamics of annual medic pastures in South Australia. *Proc. XIV Int. Grassld. Cong.* Lexington, Ky, USA. pp. 447-450.

CARTER, E.D. (1981b). The role of medics in livestock and crop production. Symposium Roseworthy Agric. College, South Australia. Sept. 1981.

CARTER, E.D. (1982). The need for change in making the best use of medics in the cereal-livestock farming systems of South Australia. *Proc. 2nd Aust. Agron. Conf.*, Wagga Wagga, NSW. p. 180.

CARTER, E.D. (1986). The production and utilisation of annual medics and alternative legumes in the cereal farming districts. In "Mid-North Sheep Seminar on Pasture Production and Sheep Management", Clare, South Australia., pp. A1-A8.

CARTER, E.D. (1987). Establishment and natural regeneration of annual species. In "Temperate pastures, their production, use and management". Wheeler, J.L., Pearson, C.J. and Robards, G.E. (Eds.). Australian Wool Corporation, CSIRO. Aust. pp. 35-51.

CARTER, E.D. (1989). The production and utilisation of sown pastures in southern Australia. *Pasture Symposium*, No. 1., The University of Adelaide. 24p.

CARTER, E.D. (1990a). Better pasture - more profitable crops. Regional Conference of Agricultural Bureau of South Australia, Ungarra, Eyre Peninsula. 13 March. 12p.

CARTER, E.D. (1990b). Pasture renovation and re-establishment - an overview. *Pasture Symposium*, No. 3., The University of Adelaide. pp. 15-18.

CARTER, E.D. (1990c). Production and management of medic pastures in the cereal belt. Agricultural Bureau, Warooka, South Australia, 13 Aug. 12p.

CARTER, E.D. (1990d). The impact of summer-autumn grazing on legume seeds. *Pasture Symposium*, No. 2, The University of Adelaide. pp. 55-58.

CARTER, E.D. (1992). Ley-farming constraints on pasture - the need to consider pastures in a whole-farm context. In "Pastures are for animals". Fortune, J.A. (Ed.). Aust. Soc. Anim. Prod.(W.A. Branch). pp. 14-23.

CARTER, E.D. (1993). Principles of sustainable pasture production. *Proc. 8th. Annual. Conf. Grassl. Soc. NSW.* pp. 18-24.

CARTER, E.D. and DAY, H.R (1970). Interrelationships of stocking rate and superphosphate rate on pasture as determinants of animal production I. Continuously grazed old pasture land. *Aust. J. Agric. Res.* 21 : 473-491.

CARTER, E.D. and LAKE, A. (1985). Seed, seedling and species dynamics of grazed annual pastures in South Australia *Proc. XV Int. Grassld. Cong.*, Kyoto, Japan, pp. 654-656.

CARTER, E.D., CHAICHI, M.R., GRIERSON, I.T., PORTER, R.G. and VALIZADEH, R. (1993). The potential for lot feeding of sheep on cereal farms to protect medic seed reserves and surface soil. *Proc. 7th. Aust. Agron. Conf.* Adelaide. p. 440.

CARTER, E.D., CHALLIS, S. and RIDGWAY, I.G. (1977). The use of heavy solvents for separating seed from soil. *Proc. XIII Int. Grassld. Cong.*, Leipzig, GDR. pp. 146-151.

CARTER, E.D., CHALLIS, S., KNOWLES, R.C. and BAHRANI, J. (1989). Pasture legume seed survival following ingestion by sheep. *Proc. 5th Aust. Agron. Conf.* Perth. p. 437.

CARTER, E.D., PORTER, R.G. (1992). Predicting the emergence of annual pasture legumes on cereal farms. *Proc. 5th Aust. Agron. Conf.*, Armidle, NSW. p. 540. a

CARTER, E.D., PORTER, R.G., ABABNEH, M.H., SQUELLA, F., MUYEKHO, F.N. and VALIZADEH, R. (1992). The production and management of annual pasture legumes in ley farming systems of South Australia. *Proc. 6th. Aust. Agron. Conf.* Armidale. pp. 418-421.

CARTER, E.D., WOLFE, E.C. and FRANCIS, C.M. (1982). Problems of maintaining pastures in the cereal-livestock areas of southern Australia. *Proc. 2nd Aust. Agron. Conf.*, Wagga Wagga, NSW. pp. 68-82.

CASSON, T. and FISHER, K. (1992). The physical and chemical composition and digestibility of pods from three different medic cultivars. *Proc. Aust. Soc. Anim. Prod.* 19: 311-314.

CASTILLO, L.S. (1983). Current utilisation of fibrous residues in Asian countries. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 33-49.

CASTILLO, L.S., ROXAS, D.B., CHAVEZ, M.A., MOMONGAN, V.G. and RANJHAN, S.K. (1982). The effects of concentrate supplementation and of chopping and soaking rice straw in its voluntary intake in Caraboas. In "The Utilisation of Fibrous Agricultural Residues as Animal Feeds". Doyle, P.T.(Ed.). School of Agriculture and Forestry Uni. Melbourne. Aust. pp. 74-80.

CASTRILLO, C., FONDEVILA, M., ALIBES, X. and JOY, M. (1991). Chemical treatments for upgrading lignocellulosic resources and strategies for their utilisation in ruminant feeding. In "Production and utilisation of lignocellulosics. . Galletti, G.C. (Ed.). Elsevier Appl. Sci. pp. 339-373.

CATE, H.A., LEWIS, J.M., WEBB, R.J., MANSFIELD, M.E. and GARRIGUS, U.S. (1954). The effect of pelleting rations of varied quality on feed utilisation of lambs. *J. Anim. Sci.* 13: 979A.

CHANDRA, S. and JACKSON, M.G. (1971). A study of various chemical treatments to remove lignin from coarse roughages and increase their digestibility. *J. Agric. Sci. Camb.* 77: 11-17.

CHAPMAN, P.G. and NORTON, B.W. (1982). The effect of sample preparation on the digestion of chopped, masticated and ground siratro and pangola grass in nylon bags. *Proc. Aust. Soc. Anim.* 14: 580-583.

CHAPMAN, R.E. and WHEELER, J.L. (1963). Dye-banding: A technique for fleece growth studies. *Aust. J. Sci.* 26: 53-54.

CHATURVEDI, M.L., SINGH, U.B. and RANJHAN, S.K. (1973). Effect of feeding water-soaked and dry wheat straw on feed intake, digestibility of nutrients and VFA production in growing zebu and buffalo calves. *J. Agric. Sci. Camb.* 80: 393-397.

CHENSON, M., GRENET, E., DEMARQUILLY, C. and JARRIGE, R. (1970). The use of the nylon bag technique for the study of forage digestion in the rumen and for predicting feed value. *Proc. XI Int. Grassld. Cong.* Qld, Australia. pp. 697-701.

CHESSON, A. (1981). Effects of sodium hydroxide on cereal straws in relation to the enhanced degradation of structural polysaccharides by rumen microorganisms. *J. Sci. Food Agric.* 32: 745-758.

CHESSON, A. (1988). Lignin-polysaccharide complexes of the plant cell wall and their effect on microbial degradation in the rumen. *Anim. Feed Sci. Technol.* 21: 219-228.

CHEVA-ISARAKUL, B. (1988). Performance of sheep fed urea-treated or urea-molasses supplemented straw with or without fresh lewcaena supplement as compared with fresh grass. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 225-231.

CHEVA-ISARAKUL, B. and KANJANAPRUTJIPONG, J. (1987). A comparison of urea-treated rice straw with urea-molasses sprayed rice straw as a base diet for growing cattle. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp 191-198.

CHOMYSZYN, M., ZIOLECKA, A., KUZDOWKS, M. and BIELINSKI, K. (1961). The use of ammoniated fodder in the feeding of ruminants 1. The use of ammoniated sugar beet pulp in the feeding of wethers. *Nutr. Abst. Rev.* 31: 306.

CHRISTIAN, K.R. (1987). Matching pasture production and animal requirements. In "Temperate pastures, their production, use and management". Wheeler, J.L., Pearson, C.J. and Robards, G.E. (Eds.). Australian Wool Corporation, CSIRO. Aust. pp. 463-476.

CHURCH, D.C. (1988). The Ruminant animal, digestive physiology and nutrition. A Reston Book, Prentice Hall, NJ, USA. 564p.

CLARK, D.A. (1993). Grazing for pasture management in New Zealand. In "Pasture management: Technology for the 21st century". Kemp, D.R. and Michalk, D.L. (Eds.). CSIRO, Melbourne. pp. 53-61.

CLARK, T. (1985a). Beef cattle feedlots, facilities. FS 15/85. Dept. Agric. South Australia. 2p.

CLARK, T. (1985b). Beef cattle feedlots, health. FS 17/85. Dept. Agric. South Australia. 2p.

CLOETE, S.W.P., de VILLIERS, T.T. and KRITZINGER, N. M. (1983). The effects of ammoniation by urea on the nutritive value of wheat straw for sheep. *S. Afr. J. Anim. Sci.* 13(3): 143-146.

COCKS, P.S. (1988). Seed production and seed survival under grazing of annual medics (*Medicago* spp.) in North Syria. *J. Agric. Sci. Camb.* 110: 455-463.

COCKS, P.S. and CARTER, E.D. (1978). Legumes in agriculture. Australian Institute of Agricultural Science, Riverina Outlook Conference, Wagga Wagga, NSW. pp. 1-12.

COOMBE, J.B. (1980). Utilisation of low-quality residues. In "World Animal Science, B1, Grazing animals". Morley, F.H.W. (Ed.). Elsevier Sci. Pub. Company. pp. 319-334.

COOMBE, J.B. and TRIBE, D.E. (1962). The effects of urea-supplements on the utilisation of straw plus molasses diets by sheep. *Aust. J. Agric. Res.* 1: 70-91.

COOMBE, J.B., DINIUS, D.A. and WHEELER, W.E. (1979). Effect of alkali treatment on intake and digestion of barley straw by beef steers. *J. Anim. Sci.* 49: 169-176.

CORBETT, J.L. (1969). The nutritional value of grassland herbage. In "Nutrition of animals of agricultural importance. Part 2. Assessment of and factors affecting requirements of farm livestock". Cuthbertson, D. (Ed.). Pergamon Press. pp. 593-644.

COTTLE, D.J. (1991). The sheep industry. In "Australian Sheep and Wool Handbook". Cottle, D.J. (Ed.). Inkata Press. Melbourne. pp. 1-18.

COTTYN, B.G. and DeBOEVER, J.L. (1988). Upgrading of straw by ammoniation. *Anim. Feed Sci. Technol.* 21: 287-294.

CRAMPTON, E.W. and HARRIS, L.E. (1969). Applied animal nutrition, the use of feedstuffs in the formulation of livestock rations. W.H. Freeman and Company. San Francisco, USA. pp. 312-395.

CRIBB, J. (1986). Agriculture in the Australian Economy. In " Australian Agricultural Yearbook. National Farmers Federation. Melbourne pp. 15-42.

CROSS, H.H., SMITH, L.W. and DeBARTH, J.V. (1974). Rates of *in vitro* forage fibre digestion as influenced by chemical treatment. *J. Anim. Sci.* 39: 808-812.

CROSTHWAITE, C., ISHIHARA, M. and RICHARDS, G.N. (1984). Acid-ageing of lignocellulosic to improve ruminant digestibility: Application to bagasse, wheat and rice straws and oat hulls. *J. Sci. Food Agric.* 35: 1041-1050.

CURLL, M.L. and JONES, R.M. (1989). The plant-animal interface and legume persistence, an Australian perspective. In "Persistence of forage legumes". Marten, G.C., Matches, A.G., Barnes, R.F., Brougham, R.W., Clements, R.J. and Sheath, G.W. (Eds.). Amer. Soc. Agron. pp. 339-359.

D'MELLO, J.P.F. (1992). Chemical constraints to the use of tropical legumes in animal nutrition. *Anim. Feed Sci. Technol.* 38: 237-261.

DALAL-CLAYTON, D.B (1985). Black's agricultural dictionary. A&C Black. London. p 312.

DALTON, H.L., HUFFMAN, C.F. and RALSTON, N.P. (1953). The effect of feeding concentrates with different degrees of fineness and water contents on the eating and milking time in dairy cattle *J. Dairy Sci.* 39: 1279-1284.

DAVIS, C.H. (1983). Experiences in Bangladesh with improving the nutritive value of straw. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 123-128.

DAY, H.R. and MICHELMORE, W.A. (1952). Barrel medic for low rainfall areas. *J. Dept. Agric. South Australia.* 56: 179-185.

De BOER, G., MURPHY, J.J. and KENNELLY, J.J. (1987). A modified method for determination of *in situ* rumen degradation of feedstuffs. *Can. J. Anim. Sci.* 67: 93-102.

De BOEVER, J.L., COTTYN, B.G., ANDRIES, J.I, BUYSSE, F.X. and VANACKER, J.M. (1988). The use of a cellulase technique to predict digestibility, metabolizable and net energy of forages. *Anim. Feed Sci. Technol.* 19: 247-260.

de KONING, C.T. (1990). The ecology and productivity of new cultivars of subterranean clovers (*Trifolium subterraneum L.*). Ph.D. Thesis, The University of Adelaide, Australia. 270p.

de KONING, C.T. and CARTER, E.D. (1987). Impact of grazing by sheep on subterranean clover cultivars. *Proc. 3rd. Aust. Agron. Conf.*, Melbourne. p. 169.

de KONING, C.T. and CARTER, E.D. (1989). Losses of subterranean clover seed from dry pasture residues during grazing by sheep in summer-autumn. *Proc. 5th. Aust. Agron. Conf.*, Perth. p. 408.

DEAR, B.S. (1988). Annual legumes: the persistence and productivity of subterranean clover and medics. *Proc. 3rd Annual. Conf. Grassl. Soc.* NSW. pp. 3-9.

DEAR, B.S. and LOVELAND, B. (1985). A survey of seed reserves of subterranean clover pastures on the southern Tableland of New South Wales. *Proc.3rd Aust. Agron. Conf.*, Tasmania. p. 214.

DEINUM, B. and VAN SOEST, P.J. (1969). Prediction of forage digestibility from some laboratory procedures. *Neth. J. Agric. Sci.* 17: 119-127.

DENNEY, G.D., HOGAN, J.P. and LINDSAY, J.R. (1979). The digestion of barrel medic (*Medicago truncatula*) hay and seed pods by sheep. *Aust. J. Agric. Res.* 30: 1177-1184.

DENNEY, G.D., LINDSAY, J.R. and HOGAN, J.P. (1978). The nutritive value of hay and pods of barrel medic (*Medicago truncatula*) for sheep. *Proc. Aust. Soc. Anim. Prod.* 12: p.148.

DIXON, R.M. (1986). Increasing digestible energy intake of ruminants given fibrous diets using concentrate supplements. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 59-75.

DIXON, R.M. (1987). Maximising the rate of fibre digestion in the rumen. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp 49-67.

DIXON, R.M. and EGAN, A.R. (1988). Strategies for optimising use of fibrous crop residues as animal feeds. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 11-26.

DJAJANEGARA, A., DOYLE, P.T. and MOLINA, B.T. (1985). Fibre digestion and mineral balances in sheep fed calcium hydroxide-treated wheat straw. In "The utilisation of fibrous agricultural residues as animal feeds". Doyle, P.T. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 94-102.

DOBIE, J.B. (1959). Engineering appraisal of hay pelleting. *Agricultural Engineering*. 40: 76-77.

DONALD, C.M. (1982). Innovation in Australian agriculture. In "Agriculture in the Australian Economy". Williams, D.B. (Ed.). Sydney University Press. pp. 55-82.

DONALD, C.M. and ALLDEN, W.G. (1959). The summer nutrition of weaner sheep, the deficiencies of the mature herbage of sown pasture as a feed for young sheep. *Aust. J. Agric. Res.* 10: 199-218.

DONEFER, E., LLOYD, L.E. and CRAMPTON, E.W. (1963). Effect of varying alfalfa: barley rations on energy intake and volatile fatty acid production by sheep. *J. Anim. Sci.* 22: 425-428.

DOVE, H. (1990). The role and place of supplementary feeding and protected protein for sheep and cattle. *Proc. 5th Annual. Conf. Grassl. Soc.* NSW. pp. 84-88.

DOWNES, R.G. (1969). Proceedings of International Conference on Mechanised Dry land Farming., held in 1968 at Moline, Illinois, USA. pp. 20-30.

DOYLE, P.T. (1983). Digestion of treated crop residues and the need for nutrient additions in balanced rations using such residues. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 69-84.

DOYLE, P.T. and EGAN, J.K. (1987). Palatability of mature subterranean clover. In "Temperate pastures, their production, use and management". Wheeler, J.L., Pearson, C.J. and Robards, G.E. (Eds.). Australian Wool Corporation, CSIRO. Aust. pp. 328-330.

DOYLE, P.T. and PANDAY, S.B. (1990). The feeding value of cereal straw for sheep. III, Supplementation with minerals or minerals and urea. *Anim. Feed Sci. Technol.* 29: 29-43.

DOYLE, P.T., DEVENDRA, C. and PEARCE, G.R. (1986). Rice straw as a feed for ruminants. International Development Program of Australian Universities and Colleges. Canberra, Australia. 117p.

DOYLE, P.T., GRIMM, M. and THOMPSON, A.N. (1993). Grazing for pasture and sheep management in the annual pasture zone. In "Pasture management: Technology for the 21st century". Kemp, D.R. and Michalk, D.L. (Eds.). CSIRO, Melbourne. pp. 71-90.

DOYLE, P.T., ROWE, J.B. and WARREN, B.E. (1989). Nutritive value of pasture species. *Proc. 5th. Aust. Agron. Conf.* pp. 141-153.

DOYLE, P.T., YOUNG, J., BOOTH, P., CRANSBERG, L. and HERBERT, A. (1992). Effects of strip (ration) grazing on pasture availability and sheep live weights during winter. *Proc. Aust. Soc. Anim. Prod.* 19: 217-220.

DULPHY, J.P. and DEMARQUILLY, C. (1983). Voluntary feed consumption as an attribute of feeds. In "Feed information and animal production" Robards, G.E. and Packham, R.G. (Eds.). CAB (Commonwealth Agricultural Bureau). UK. pp. 135-156.

DULPHY, J.P., REMOND, B., THERIEZ, M. (1980). Ingestive behaviour and related activities in ruminants. In "Digestive physiology and metabolism in ruminants". Ruckebusch, Y. and Thivend, P. (Eds.). Lancaster, UK. pp. 103-122.

DUNLOP, A.C. and McDONALD, C.L. (1986). Protein enrichment of cereal grain for livestock. *West. Aust. J. Agric.* 27: 64-67.

DUNLOP, A.C., BOWDEN, J.W. and ALLSDEN, G.M. (1984). The effect of stocking rate on dry matter production of Mediterranean annual pastures. *Proc.Soc. Anim. Prod.* 15: 33-336.

EGAN, A.R. (1986). Principals of supplementation of poor-quality roughages with nitrogen. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 49-57.

ELLIOTT, R.C. (1967a). Voluntary intake of low protein diets by ruminants. I. Intake of feed by cattle. *J. Agric. Sci. Camb.* 69: 375-382.

ELLIOTT, R.C. (1967b). Voluntary intake of low protein diets by ruminants. II. Intake of feed by sheep. *J. Agric. Sci. Camb.* 69: 383-390.

ELLIS, W.C., WYLIE, M.J. and MATIS, J.H. (1988). Dietary digestive interactions determining the feeding value of forages and roughages. In "World Animal Science, B4. Feed science". Ørskov, E.R. (Ed.). Elsevier Sci. Pub. Company. pp. 177-229.

ENTWISTLE, K.W. and BAIRD, D.A. (1976). Studies on the supplementary feeding of sheep consuming mulga (*Acacia aneura*). 2. Comparative levels of molasses and urea supplements fed under pen conditions. *Aust J. Exp. Agric. Anim. Husb.* 16: 174-180.

ERNST, A.J., LIMPUS, J.F. and O'ROURKE, P.K. (1975). Effect of supplements of molasses and urea on intake and digestibility of native pasture hay by steers. *Aust J. Exp. Agric. Anim. Husb.* 15: 451-455.

ERWIN, E.A. and ELLISON, N.G. (1959). Rapid method of determining digestibility of concentrates and roughages in cattle. *J. Anim. Sci.* 18: 1518A.

EVANS, P.J. (1979). Chemical and physical aspects of the interaction of sodium hydroxide with the cell wall components of straw. In "Straw decay and its effect on disposal and utilisation". Grassbard, E. (Ed.). John Wiley & Sons. London. pp. 187-229.

EVANS, T.R. (1981). Overcoming nutritional limitations through pasture management. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham, Royal, UK. pp. 343-361.

FAICHNEY, G.J. and WHITE, G.A. (1983). Methods for the analysis of feeds eaten by ruminants. CSIRO. NSW., Australia. 35p.

FAO (1990). FAO. Production Yearbook. FAO statistics series. No. 99. Rome, Italy. pp. 71-87.

FAU (Feedlot Advisory Unit). (1990). The feedlot manual. Dept. Agric. Fish. NSW., Australia.

FEIST, W.C., BAKER, A.J. and TARKOW, H. (1970). Alkali requirements for improving digestibility of hard woods by rumen micro organisms. *J. Anim. Sci.* 30: 832-835.

FELIX, A., HILL, R.A. and DIARRA, B. (1990). *In vitro* and *in vivo* digestibility of soya-bean straw treated with various alkalis. *Anim. Prod.* 51: 47-61.

FELS, H.E. (1980). Principles of lot-feeding and the design and operation of feedlots. In *Proc.* of a seminar on grain feeding of sheep for survival and growth. Hunter, R.A. (Ed.). *Aust. Soc. Anim. Prod.* pp. 76-89.

FERNANDEZ CARMONA, J. and GREENHALGH, J.F.D. (1972). The digestibility and acceptability to sheep of chopped or milled barley straw soaked or sprayed with alkali. *J. Agric. Sci. Camb.* 78: 477-485.

FLACHOWSKY, G., TIROKE, K. and SCHEIN, G. (1991). Botanical fractions of straw of 51 cereal varieties and *in sacco* degradability of various fractions. *Anim. Feed Sci. Technol.* 34: 279-289.

FLATT, W.P. (1988). Feed evaluation systems: Historical background. In "World Animal Science, B4. Feed science". Ørskov, E.R. (Ed.). Elsevier Sci. Pub. Company. NY. pp. 1-22.

FORD, C.W. (1978). Effect of particle de-lignification on the *in vitro* digestibility of cell wall polysaccharides in *Digitaria decumbens* (Pangola grass). *Aust. J. Agric. Res.* 29: 1157-1161.

FORD, C.W. (1983). Effect of particle size and de-lignification on the rate of digestion of hemicellulose and cellulose by cellulase in mature pangola grass stems. *Aust. J. Agric. Res.* 34: 241-248.

FORD, C.W., ELLIOTT, R. and MAYNARD, P.J. (1987). The effect of chlorite de-lignification on digestibility of some grass forages and on intake and rumen microbial activity in sheep fed barley straw. *J. Agric Sci. Camb.* 108: 129-136.

FRANCIS, C.M. (1973). The influence of isoflavone glycosides on the taste of subterranean clover leaves. *J. Sci. Food Agric.* 24: 1235-1240.

FRANKLIN, M.C. and POWNING, R.F. (1942). Studies on the chemical composition of pods and seeds of certain species of *Medicago* with a note on the apparent digestibility of cluster clover (Trifolium glomeratum L.) seed. *J. CSIR. Aust.* 15: 191-200.

FRANKLIN, M.C., McINNES, P. and BRIGGS, P.K. (1964). The seed of *Medicago* species (burr clover) as a supplement to a low protein roughage diet for Merino sheep. *Aust. J. Exp. Agric. Anim. Husb.* 4: 129-131.

FREER, M. (1981). The control of food intake by grazing animals. In "World Animal Science, B1, Grazing animals". Morley, F.H.W. (Ed.). Elsevier sci. Pub. Company. pp. 105-124.

GADDEN, W. (1920). The digestibility of straw after treatment with soda. *J. Agric. Sci. Camb.* 10: 437-456.

GAILLARD, B.D.E. (1962). The relationship between the cell-wall constituents of roughages and digestibility of the organic matter. *J. Agric. Sci. Camb.* 59: 369-373.

GARNSWORTHY, P.C. and COLE, D.J.A. (1990). The importance of intake in feed evaluation. "Feedstuff evaluation". Wiseman, J. and Cole, D.J.A. (Eds.). Butterworths. UK. pp. 147-160.

GARRETT, W.N., WALKER, Jr., H.G., KOHLER, G.O., HART, M.R. and GRAHAM, R.P. (1981). Steam treatment of crop residues for increased ruminant digestibility. II. Lamb feeding studies. *J. Anim. Sci.* 51: 409-413.

GHARIB, F.H., GOODRICH, R.D., MEISKE, J.C. and ELSERAFY, A.M. (1975). Effects of grinding and sodium hydroxide treatment on poplar bark. *J. Anim. Sci.* 40: 723-733.

GILLESPIE, D.J. (1983). Pasture deterioration causes and cures. *West. Aust. J. Agric.* 1: 3-8.

GIVENS, D.I., EVERINGTON, J.M. and ADAMSON, A.H. (1989). Chemical composition, digestibility and energy value *in vivo* of untreated cereal straws produced on farms throughout England. *Anim. Feed Sci. Technol..* 26: 323-335.

GOERING, H.K., SMITH, L.W., VAN SOEST, P.J. and GORDON, C.H. (1973). Digestibility of roughages materials ensiled with sodium chlorite. *J. Dairy Sci.* 56: 233-240.

GÖHL, B. (1981). Tropical feeds. FAO, Animal Production and Health Series, No., 12 Rome, Italy. 529p.

GOMEZ CABRERA, A. and VAN der MEER, J.M. (1988). Rate of degradation of organic matter and neutral detergent fibre in barley straw: Effect of genetic variation and treatment with ammonia on degradation *in sacco* and *in vitro*. *Neth. J. Agric. Sci.* 36: 108-110.

GOULD, J.M. (1985). Studies on the mechanism of alkaline peroxide de-lignification of agricultural residues. (Cited by Lewis *et al.* 1987.)

GRAMSHAW, D., READ, J.W., COLLINS, W.J. and CARTER, E.D. (1989). Sown pastures and legume persistence: an Australian overview. In "Persistence of forage legumes". Marten, G.C., Matches, A.G., Barnes, R.F., Brougham, R.W., Clements, R.J. and Sheath, G.W. (Eds.). Amer. Soc. Agron. pp. 1-21.

GREEHALGH, J.F.D. (1980). Use of straw and cellulosic wastes and methods of improving their value. In "By-products and wastes in Animal feeding". Occasional Publi. No. 3. Ørskov, E.R. (Ed.). *Br. Soc. Anim. Prod.* pp. 25-31.

GREENHALGH, J.F.D. and REID, G.W. (1973). The effects of pelleting various diets on intake and digestibility in sheep and cattle. *Anim. Prod.* 16: 223-233.

GREENHALGH, J.F.D. and REID, G.W. (1974). Long and short term effects on intake of pelleting roughage for sheep. *Anim. Prod.* 19: 77-86.

GREENHALGH, J.F.D. and WAINMAN, F.W. (1972). The nutritive value of processed roughages for fattening cattle and sheep. *Proc. Br. Soc. Anim. Prod.* pp. 61-72.

GROVUM, W.L. (1988). Appetite, palatability and control of feed intake. In "The ruminant animal, digestive physiology and nutrition". Church, D.C. (Ed.). A Reston Book, Prentice Hall, Englewood, Cliffs. NJ. pp. 202-216.

GUGGOLZ, J., KOHLER, G.O. and KLOPFENSTEIN, T.J. (1971). Composition and improvement of grass straw for ruminant nutrition. *J. Anim. Sci.* 33: 151-156.

HACK, W, ASHTON, B. and GILES, B. (1988a). Production feeding of sheep, Management and facilities. Fact Sheet, FS 10/88. Dept. Agric. South Australia. 4p.

HACK, W., ASHTON, B., GILES, B. (1988b). Production feeding of sheep; Health. Fact Sheet., FS 11/88. Dept. Agric. South Australia. 2p.

HACK, W., ASHTON, B., GILES, B. (1988c). Production feeding of sheep. Rations. Fact Sheet, .FS. 12/88. Dept. Agric. South Australia. 4p.

HALL, D.G. and MULHOLLAND, J.G. (1982). Some problems of introducing feedlot rations to lambs. *Proc. Aust. Soc. Anim. Prod.* 14: p. 650.

HALSE, N.J. and WOLFE, E.C. (1985). The contribution of science to Australian temperate zone agriculture. 5. The wheat and sheep zone. *J. Aust. Inst. Agric. Sci.* 51: 185-195.

HAN, Y.W. (1978). Microbial utilisation of straw (a review). *Advances in Applied Microbiology*. 23: 119-153.

HAN, Y.W. and ANDERSON, A.W. (1975). Semisolid fermentation of ryegrass straw. *Appl. Microb.* 30: 930-934.

HAN, Y.W. and CALLIHAN, C.D. (1974). Cellulose fermentation; effect of substrate pre-treatment on microbial growth. *Appl. Microbio.* 27: 159-165.

HAQUE, M.S.M and DOLBERG, F. (1983). Effect of chemical treatment of rice straw supplemented with concentrate on feed intake and weight gain in growing calves. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 129-139.

HARKIN, J.M. (1973). Lignin. In "Chemistry and biochemistry of herbage". Vol. 1. Butter, G.W. and Bailey, R.W. (Eds.) Academic Press. NY. pp. 323-373.

HARRIS, L.E. (1970). Nutrition research techniques for domestic and wild animals. Vol. 1. Utah State University, Logan, Utah, USA.

HART, M.R., WALKER, Jr., H.G., GRAHAM. R.P., HANNI, P.J., BROWN, A.H. and KOHLER, G.O. (1981). Steam treatment of crop residues for increased ruminant digestibility. 1. Effects of process parameters. *J. Anim. Sci.* 51: 402-408.

HARTLEY, R.D. (1981). Chemical constitution, properties and processing of lignocellulosic wastes in relation to nutritional quality for animals. *Agric. Environ.* 6: 91-113.

HARTLEY, R.D. and JONES E.C. (1977). Phenolic compounds and degradability of cell walls of grass and legume species. *Phytochemistry*. 16: 1531-1534.

HARTLEY, R.D. and JONES, E.C. (1978). Effects of aqueous ammonia and other alkalis on the *in vitro* digestibility of barley straw. *J. Sci. Food Agric.* 29: 92-98.

HARTLEY, R.D., JONES, E.C., KING, N.J. and SMITH , G.A. (1974). Modified wood waste and straw as potential components of animal feeds. *J. Sci. Food Agric.* 25: 433-437.

HEGARTY, M.P. (1981). Deleterious factors in forages affecting animal production. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham, Royal, UK. pp. 133-150.

HENING, P.A., der LINDEN, V.Y., MATTHEYSE, M.E., MAUHAUS, W.K. and SCHWARTZ, H.M. (1980). Factors affecting the intake and digestion of roughages by sheep fed maize straw supplemented with maize grain. *J. Agric. Sci. Camb.* 94: 565-573.

HEYN, C.C. (1963). The annual species of Medicago. *Scripta Hierosoly mitana,* Vol XII. The Magnes Press, The Hebrew University. Jerusalem. 154p.

HOGAN J.P. and LECHE, T.F. (1983). Types of fibrous residues and their characteristics. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 3-13.

HOGAN, J. P. and WESTON, R. H. (1969). The digestion of pasture plants by sheep. III. The digestion of forage oats varying in maturity and in content of protein and soluble carbohydrate. *Aust. J. Agric. Res.* 20: 347-363.

HOGAN, J.P., WESTON, R.H. and LINDSAY, J.R. (1969). The digestion of pasture plants by sheep. IV. The digestion of *Phalaris tuberosa* at different stages of maturity. *Aust. J. Agric. Res.* 20: 925-949.

HOLZER, Z., LEVY, D., TAGAR, H. and VOLCANI, R. (1975). Soaking of complete fattening rations high in poor-roughage. 1. The effect of moisture content and spontaneous fermentation on nutritional value. *Anim. Prod.* 21: 323-335.

HOLZER, Z., TAGARI,H. LEVY,D. and VOlCANI, R. (1976). Soaking of complete fattening ration. 2. The effect of moisture content on the performance of male cattle. *Anim. Prod.* 22: 41-53.

HOVELL, F.D. DEB., NGAMBI, J.W.W., BARBER, W.P. and KYLE, D.J. (1986). The voluntary intake of hay by sheep in relation to its degradability in the rumen as measured in nylon bags. *Anim. Prod.* 42: 111-118.

HOWARD, K. and PLASTO, T. (1991). Feedlotting, a guide for beef producers. Qld, Dept. Primary Industry Information Series, No., Q 191015. Brisbane. 81p.

HOWARTH, R.E. (1988). Antiquality factors and non-nutritive chemical components. In "Alfalfa and alfalfa improvement". *Amer. Soc. Agron.* 29: 493-514.

HUFFMAN, J.G., KITTS, W.D. and KRISHNAMURTI, C.R. (1971). Effects of alkali treatment and gamma irradiation on the chemical composition and *in vitro* rumen digestibility of certain species of wood. *Can. J. Anim. Sci.* 51: 457-464.

HUGHES, A.D., EGAN, J.P. and GLAETZER, B.M. (1983). Computer-based least-cost ration formulation for ruminant. In "Feed information and animal production". Robards, G.E. and Packham, R.G. (Eds). Commonwealth Agricultural Bureaux, UK. pp. 369-374.

HUMPHREYS, L.R. (1974). Pasture species, nutritive value and management. In "A course manual in tropical pasture science. Whiteman, P.C. Humphreys, L.R., Monteith, N.H., Hoult, E.H., Bryant, P.M. and Slater, J.E. (Eds.). Australian Vice-Chancellors' Committee. pp. 69-130.

HUNTER, R.A. (1988). Some aspects of the role of concentrates in increasing feed intake and productivity of cattle fed fibrous diets. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 37-48.

HUPP, E.W. and LEWIS, R.C. (1958). Effect of adding water to the concentrate mix on maximum milking rate, average milking rate and eating rate. *J. Dairy Sci.* 724 A.

HUTTON, J.B. (1961). Studies of the nutritive value of New Zealand dairy pastures. I. Seasonal changes in some chemical components of pastures. *NZ. J. Agric. Res.* 4: 583-590.

HYND, P.I. (1982). Wool growth efficiency, a study of the effects of live weight status and diet on wool growth. Ph. D. Thesis, The University of Adelaide, Australia. 211p.

IBRAHIM, M.N.M, KETELAAR, R.S., TAMMINGA, S. and ZEMMELINK, G. (1988). Degradation characteristics of untreated and urea-treated rice straw in the rumen. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 123-126.

IBRAHIM, M.N.M. (1983). Physical, chemical, physico-chemical and biological treatments of crop residues. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 53-68.

IBRAHIM. M.N.M. (1985). Effects of *Gliricidia maculata* leaves on the duration of urea-ammonia treatment of rice straw. In "The utilisation of fibrous agricultural residues as animal feeds". Doyle, P.T. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 77-80.

ICARDA (1984). Research highlights. International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria. pp. 60-64.

ICARDA (1985a). Annual report. International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria. pp. 318-324.

ICARDA (1985b). Research highlights. International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria. pp. 48-49.

ICARDA (1986). Annual report. International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria. pp. 21-24.

ICARDA (1991). Annual report. International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria. pp. 52-55.

ICARDA. (1990-1991). Pasture, forage and livestock program, annual report for 1990/1991. ICARDA, Alippo, Syria. 192p.

JACKSON, M.G. (1977). Review article: The alkali treatment of straws. *Anim. Feed Sci. Technol.* 2: 105-130.

JAYASURIYA, M.C.N. (1983). Problems for treating crop residues at the village level. In "The utilisation of fibrous agricultural residues". Australian Development Assistance Bureau, Canberra, Australia. pp. 100-106. G.R. Pearce Ed.

JEFFERIES, B.C. (1961). Body condition scoring and its use in management. *Tasm. J. Agric.* 32: 19-21.

JEFFERIES, B.C. and NASH, H.M. (1989). Sheep husbandry in South Australia. 98p.

JELAN, Z.A. and KABUL, M.A. (1988). Rate of rumen degradation of several varieties of rice straw. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 127-131.

JOANING, S.W., JOHNSON, D.E. and BARRY, B.P. (1981). Nutrient digestibility depressions in corn silage-corn grain mixture fed to steers. J. Anim. Sci. 53: 1095-1103.

JOHANSON, R.R., RICKETTS, G.E., KLOSTERMAN, E.W. and MOXON, A.L. (1964). Studies on the utilisation and digestion of long, ground and pelleted alfalfa and mixed hay. *J. Anim. Sci.* 23: 94-99.

JONES, M.J. and KLOPFENSTEIN, T.J. (1967). Chemical treatment of poor-quality roughages. *J. Anim. Sci.* 26: 1492 A.

JONES, R.M. and CARTER, E.D. (1989). Demography of pasture legumes. In "Persistence of forage legumes". Marten, G.C., Matches, A.G., Barnes, R.F., Brougham, R.W., Clements, R.J. and Sheath, G.W. (Eds.). Amer. Soc. Agron. pp. 139-156.

JUNG, H.G. (1989). Forage lignins and their effects on fibre digestibility. *Agron. J.* 81: 33-38.

JUNG, H.G., VALDEZ, F.R., ABAD, A.R., BLANCHETLE R.A. and HATFIELD, R.D. (1992). Effect of white rot *basidiomycetes* on chemical composition and *in vitro* digestibility of oat straw and alfalfa stems. *J. Anim. Sci.* 70: 1928-1935.

KANDYLIS, K. and NIKOKYRIS, P. (1991). A reassessment of the nylon bag technique. *World Rev. Anim. Prod.* XXVI: 23-32.

KAPASIOTIS, G.D. (1976). The world food problem. In "Food from waste". Birch, G.G., Parker, K.J. and Worgan, J.T. (Eds.). Applied Science Publishers Ltd. London. pp. 232-241.

KEMP, D. (1993). Managing pastures by grazing. *Proc. Eighth Ann. Conf. Grassland Soc.* NSW. pp. 32-38.

KEMP, D.R. and MICHALK, D.L. (1993). Pasture management: Technology for the 21st century. CSIRO, Melbourne. pp. ix-xi.

KEMPTON, T.J. (1980). The use of nylon bags to characterise the potential degradability of feeds for ruminants. *Torp. Anim. Prod.* 5: 107-116.

KERNAN, J.A., COXWORTH, E.C. and SPURR, D.T. (1981). New crop residues and forages for western Canada: assessment of feeding value *in vitro* and response to ammonia treatment. *Anim. Feed Sci. Technol.* 6: 257-271.

KERNAN, J.A., COXWORTH, E.C., CROWLE, W.L. and SPURR, D.T. (1984). The nutritional value of crop residue components from several wheat cultivars grown at different fertiliser levels. *Anim. Feed Sci. Technol.* 11: 301-311.

KERNAN, J.A., CROWLE, W.L., SPURR, D.T. and COXWORTH, E.C. (1979). Straw quality of cereal cultivars before and after treatment with anhydrous ammonia. *Can. J. Anim. Sci.* 59: 511-517.

KETELAARS, J.J.M.H. and TOLKAMP, B.J.(1992). Toward a new theory of feed intake regulation in ruminants. 1. Causes of differences in voluntary feed intake: Critique of current views. *Livestock Prod. Sci.* 30: 269-296.

KIANGI, E.M.I. and KATEGILE, J.A. (1981). Different sources of ammonia for improving the nutritive value of low-quality roughages. *Anim. Feed Sci. Technol.* 6: 377-386.

KIFLEWAHID, B. (1983). An overview of research methods employed in the evaluation of by-products for use in animal feed. In "By-product utilisation for animal production". Kiflewahid, B., Potts, G.R. and Drysdale, R.M. (Eds.). pp. 93-115.

KING, J.O.L. (1982). Effect of processing on nutrient content of foods and feeds; Water treatment. In "Handbook of nutritive value of processed food". Vol. II. Animal feedstuffs. Milosan, R. Jr. (Ed.). CRC, Press, Inc., Boca Raton, Florida, USA. pp. 129-134.

KJOS, N.P., SUNDSTØL, F. and McBURNEY, M.I. (1987). The nutritive value of weather-damaged and good-quality straw of barley, wheat and oats, untreated and treated with ammonia or sodium hydroxide. *J. Anim. Physiol. Anim. Nutr.* 57: 1-15. (Cited by Castrillo *et al.* 1991).

KLOPFENSTEIN, T.J. and BOLSEN, K.K. (1971). High temperature pressure treated crop residues. *J. Anim. Sci.* 33: 290 A.

KLOPFESTEIN, T.J. (1978). Chemical treatments of crop residues. J. Anim. Sci. 46: 841-848.

KLOPFESTEIN, T.J., KRAUSE, V.E., JONES, M.J. and WOODS, W. (1972). Chemical treatment of low-quality roughages. *J. Anim. Sci.* 35: 418-422.

KOES, R.M. and PFANDEN, W.H. (1974). Increased utilisation of bluestem hay with the addition of water or certain protein sources. *J. Anim. Sci.* 38: 662-668.

KRISTENSEN, V.F. (1982) Effect of processing on nutrient content of feeds: Alkali treatment. In "Handbook of nutritive value of processed food, Vol., II. Animal feedstuffs". Rechcigl, Jr. M. (Ed.). CRC Press. Inc. Boca Raton, Florida. pp. 65-101.

LADD, J.N. and BUTLER, J.H.A. (1992). Sustainability of cropping: The influence of pastures on carbon and nitrogen cycling. *Pasture Symposium*, No. 5. The University of Adelaide. pp. 4-7.

LANGER, R.H.M. (1972). Growth of grasses and clovers. In "Pastures and pastoral plants". Langer, R.H.M. (Ed.). A.H. & A.W. Reed, Wellington. pp. 41-63.

LANGER, R.H.M. and HILL, G.D. (1991). Agricultural plants. Cambridge University Press, Cambridge. 344p.

LANGLANDS, J.P. and WHEELER, J.L. (1968). The dye-banding and tattooed patch procedures for estimating wool production and obtaining samples for the measurement of fibre diameter. *Aust. J. Exp. Agric. Agric. Anim. Husb.* 8: 265-269.

LANGMAN, M. (1988). Worm control in sheep, "the cereal zone". Fact Sheet., FS 26/88. Dept. Agric. South Australia. 4p.

LANGMAN, M., ASHTON, B., MORBEY, T. (1990). Health of sheep lotfed for maintenance. Fact Sheet., FS 5/90. Dept. Agric. South Australia. 5p.

LATHAM, M.J. (1979). Pre-treatment of barley straw with white-rot fungi to improve digestion in the rumen. In "Straw decay and its effect on disposal and utilisation". Grossbard, E. (Ed.). John Wiley and Sons, London. pp. 131-137.

LAZENBY, A. and SWAIN, F.G. (1969). Pasture species. In "Intensive pasture production". Lazenby, A. and Swain, F.G. (Eds). Angus and Robertson, Sydney. pp. 67-69.

LEATHERWOOD, J.M., MOCHZIC, R.D. and THOMAS, N.E. (1960). Some effects of a supplementary cellulose preparation on feed utilisation by ruminants. *J. Dairy Sci.* 43: 1460-1464.

LEHMANN, F. (1895). Uber die Moglichkeit, Stroh Hoher Verdaulich zu Machen. (Cited by SUNDSTØL *et al.* 1979 and BODA 1990).

LEIBHOLZ, J. (1981). Effect of adding water to paspalum (*Paspalum dilatatum*) hay on the feed intake of sheep. *J. Agric. Sci. Camb.* 96: 487-488.

LEIGH, J.H. and HOLGATE, M.D. (1978). Effects of pasture availability on the composition and quality of the diet selected by sheep grazing mature degenerate and improved pastures in the upper Shoalhaven Valley, NSW. *Aust. J. Exp. Agric. Anim. Husb.* 18: 381-390.

LENG, R.A. (1982). A theoretical discussion of the factors limiting production in cattle fed basal diets of straw. In Joint FAO/IAE, division of isotope and radiation applications of atomic energy for feed and agricultural development. Paper No. 1. Vienna, Austria. 21p.

LENG, R.A. (1991). Application of biotechnology to nutrition of animals in developing countries. FAO Animal Production and Health Paper. No. 90. FAO. Rom, Italy. 146 p.

LESOING, G. and KLOPFENSTEIN, T.J (1981). Chemical treatment of wheat straw. *J. Anim. Sci.* 51: 263-269.

LEVY, D., HOLZER, Z., NEUMARK, H. and FOLMAN, Y (1977). Chemical processing of wheat straw and cotton by-products for fattening cattle. *Anim. Prod.* 25: 27-37.

LEWIS, S.M., HOLZGRAEFE, D.P., BEGNE, L.L., FAHEY Jr. G.C., GOULD, J.M. and FANTA, G.F. (1987). Alkali-hydrogen peroxide treatments of crop residues to increase ruminal dry matter disappearance *in sacco*. *Anim. Feed Sci. Technol.* 17: 179-199.

LI, X., KELLAWAY, R.C., ISON, R.L. and ANNISON, G. (1992). Chemical composition and nutritive value of mature annual legumes for sheep. *Anim. Feed Sci. Technol.* 37: 221-231.

LIENER, I.E. (1990). Naturally occurring toxic factors in animal feedstuffs. In "Feedstuff evaluation". Wiseman, J. and Cole, D.J.A. (Eds.). Butterworths. UK. pp. 377-393.

LINDBERG, J.E. (1985). Estimation of rumen degradability of feed protein with the *in sacco* technique and various *in vitro* methods: A review. *Acta Agric. Scand. Suppl.* 25: 64-97.

LINDBERG, J.E. and KNUTSSON, P.G. (1981). Effect of bag pore size on the loss of particular matter and on the degradation of cell wall fibre. *Agric and Environ.* 6: 171-182.

LLOYD DAVIES, H. (1962). Studies of time of lambing in relation to stocking rate in southern-western Australia. *Proc. Aust. Soc. Anim. Prod.* 4: 113.

LLOYD DAVIES, H. (1968). Studies in pasture management for the breeding ewe I. Effects on ewe live weights, incidence of pregnancy toxaemia, lamb birth weights and neo-natal mortality. *Aust. J. Agric. Res.* 19: 605-620.

LLOYD DAVIES, H. and SOUTHEY I.N. (1985). The effect of stocking rate and grazing management upon ewe live weight, ewe fertility, lamb growth and pasture production on subterranean clover based pasture in western Australia. *Proc. XV Int. Grassld. Cong.* pp. 1158-1160.

LOWTON, E.J., BELLANY, W.D., HANGATE, R.T., BRYANT, M.P. And HALL, E. (1951). Some effects of high velocity electrons on wood. *Science.* 113: 380-382.

MACQUARIE LIBRARY (1990). The Macquarie everyday dictionary. Delbridge, A., Bernard, J., Blair, D., Butler, S., Peters, P., Tardif, R. and Butler, J. (Eds). Macquarie University, NSW. Australia. p.589.

MAPOON, L.K. (1980). Degradability of some high protein forages in the rumen. *Trop. Anim. Prod.* 5: 53-56.

MARTEN G.C., BUXTON D.R. and BARNES R.F. (1988). Feeding value (forage quality). In "Alfalfa and alfalfa improvement". Hanson A.A., Barnes, D.K. and Hill, Jr., R.R. (Eds.). *Amer. Soci. Agron.* 29: 463- 291.

MARTEN, G.C. (1985). Factors influencing feeding value and effective utilisation of forages for animal production. *Proc. XV Int. Grassld. Cong.* pp. 89-96.

MARTEN, G.C., MATCHES, A.G., BARNES, R.F., BROUGHAM, R.W., CLEMENTS, R.J. and SHEATH, G.W. (Eds.). (1989). Persistence of forage legumes. Amer. Soc. Agron. Inc., Madison, Wisconsin, USA. pp. XI-XII.

MAYNARD, L.A. and LOOSLI, J.K. (1956). Animal nutrition. McGraw-Hill, Book Company. Inc. NY. 484p.

McDONALD, C.L., NORRIS, R.T., SPEIJERS, E.J. and RIDINGS, H. (1990). Feeding behaviour of Merino wethers under conditions similar to lot-feeding before live export. *Aust. J. Exp. Agric.* 30: 343-348.

McDONALD, P. EDWARDS, R.A., GREENHALGH, J.F.D. (1988). Animal nutrition. Longman Scientific & Technical, London. 543p.

McLEOD, M.N. (1974). Plant tannins, their role in forage quality. *Nutr. Abst. Rev.* 44(11): 803-815.

McLEOD, M.N. and MINSON, D.J. (1976). The analytical and biological accuracy of estimating the dry matter digestibility of different legume species. *Anim. Feed Sci. Technol.* 1: 61-72.

McMANUS, W.R. (1978). Alkali effects on agricultural wastes and their cell wall fraction. *Aust. J. Exp. Agric. Anim. Husb.* 18: 231-242.

McMANUS, W.R. and CHOUNG, C.C. (1976). Studies on forage cell walls. 2. Conditions for alkali treatment of rice straw and rice hulls. *J. Agric. Sci. Camb.* 86: 453-470.

McMANUS, W.R., MANTA, L. and McFARLANE, J.D. (1972). The effect of diet supplements and gamma irradiation on dissimilation of low-quality roughages by ruminants. II. Effects of gamma irradiation and urea supplementation on dissimilation in the rumen. *J. Agric. Sci. Camb.* 79: 41-55.

McMANUS, W.R., MANTA, L., McFARLANE, J. D. and GRAY, A. C. (1972). The effect of diet supplements and gamma-irradiation on dissimilation of low-quality roughages by ruminants. III. Effects of feeding gamma-irradiated based diets of wheaten straw and rice straw to sheep. *J. Agric. Sci. Camb.* 79: 55-66.

McMEEKAN, C.P. (1956). Grazing management and animal production. *Proc. VII Int. Grassld. Cong.* New Zealand. 146-156.

McSWEENEY, C.S. and WESLEY-SMITH, N.W. (1986). Factors limiting the intake by sheep of the tropical legume, *Calopogonium mucunoides*. *Aust. J. Exp. Agric.* 26: 659-664.

MEESKE, R., MEISSNER, H.H. and PIENNAAR, J.P. (1993). The upgrading of wheat straw by alkaline hydrogen peroxide treatment: the effect of NaOH and H_2O_2 on the site and extent of digestion in sheep. *Anim. Feed Sci. Technol.* 40: 121-133.

MEHREZ, A.Z. and ØRSKOV, E.R. (1977). A study of the artificial fibre bag technique for determining the digestibility of feeds in the rumen. *J. Agric. Sci. Camb.* 88: 645-650.

MERCHEN, N.R. (1988). Digestion, absorption and excretion in ruminants. In "The ruminant animal, digestive physiology and nutrition". Church, D.C. (Ed.). A Reston Book Prentice Hall, Eaglewood, Cliffs. N.J. pp. 172-201.

MERTENS, D.R. (1987). Predicting intake and digestibility using mathematical models of-ruminal function. *J. Anim. Sci.* 64: 1548-1558.

MEYER, J.H. and JONES, L.G. (1962). Controlling alfalfa quality. Calif. Agric. Exp. Stn. Bull. 784. (Cited BY Marten, G. C., *et al* 1988).

MEYER, J.H., GASKILL,R.C., STOEWSAND, G.S. and WEIR., W.C. (1959). Influence of pelleting on the utilisation of alfalfa. *J. Anim. Sci.* 18: 336-346.

MICHALET-DOREAU, B. and CERNEAU, P. (1991). Influence of foodstuff particle size on *in situ* degradation of nitrogen in the rumen. *Anim. Feed Sci. Technol.* 35: 69-81.

MILLER, B.L., FAHEY, Jr., G.C., RINDSIG, R.B., BERGER, L.L. and BOTTJE, W.G. (1979). *In vitro* and *in vivo* evaluations of soy-bean residues ensiled with various additives. *J. Anim. Sci.* 49: 1545-1551.

MILLETT, M.A., BAKER, A.J., FEIST, W.C., MELLENBERGER, R.W. and SATTER, L.D. (1970). Modifying wood to increase its *in vitro* digestibility. *J. Anim. Sci.* 31: 781-785.

MINSON, D.J. (1963). The effect of pelleting and wafering on the feeding value of roughage. A review. *J. Br. Grassld. Soc.* 18: 39-49.

MINSON, D.J. (1980). Nutritional differences between tropical and temperate pastures. In "World Animal Science, B1, Grazing animals". Morley, F.H.W. (Ed.). Elsevier sci. Pub. Company. pp. 143-157.

MINSON, D.J. (1981). Effects of chemical and physical composition of herbage eaten upon intake. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham, Royal, UK. pp. 167-182.

MINSON, D.J. (1987). Estimation of the nutritive value of forage. In "Temperate pastures, their production, use and management". Wheeler, J.L., *et al.* (Eds.). Australian Wool Corporation, CSIRO. Australia. pp. 415-422.

MINSON, D.J. (1990). Forage in ruminant nutrition. Academic Press, Inc. San Diego. USA. 483p.

MINSON, D.J. and MILFORD, R. (1966). The energy value and nutritive value indices of *Digitaria decumbens, Sorghum almum and Phaseolus atropurpureus. Aus. J. Agric. Res.* 17: 411-423.

MOE, P.W. (1981). Energy metabolism of dairy cattle. *J. Dairy Sci.* 64: 1120-1139.

MOIR, K.W., LAWS, L. and BLIGHT, G. (1975). The relative importance of the total cell wall and quantity of digested cell wall in the regulation of the voluntary intake of grass hays by sheep. *J. Agric. Sci. Camb.* 85: 39-43.

MONTGOMERY, M.J. and BAUMGARDT, B.R. (1965). Regulation of food intake in ruminants 1. Pelleted rations varying in energy concentration. *J. Dairy Sci.* 48: 569-574.

MOORE, J. (1990). Current lot-feeding industry in Australia. In "Lot-feeding and beef production", Postgraduate Committee in Veterinary Science., Proc. No. 137., University of Sydney, Sydney. pp. 323-326.

MORBEY, A.S.C. and ASHTON, B.L. (1990). Lot-feeding of sheep on Eyre Peninsula during the 1988 drought. Tech. Report. No. 155. Dept. Agric. South Australia. 33p.

MORLEY, F.H.W., BENNETT, D. and McKINNEY, G.T. (1969). The effect of intensity of rotational grazing with breeding ewes on phalaris-subterranean clover pasture. *Aust. J. Exp. Agric. Anim. Husb.* 9: 74-84.

MORRIS, E.J. and BACON, J.S.D. (1977). The fate of acetyl groups and sugar components during digestion of grass cell wall in sheep. *J. Agric. Sci.* 89: 327-340.

MORRISON, F.B. (1957). Feeds and feeding, A handbook for the student and stockman. The Morrison Publishing Company, Ithaca, NY., USA. 1165p.

MOULD, F.L. (1988). Associative effects of feeds. In "World Animal Science, B4. Feed science". Ørskov, E.R. (Ed.). Elsevier Sci. Pub. Company. pp. 279-292.

MOWAT, D.N. and OLOLADE, B.G. (1970). Effect of level of sodium hydroxide treatment on digestibility and voluntary intake of straw. *Proc. Can. Soc. Anim. Prod.* p. 35 A.

NAKASHIMA, Y. and ØRSKOV, E.R. (1992). Rumen degradation of straw A. Effect of cellulase and ammonia treatment on different varieties of rice straw and their botanical fractions. *Anim. Prod.* 50: 309-317.

NAVARATNE, H.V.R.G., IBRAHIM, M.N.M. and SCHIERE, J.B. (1987). Validity of some laboratory techniques to predict *in vivo* organic matter digestibility of roughages.

In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 107-113.

NIKOLIC, J.A. (1982). Some factors influencing the effect of alkali treatment on crop residues. *J. Agric. Sci. Camb.*. 99: 115-122.

NIKOLOEVA, L.I. (1938). Ammonium hydroxide treatment of straw. Problems, Animal Husbandry (USSR). 7: 175-178. *Chem. Abst.* 35: 817, 1941).

NIVEN, D.R. and ENTWISTLE, K.W. (1983). Supplementary feeding of sheep consuming mulga (*Acacia aneura*) with low levels of molasses and urea under field conditions. *Aust. Rangeland. J.* 5(2): 74.

NOCEK, J.E. (1985). Evaluation of specific variables affecting *in situ* estimates of ruminal dry matter and protein digestion. *J. Anim. Sci.* 60: 1347-1358.

NOCEK, J.E. (1988). *In situ* and other methods to estimate ruminal protein and energy digestibility: A review. *J. Dairy Sci.* 71: 2051-2069.

NRC (National Research Council). (1988). Nutrient requirement of dairy cattle. National Academy Press, Washington D.C., USA. 54p.

O'SHEA, J. and BALDWIN, A. (1986). Evaluation of the increase in feeding value of barley straw following mild treatment with sulphur dioxide. *Anim. Feed Sci. Technol.* 15: 13-19.

ODDY, V.H., ROBARDS, G.E. and LOW, S.G. (1983). Prediction of *in vivo* dry matter digestibility from the fibre and nitrogen content of a feed. In "Feed information and animal production". Commonwealth Agricultural Bureaux. UK. pp. 395-398.

OECD (Organisation for Economic Co-operation and Development). (1975). Agricultural policy in Australia. pp. 11-27.

OJI, U.I. and MOWAT, D.N. (1978). Nutritive value of steam-treated corn stover. *Can. J. Anim. Sci.* 58: 771-781.

OLDHAM, J.D. and EMMANS, G.C. (1990). Animal performance as the criterion for feed evaluation. In "Feedstuff evaluation". Wiseman, J. and Cole, D.J.A. (Eds.). Butterworths. UK. pp. 73-90.

OLOLADE, B.G., MOWAT, D.N. and WINCH, J. E. (1970). Effect of processing methods on the *in vitro* digestibility of sodium hydroxide treated roughages. *Can. J. Anim. Sci.* 50: 657-662.

ORAM, P.A (1993). Global perspective on population, resources and agricultural production. *Proc. 7th Aust. Agron. Conf.*, Adelaide. p. 7.

ØRSKOV, E.R. and DeB HOVEL, F.D. (1978). Rumen digestion of hay (measured with dacron bags) by cattle given sugar cane or pangola hay. *Trop. Anim. Prod.* 3: 9-11.

ØRSKOV, E.R., DeB HOVELL, F.D. and MOULD, F. (1980). The use of the nylon bag technique for the evaluation of feedstuffs. *Trop Anim. Prod.* 5: 195-213.

ØRSKOV, E.R., REID, G.W. and KAY, M. (1988). Prediction of intake by cattle from degradation characteristics of roughages. *Anim. Prod.* 46: 29-34.

ØRSKOV, E.R., REID, G.W., HOLLAND, S.M., TAIT, C.G. and LEE, N.H. (1983). The feeding value for ruminants of straw and whole-crop barley and oats treated with anhydrous or aqueous ammonia or urea. Anim. Feed Sci. Technol. 8: 247-257.

OWEN, E. (1976). Farm wastes; straw and other fibrous materials. In "Food production and consumption, the efficiency of human food chains and nutrient cycles". North-Holland publishing company. Amsterdam. pp. 299-318.

OWEN, E. (1978). Processing of roughages. In "Recent advances in animal nutrition". Butterworths, London. pp. 127-148.

PADUANO, D.C., SLOCOMBE, R.F., HOLMES, J.H.G. and DIXON, R.M. (1990). Cow peas and navy beans as supplements for roughage diets for sheep. *Proc. Aust. Soc. Anim. Prod.* 18: 536.

PARR, W.H., CAPPER, B.S., COX, D.R.S., JEWERS, K., MARTER, A.D., NICHOLS, W., SILVEY, D.R. and WOOD, J.F. (1988). The small-scale manufacture of compound animal feed. Overseas Development Natural Resources Institute. Bulletin No. 9. ODNRI, London. (Cited by Capper 1988).

PEARCE, G.R. and MOIR, R.J. (1964). Rumination in sheep. 1. The influence of rumination and grinding upon the passage and digestion of food. *Aust. J. Agric. Res.* 15: 635-644.

PEARCE, G.R., SIMPSON, R.J., BALLARD, R. and STEPHENSON, D. (1987). The feeding value of dead pasture grasses. In "Temperate pastures, their production, use and management". Wheeler, J.L., Pearson, C.J. and Robards, G.E. (Eds.). Australian Wool Corporation, CSIRO. Aust. pp. 429-431.

PESTANA, B. (1993-1994). Agriculture in the Australian economy. In "Australian agriculture, the complete reference on rural industry. National Farmers Federation. Melbourne. pp. 9-31.

PIENAAR, J.P., ROUX, C.Z. and CRONJE, P.B. (1989). Comparison of *in vivo* and *in sacco* methods to estimate mean retention time of fermentable organic matter in the rumen. *S. Afr. Anim. Sci.* 19: 71-75.

PLAYNE, M.J., KHUMNUALTHONG, W. and ECHEVARRIA, M.G. (1978). Factors affecting the digestion of oesophageal fistula samples and hay samples in nylon bags in the rumen of cattle. *J. Agric. Sci. Camb.* 90: 193-204.

PRATLEY, J.E. (GODYN, D.L.) (1991). Pasture management. In "Australian Sheep and Wool Handbook". Cottle, D.J. (Ed.). Inkata Press. Melbourne. pp. 267-285.

PRITCHARD, D.A., STOCKS, D.L., O'SULLIVAN, B.M., MARTIN, P.R., HURWOOD, I.S. and O'ROUKE, P.K. (1988). The effect of Poly-Ethylene Glycol (PEG) on wool growth and live weight of sheep consuming a mulga (*Acacia aneura*) diet *Proc. Aust. Soc. Anim. Prod.* 17: 290-293.

PRITCHARD, G. I., PIDGEN, W.J. and MINSON, D.J. (1962). Effect of gamma irradiation on the utilisation of wheat straw by rumen microorganisms. *Can. J. Anim. Sci.* 42: 215-217.

PROMMA, S. (1988). Urea treatment of roughages: A review of present technology and adoption. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 27-35.

PROMMA, S., TUIKUMPEE, S., RATNAVANIJA, A., VIDHYAKORN, N. and FROEMERT, R.W. (1985). The effects of urea-treated rice straw on growth and milk production of crossbred Holstein Friesian dairy cattle. In "The utilisation of fibrous agricultural residues as animal feeds". Doyle, P.T. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 88-93.

PUCKRIDGE, D.W. and FRENCH, R.J. (1983). The annual legume pasture in cereal-ley farming systems of southern Australia: A review. *Agric. Ecosys. Environ.* 9: 229-267.

PURSER, D.B, TAYLOR, G.B. and COLLINS, W.J. (1987). Nutritive value improvement in Mediterranean regions. In "Improving the nutritive value of forage". Technical report No. 20. Standing Committee on Agriculture, Canberra, Australia. pp. 94-104.

PURSER, D.B. (1980). Nutritional value of Mediterranean Pastures. In "World Animal Science, B1, Grazing animals". Morley, F.H.W. (Ed.). Elsevier sci. Pub. Company. pp. 159-180.

QUIGLEY, P.E. (1988). The effects of cereal straw residues on germination, emergence and productivity of annual medics. Ph.D. Thesis, The University of Adelaide, Australia. 254p.

QUIGLEY, P.E. and CARTER, E.D. (1985). The effects of cereal straw on productivity of annual medic pastures. *Proc. Aust. Agron. Conf.*, Hobart, Tasmania. p. 205.

QUIN, J.I., VANDER WATH, J.G. and MYBURGH, S. (1938). Studies in the alimentary tract of Merino sheep in South Africa. 4. Description of experimental techniques. *J. Vet. Sci. Anim. Ind.* 11: 341.

QUINLIVAN, B.J. (1962) The effect of constant and fluctuating temperatures on the permeability of the hard seeds of some legume species. *Aust. J. Agric. Res.* 12: 1009-1022.

QUINLIVAN, B.J. (1965). The influence of the growing season and the following dry season on the hardseededness of subterranean clover in different environments. *Aust. J. Agric. Res.* 16: 277-291.

RADCLIFFE, J.C. and COCHRANE, M.J. (1970). Digestibility and crude protein changes in ten maturing pasture species. *Proc. Aust. Soc. Anim. Prod.* 8: 531-536.

RALSTON, A.T., CHURCH, D.C. and OLDFIELD, J.F. (1962). Effect of enzymes on digestibility of low-quality roughage. *J. Anim. Sci.* 21: 306-308.

RAMANZIN, M., ØRSKOV, E.R. and TUAH, A.K. (1986). Rumen degradation of straw. 2. Botanical fraction of straw from two barley cultivars. *Anim. Prod.* 43: 271-278.

RAMASAMY, K. and VERACHTERT, H. (1979). Fermentation of wheat straw by *Pseudomonas* sp. In "Straw decay and its effect on disposal and utilisation". Grassbard, E. (Ed.). John Wiley & Sons. London. pp. 155-163.

RANGNEKAR, D.V., BADVE, V.C., KHARAT, S.T., SOBALE, B.N. and JOSHI, A.L. (1982). Effect of high-pressure steam treatment on chemical composition and digestibility *in vitro* of roughages. *Anim. Feed Sci. Technol.* 7: 61-70.

RAYMOND, W.F. (1969). The nutritive value of forage crops. *Adv. Agron.* 21: 1-108.

REED, K.F.M. and COCKS, P.S. (1982). Some limitations of pasture species in southern Australia. *Proc. 2nd Aust. Agron. Conf.* Wagga Wagga. NSW. pp. 142-160.

REED, K.F.M., MATHISON, M.J. and CRAWFORD, E.J. (1989). The adaptation, regeneration and persistence of annual legumes in temperate pasture. In "Persistence of forage legumes". Marten, G.C., Matches, A.G., Barnes, R.F., Brougham, R.W., Clements, R.J. and Sheath, G.W. (Eds.). Amer. Soc. Agron. pp. 69-89.

REEVE, R.C. (1991). A manual of integrated cereal/livestock farming systems in Jordan. SAGRIC International, Australian International Development Assistance Bureau. p. 38.

REEVES, T.G. (1987). Pastures in cropping systems. In "Temperate pastures, their production, use and management". Wheeler, J.L., Pearson, C.J. and Robards, G.E. (Eds.). Australian Wool Corporation, CSIRO. Aust. pp. 501-515.

REHN, B. (1988). Overcoming the feedlot phobia. *Stock Journal, Adelaide, Aug. 18*, p. 17.

REID, C.S.W. (1973). Limitations to the productivity of the herbage-fed ruminant that arise from the diet. In "Chemistry and biochemistry of herbage". Butter, G.W. and Bailey, R.W.(Eds.). NY. Academic Press. pp. 215-262.

REID, G.W., ØRSKOV, E.R. and KAY, M. (1988). A note on the effect of variety, type of straw and ammonia treatment on digestibility and on growth rate in steers. *Anim. Prod.* 47: 157-160.

REXEN, F. and THOMSON, K.V. (1976). The effect on digestibility of a new technique for alkali treatment of straw. *Anim. Feed Sci. Technol.* 1: 73-83.

REYNOLDS, P. J. and LINDAHL, I. L. (1960). Effect of pelleting on the digestibility of hay by sheep. *J. Anim. Sci.* 19: 873-880.

ROBARDS, G.E., ANDREWS, C.L. and WILLIAMS, G.A. (1983). Sodium hydroxide treatment and urea supplementation of chaffed wheaten straws. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 109-111.

RODDA, Q. (1992). Flexibility in management - feedlotting. *Pasture Symposium,* No. 5. The University of Adelaide. pp. 46-48.

ROSSITER, R.C. (1966). Ecology of the Mediterranean annual-type pasture. *Advances in Agronomy*. 18: 1-56.

ROUNDS, W., KLOPFENSTEIN, T.J., WALLER, J. and MESSERSMITH, T. (1976). Influence of alkali treatments of corn cobs on *in vitro* dry matter disappearance and lamb performance. *J. Anim. Sci.* 43: 478-482.

ROWE, J.B., BROWN, G., RALPH, I.G., FERGUSON, J. and WALLACE, J.F. (1989). Supplementary feeding of young Merino sheep grazing wheat stubble, with different amounts of lupin, oat or barley grain. *Aust. J. Exp. Agric.* 29: 29-35.

ROXAS, D.B., LAPITAN, R.M., ROXAS, E., del BaRRIO, A.N., MOMONGAN, V.G. and RANJHAN, S.K. (1987). Effects of soaking rice straw on growth performance of Philippine Carabaos. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 173-175.

RUSSLE, A.J.F., DONEY, J.M., GUNN, R.G. (1969). Subjective assessment of body fat in live sheep. *J. Agric. Sci. Camb.* 72: 451-454.

SAHNOUNE, S., BESLE, J.M., CHENOST, M., JOUANY, J.P. and COMBES, D. (1991). Treatment of straw with urea. 1. Ureolysis in a low water medium. *Anim. Feed Sci. Technol.* 34: 75-93.

SAVVANT, D., CHAPOUTOT, P. and LAPIERRE, O. (1983). A general model of diet least cost formulation for lactating and growing cattle. In "Feed information and animal production". Robards, G.E. and Packham, R.G. (Eds). Commonwealth Agricultural Bureaux, UK. pp. 275-382.

SCA (Standing Committee on Agriculture). (1990). Feeding standard for Australian livestock. Ruminants. CSIRO. Australia. 266p.

SCHIERE, J.B., IBRAHIM, M.N.M., SEWALT, V.J.H. and ZEMMELINK, G. (1988). Effect of urea-molasses lick block supplementation on intake and digestibility of rice straw fed to growing animals. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 205-212.

SCHIERE, J.B., NELL, A.J. and IBRAHIM, M.N.M. (1985). Approaches to determine the economics of feeding urea-ammonia treated straw, untreated straw or urea supplemented straw. In "The utilisation of fibrous agricultural residues as animal feeds". Doyle, P.T. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. 127-131.

SCHNEIDER, B.H. and FLATT, W.P. (1975). The evaluation of feeds through digestibility experiments. The University of Georgia Press, Athens. USA. 423p.

SCOTT, B.J. and BROWNLEE, H. (1970). Annual medic for improved pastures in the central western low rainfall wheat belt. *Agric. Gaz.* NSW.81: 62-69.

SEOANE,J.R., COTE, M. and VISSER, S.A. (1982). The relationship between voluntary intake and the physical properties of forages. *Can. J. Anim. Sci.* 62: 473-480.

SETÄLÄ, J. (1985). Aspects on the determination of ruminal feed protein degradation and the quality of the undegradable feed protein *in sacco. Acta Agric. Scand. Suppl.* 25: 98-102.

SHARKEY, M.J., DAVIS, I.F. and KENNEY, P.A. (1962). The effect of previous and current nutrition on wool production in southern Victoria. *Aust. J. Exp. Agric. Anim. Husb.* 2: 160-169.

SHARKEY, M.J., DAVIS, I.F. and KENNEY, P.A. (1964). The effect of rate of stocking with sheep on the botanical composition of an annual pasture in southern Victoria. *Aust. J. Exp. Agric. Anim. Husb.* 4: 34-38.

SHAW, F.D. and THORNTON, R.F. (1974). Technical notes, linear programming techniques for the formulation of least cost feedlot ration. *J. Aust. Inst. Agric. Sci.* Dec., 1974: 295-298.

SHEEHY, E.J. (1955). Animal nutrition. MacMillan & Co. Ltd. London. 732p.

SIEBERT, B.D. (1974). The treatment of a tropical roughages with alkali, nitrogen and sulphur in relation to the nutritional limitations of pastures in northern Australia. *Proc. Aust. Soc. Anim. Prod.* 10: 86-90.

SIEBERT, B.D., HUNTER, R.A. (1981). Supplementary feeding of grazing animals. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham Royal, UK. pp. 409-426.

SIMAO NETO, M. and JONES, R.M. (1987). Recovery of pasture seed ingested by ruminants. 2. Digestion of seed *in sacco* and *in vitro. Aust. J. Exp. Agric.* 27: 247-251.

SIMAO NETO, M., JONES, R.M and RATCLIFF, D. (1987). Recovery of pasture seed ingested by ruminants. 1. Seed of six tropical pasture species fed to cattle, sheep and goats. *Aust. J. Exp. Agric.* 27: 239-246.

SINGH, M. and JACKSON, M.G. (1971). The effects of different levels of sodium hydroxide spray treatment of wheat straw consumption and digestibility by cattle. *J. Agric. Sci. Camb.* 77: 5-10.

SMETHAM, N.L. (1967). Grazing management. In Pastures and Pasture plants. Langer, R.H.M. (Ed.). A.H & A. Reed. Wellington, New Zealand. pp. 179-228.

SMITH, T. and BROSTER, W.H. (1977). The use of poor-quality fibrous source of energy by young cattle. *World Review of Animal Production.* 13(1): 49-58.

SNEDECOR, G.W. and COCHRAN, W.G. (1971). Statistical methods. The Iowa State University Press, Ames, Iowa, USA. 593p.

SOLOMON, R., MIRON, J., RUBINSTEIN, A. and BEN-GHEDALIA, D. (1992). Ozone-treated cotton stalks as a component of a ration for growing lambs. *Anim. Feed Sci. Technol.* 37: 185-192.

SOUTH AUSTRALIA DEPARTMENT of AGRICULTURE. (1991). Agriculture in South Australia: a profile. Dep. Agric. South Australia. Adelaide. 23p.

SPEDDING, C.R. (1971). Grassland ecology. Claredon Press, Oxford. 221p.

SQUELLA, F. (1992). The ecological significance of seed size in Mediterranean annual pasture legumes. Ph. D. Thesis, The University of Adelaide, 466p.

SQUELLA, F. and CARTER, E.D. (1992). Effects of seed size and level of hard-seededness on survival of medic seeds in whole pods fed to sheep or as clean seed exposed in the sheep rumen. *Proc. 6th Aust. Soc. Agron. Conf.*, Armidale, Australia. p. 537.

SQUIRES, V.R. (1981) Livestock management in the arid zone. Inkata Press. Melbourne. pp. 3-13.

SQUIRES, V.R. (1991). Extensive grazing systems. In "Australian Sheep and Wool Handbook. Cottle, D.J. (Ed.). Inkata Press. Melbourne. pp. 369-379.

STOBBS, T.H. (1973). The effect of plant structure on the intake of tropical pastures, II. Differences in sward structure, nutritive value, and bite size of animal grazing *Setaria anceps* and *Chloris gayana* at various stages of growth. *Aust. J. Agric. Res.* 24: 821-829.

STUTH, T.W., BROWN, J.R., OLSON, P.D. and ARAUGO, M.R. (1985). Influence of stocking rate on the plant-animal interface in rotational grazed mixed swards. *Proc. XV Int. Grassld. Cong.* 1148-1150.

SUCKLING, F.E.T. (1950). The passage of white clover seeds through the body of sheep and the effect on germination capacity. *Proc. NZ Grassld. Assoc. Conf.* 12: 108-121.

SUNDSTØL, F. (1984). Ammonia treatment of straw: Methods for treatment and feeding experience in Norway. *Anim. Feed. Sci. Technol.* 10: 173-187.

SUNDSTØL, F. (1988). Improving of poor-quality forages and roughages. In "World Animal Science, B4. Feed science". Ørskov, E.R. (Ed.). Elsevier Sci. Pub. Company. pp. 257-277.

SUNDSTØL, F. SAID, A.N. and ARNASON, J. (1979). Factors influencing the effect of chemical treatment on the nutritive value of straw. *Acta Agric. Scand.* 29: 179-190.

SUNDSTØL, F., COXWORTH, E. and MOWAT, D.N. (1978). Improving the nutritive value of straw and other low-quality roughages by treatment with ammonia. *World Anim. Rev.*. 26: 13-21.

SUSMEL, P., STEFANON, B., MILLS, C.R. and SPANGHERO, M. (1990). Rumen degradability of organic matter, nitrogen and fibre fractions in forages. *Anim. Prod.* 51: 515- 526.

TANNENBAUM, S.R. and PACE, G.W. (1976). Food from waste: an over-view. In Food from waste. ASP Ltd., London. pp. 8-22.

TAYLOR, G.B., ROSSITER, R.C. and PALMER, M.J. (1984). Long term patterns of seed softening and seedling establishment from single crops of subterranean clover. *Aust. J. Exp. Agric.* 24: 200-212.

THIAGO, L.R.L.S. and KELLAWAY, R.C. (1982). Botanical composition and extent of lignin fraction affecting digestibility of wheat and oat straw and paspalum hay. *Anim. Feed Sci. Technol.* 7: 71-81.

THOMAS, C. and CHAMBERLAIN, D.G. (1990). Evaluation and prediction of the nutritive value of pastures and forages. In "Feedstuff evaluation". Wiseman, J. and Cole, D.J.A. (Eds). Butterworths. UK. pp. 319-336.

THOMSON, E.F., RIHAWI, S. and COCKS, P.S. (1987). The survival of medic seed ingested by sheep. In ICARDA Pasture Forage and Livestock Program: Annual report. Aleppo, Syria. pp. 135-141.

THOMSON, I.J.M. and POOLE, N.J. (1979). Improving the nutritional value of straw. "Straw decay and its effect on disposal and utilisation". Grassbard, E. (Ed.). John Wiley & Sons. London. p.261.

TILLEY, J.M.A., and TERRY, R.A. (1963). A two-stage technique for the *in vitro* digestion of forage. *J. Br. Grassld. Soc.* 18: 104-111.

TRUMBLE, H.C. (1937). Some factors affecting the germination and growth of herbage plants in *South Australia. J. Agric.* 49: 779-786.

TRUMBLE, H.C. and DONALD, C.M. (1938). Soil factors in relation to the distribution of subterranean clover and some alternative legumes. *J. Aust. Inst. Agric. Sci.* 14: 206-208.

TUAH,A.K., LUFADEJU, E., ØRSKOV, E.R. and BLACKET, G.A.(1986). Rumen degradation of straw 1. Untreated and ammonia-treated barley, oat and wheat straw varieties and triticale straw. *Anim. Prod.* 43: 261-269.

TUCKER, R.W., WATTS, P.J., LOTT, S.L. and JUKES, P. (1991). Lot-feeding in Australia, a survey of the Australian lot-feeding industry. Qld. Dept. Prim. Indus. 143p.

TYLER, C. (1966). Animal nutrition. Chapman and Hall. London. UK. 253p.

UDEN, P. and VAN SOEST, P.J. (1984). Investigation of the *in situ* bag technique and a comparison of the fermentation in heifers, sheep, ponies and rabbits. *J. Anim. Sci.* 58: 213-221.

UDEN,P., PARRA, R. and VAN SOEST P.J. (1974). Factors influencing reliability of the nylon bag technique. *J. Dairy Sci.* 57: 622 A.

VAN der HONING, Y. and STEG, A. (1990). Comparison of energy evaluation systems of feeds for ruminants. In "Feedstuff evaluation". Wiseman, J. and Cole, D.J.A. (Eds.). Butterworths. UK. pp. 1-19.

VAN der KOELEN, C.J., GOEDHART, P.W., VAN VUUREN, A.M. and SAVOINI, G. (1992). Sources of variation of the *in situ* nylon bag technique. *Anim. Feed Sci. Technol.* 38: 35-42.

VAN KEULEN, J. and YOUNG, B.A. (1977). Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. *J. Anim. Sci.* 44: 282-287.

VAN KEUREN, R.W. and HEINEMANN, W.W. (1962). Study of a nylon bag technique for *in vivo* estimation of forage digestibility. *J. Anim. Sci.* 21: 340-345.

VAN NIEKERK, A.I., GREENHALGH, J.F.D. and REID, G.W. (1973). Importance of palatability in determining the feed intake of sheep offered chopped and pelleted hay. *Br. J. Nutr.* 30: 95-105.

VAN SOEST, P.J. (1967). Development of a comprehensive system of feed analysis and its application to forages. *J. Anim. Sci.* 26: 119-128.

VAN SOEST, P.J. (1969). Newer knowledge on the composition and methods of analysis of feedingstuffs . In "Nutrition of animals of agricultural importance, part 1: The science of nutrition of farm livestock. Cuthbertos, D. (Ed.). Pergamon Press. UK. pp. 38-58.

VAN SOEST, P.J. (1981). Limiting factors in plant residues of low biodegradability. *Agric. Environ.* 6: 135-143.

VAN SOEST, P.J. (1982). Nutritional ecology of the ruminant. O&B Books, Inc., Corvallis, Oregon, USA. 374p.

VARVIKKO, T., LINDBERG, J.E., SETÄTÄ, J. and SYRJÄLÄ QVIST, L. (1983). The effect of formaldehyde treatment of soya-bean meal and rapeseed meal on the amino acid profiles and acid-pepsin solubility of rumen undegraded protein. *J. Agric. Sci. Camb.* 101: 603-612.

VERCOE, J.E. and PEARCE, G.R. (1960). Digestibility of *Medicago tribuloides* (barrel medic) pods. *J. Aust. Inst. Agric. Sci.* 26: 67-70.

VERMA, M.L. (1983). Practical aspects of treatment of crop residues. In "The utilisation of fibrous agricultural residues". Pearce, G.R. (Ed.). Australian Development Assistance Bureau, Canberra, Australia. pp. 85-99.

VERMA, M.L., AGARWAL, I.S., JAISWAL, R.S. and SINGH, R. (1982). Effect of chemical treatment of crop residues on animal performance. In "Maximum livestock production from minimum land". Preston, T.R., Davis, C.H., Dolberg, F., Mozammel, H. and Saadullah, M. (Eds.). pp. 135-140. (Cited by Doyle *et al.* 1986).

VIK-MO, L. and LINDBERG, J.E. (1985) *In sacco* degradability of protein (N) and dry matter in samples of individual feeds or combinations tested with diets medium or high in protein. Acta Agric. Scand. 35: 117-128.

VON KEYSERLINGK, M.A.G. and MATHISON, G.W. (1989). Use of the *in situ* technique and passage rate constant predicting voluntary intake and apparent digestibility forages by steers. *Can. J. Anim. Sci.* 69: 973-987.

WAISS, Jr., A.C., GUGGOLZ, J., KOHLER, G.O., WALKER, Jr., H.G. and GARRETT, W.N. (1972). Improving digestibility of straws for ruminant feed by aqueous ammonia. *J. Anim. Sci.* 35: 109-112.

WALLACE, J.D., RALEIGH, R.J. and SOWYER, W.A. (1961). Utilisation of chopped, wafered and pelleted native meadow hay by weaned Hereford calves. *J. Anim. Sci.* 20: 778-781.

WALLER, J.C. and KLOPFENSTEIN, T.J. (1975). Hydroxides for treating crop residues. *J. Anim. Sci.* 41: 424 A.

WALSH, F. (1974). Cheap feed-clutching at straw. *Dairy Farmer.* May, 1974, p. 29.

WANAPAT, M. (1987). Effect of concentration of urea, addition of salt and form of urea-treated rice straw on intake and digestibility. In "Ruminant feeding systems utilising fibrous agricultural residues". Dixon, R.M. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 177-179.

WANAPAT, M., SUNDSTØL, F. and GARMO, T.H. (1985). Comparison of different alkali treatments applications to barley straw. In "The utilisation of fibrous agricultural residues as animal feeds". Doyle, P.T. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 103-109.

WANAPAT, M., SUNDSTØL, F. and HALL, J.M.R. (1985). Comparison of in vivo, *in vitro* and *in sacco* digestibility estimates and barley straw treated in different ways. In "The utilisation of fibrous agricultural residues as animal feeds". Doyle, P.T. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 110-115.

WANAPAT, M., SUNDSTØL, F. and HALL, J.M.R. (1986). A comparison of alkali treatment methods used to improve the nutritive value of straw, II *In sacco* and *in vitro* degradation relative to *in vivo* digestibility. *Anim. Feed. Sci. Technol.* 14: 215-220.

WARREN, B.E., BUNNY, C.J. and BRYANT, E.R. (1990). A preliminary examination of the nutritive value of four saltbush (*Atriplex*) species. *Proc. Aust. Soc. Anim. Prod.* 18: 424-427.

WEAKLEY , D.C., STERN, M.D. and SATTER. L.D. (1983). Factors affecting disappearance of feedstuffs from bags suspended in the rumen. *J. Anim. Sci.* 56: 493-507.

WEAKLEY, D.C. and OWENS, F.N. (1975). Ozone delignification. *J. Anim. Sci.* 41: 425A.

WEBBER, G.D., COCKS, P.S. and JEFFERIES, B.C. (1976). Farming systems in South Australia. Dry land farming in a semi-arid climate. Dept. Agric. and Fisheries and Trade and Development. Division Premier's Department. South Australia. 102p.

WEIR, W.C., MEYER, J.H., GARRETT, W.N. and LOFGREEN, G.P. (1959). Pelleted rations compared to similar rations fed chopped or ground for steers and lambs. *J. Anim. Sci.* 18: 805-814.

WESTON, R.H. (1966). Factors limiting the intake of feed by sheep. 1. The significance of palatability, the capacity of the alimentary tract to handle digesta and the supply of glycogenic substrate. *Aust. J. Agric. Res.* 17: 939-954.

WESTON, R.H. (1967). Factors limiting the intake of feed by sheep. II Studies with wheaten hay. *Aust. J. Agric. Res.* 18: 983-1002.

WESTON, R.H. (1979). Feed intake regulation in sheep. In ""Physiological and environmental limitations to wool growth". Black, J.L. and Reis, D.J. (Eds). University of New England Publishing Unit. Armidale, NSW. pp. 163-177.

WESTON, R.H. (1981). Animal factors affecting feed intake. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham Royal, UK. pp. 183-198.

WESTON, R.H. (1984). Rumen digesta load in relation to voluntary feed consumption and rumination in roughage-fed young sheep. Can. J. Anim. Sci. 64(Suppl.): 324.

WESTON, R.H. (1985). The regulation of feed intake in herbage-fed ruminants. *Proc. Nutr. Soc. Aust.* 10: 55-62.

WHALLEY, R.D.B. (1980). The management of Australian pastures. *Proc. 1st. Aust. Agron. Conf.*, Lawes, Queensland. pp. 1-14.

WHEELER, J.L. and FREER, M. (1986). Pasture and forage: The feed base for pastoral industries. In "The Pastoral Industries of Australia". Alexander, G. and Williams, O.B. (Eds). Sydney University Press, Australia. pp. 165-182.

WILKINS, R.J. (1981). Improving forage quality by processing. In "Nutritional limits to animal production from pastures". Hacker, J.B. (Ed.). CAB (Commonwealth Agricultural Bureaux), Farnham Royal, UK. pp. 389-408.

WILKINSON, J.M. and GONZALEZ SANTILLANA, R. (1978). Ensiled alkali-treated straw. I. Effect of level and type of alkali on the composition and digestibility *in vitro* of ensiled barley straw. *Anim. Feed Sci. Technol.* 3: 117-132.

WILLIAMS, I.H. (1982). Growth and energy. In "Nutrition and growth manual." Lloyd Davies, H. (Ed.). Australian Vice-chancellors' Committee. Canberra, Australia. pp. 1-24.

WILLIAMS, O.B. and CHAPMAN, R.E. (1966). Additional information on the dye-banding technique of wool growth measurement. *J. Aust. Inst. Agric. Sci.* 32: 298-300.

WILLIS, C.M., STALLCUP, O.T. and KREIDER, D.L. (1980). Influence of sodium hydroxide and enzyme additions on nutritive values of rice straw. *J. Anim. Sci.* 50: 303-308.

WILSON, A.D. and HINDLEY, N.L. (1968). The value of the seed, pods and dry tops of subterranean clover (*Trifolium subterraneum*) in the summer nutrition of sheep. *Aust. J. Exp. Agric. Anim. Husb.* 8: 168-171.

WILSON, R.K. and PIGDEN, W.J. (1964). Effect of a sodium hydroxide treatment on the utilisation of wheat straw and poplar wood by ruminant micro organisms. *Can. J. Anim. Sci.* 44: 122-123.

WONGSRIKEAO, W. and WANAPAT, M. (1985). The effects of urea treatment of rice straw on the feed intake and live weight gain of buffaloes. In "The utilisation of fibrous agricultural residues as animal feeds". Doyle, P.T. (Ed.). International Development Program of Australian Universities and Colleges, Canberra, Australia. pp. 81-84.

WULIJI, T. (1990). The effects of alkali processing of diet components upon dietary changes, live weight and wool production of Merino sheep. *Proc. Aust. Soc. Anim. Prod.* 18: 440-443.

YAMADA, T. and KAWAGUCHI, T. (1971). Dissemination of pasture plants by livestock. I. Recovery and viability of some pasture plant seeds passed through the digestive tract of goats. *Jap. Soc. Grassl. Sci. J.* 18: 8-15.

YU, Y., THOMAS, J.W. and EMERY, R.S. (1971). Treatment of straw with chlorine compounds and radiation. *J. Anim. Sci.* 33: 1155 A.

YU, Y., THOMAS, J.W. and EMERY, R.S. (1975). Estimated nutritive value of treated forages for ruminants. *J. Anim. Sci.* 41: 1742-1751.

ZADRAZIL, F. (1979). Screening of *Basidiomycetes* for optimal utilisation of straw (production of fruiting bodies and feed). In "Straw decay and its effect on disposal and utilisation". Grassbard, E. (Ed.). John Wiley & Sons. London. pp. 139-146.