School of Agriculture and Environment

The Effect of Diet on the Nutrition and Production of Merino Ewes in the Arid Shrublands of Western Australia

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgements have been made.

This thesis contains no material, which has been accepted for the award of any other degree or diploma in any university

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Fiona Frances Margaret Daly

Date

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Abstract

For the Arid Shrublands of Western Australia (WA) knowledge is limited on what sheep eat and how nutritious their diets are. A study was undertaken on two stations near Yalgoo (28º18'S 116º38'E) in WA, from November 2005 to December 2007. Station 1 (28º39'S 116º18'E) used a flexible rotational grazing management system (RGS), moving 3000-4000 Merino sheep every 3 – 6 weeks through a choice of 20 paddocks. Station 2 (28º18'S 116º42'E) used a flexible continuous grazing management system where small mobs (≤500 sheep) stayed in paddocks all year, until shearing. Two paddocks on Station 2 were chosen to represent paddocks with high (CGS-G) and low (CGS-P) feed value.

A total of 300 Merino hogget (18 months old) ewes were randomly selected from the stations. One hundred and fifty sheep from each station were selected and separated into three mobs of 50 sheep by stratifying live weights. The selected sheep were allocated to either of the two paddocks on Station 2 or the single rotating mob on Station 1. Therefore there were a total of 100 sheep, 50 from each station, on each of the two paddocks on Station 2 and the one rotating mob on Station 1.

Throughout the study period sheep live weights, body condition scores (BCS) and wool production were measured and related to plant photosynthetic activity (derived from Normalised Difference Vegetation Index - NDVI), and dietary energy, protein and digestibility (determined from faecal NIRS calibrations). A DNA reference data bank of some common native plant species was established and then used as a library to identify plant species in sheep faeces and thus provide information on variations in diet composition over the study period. Plant nutritional content was also measured and compared to climatic changes and sheep nutrition.

Over the study period Merino ewe live weights, wool production, faecal samples and native plant leaf material were collected and analysed from each of the three

management treatments (RGS, CGS-G, CGS-P). Wool production measurements included wool length, strength and fibre diameter, including position of breaks, minimum and maximum diameter along the staple of midside samples. Oven dried plant and faecal samples were ground and subsequently analysed for proximate composition. Plant samples were further analysed for mineral contents and 24 h *in vitro* gas production (GP) using the rumen buffer gas fermentation technique. Organic matter digestibility (OMD) and metabolisable energy (ME) content of the plants were determined using 24 h net gas production. Faecal near infrared reflectance spectroscopy (*f*NIRS) calibrations, developed by Curtin University of Technology and ChemCentre WA, were used to predict the nutritional attributes of sheep diets.

Sheep production was found to be affected by rainfall, seasons, management and differing blood lines. In 2006, live weights, BCS and wool fibre diameter increased in response to high summer rainfall. Lower rainfall in 2007 resulted in variable, but generally less animal production with lower live weights, BCS and wool fibre diameter. Management decisions to avoid mating in 2006 on CGS; and agistment for sheep on RGS at the end of 2006 resulted in better sheep production results. Sheep originally sourced from Station 2 generally had higher live weights than sheep sourced from Station 1, suggesting a difference in bloodlines.

Faecal DNA provided useful information regarding diet selection and diversity of sheep grazing on the Arid Shrublands of WA. Of the species that were DNA profiled, the sheep ate *Acacia saligna, Aristida contorta, Atriplex* spp., *Enchylaena tomentosa, Frankenia* sp., *Ptilotus obovatus, Rhagodia eremaea* and *Scaevola spinescens* in 2006 whilst in 2007; the sheep consumed *A. saligna, A. contorta, Atriplex* spp., *Eremophila forrestii, Enneapogon caerulescens, Frankenia* spp., *Maireana* spp., *Ptilotus obovatus, Rhagodia eremaea, Solanum lasiophyllum* and *Stipa elegantissima*. However, there were 28 amplified bands in 2006 and 51 in 2007 that did not conclusively match any of the reference plant species. This indicates that the sheep were consuming diets that contained more species than what was analysed in this study. Faecal DNA results indicated a decrease in the

diversity of the diets selected by the sheep during summer, which coincided with a decrease in animal production.

Native plants were found to be low in OMD and ME, but high in crude protein (CP), and variable in mineral content. Sheep were able to select diets adequate in OMD, ME and CP for maintenance requirements, and low in tannins and phenolics, although continuous drought conditions resulted in reduced production, indicating that the sheep were not getting adequate nutrition to meet their growth requirements. The use of *f*NIRS provided more useful information about the quality of the diet of the sheep than nutritionally profiling individual plants. NDVI was found to be related to dietary OMD and wool fibre diameter changes along the staple.

Overall, the effects of management seemed to be secondary to the effects of climate on sheep production and nutrition. The statistical accuracy of results was low; however, the use of advanced technologies to explore relationships between climate, plant nutritional profiles and animal production and nutrition has provided an expansion of knowledge of sheep nutrition in the region. This extra knowledge may help land owners in the region to make more sustainable management decisions concerning livestock management and grazing pressures on native pastures.

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Dedication

This thesis is dedicated to the station owners who generously allowed us to conduct this study on their property. I hope the information gathered will be useful to them.

This thesis is also written in memory of William (Bill) John Rowe who was loved and respected by all walks of life. He is missed by many.

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These were some of the most difficult, but life changing, years of the station owners, my supervisors and my family's lives. The quality of this thesis was affected both positively and negatively by numerous significant events that occurred and I believe we have all become stronger, wiser and better people because of those events. Personally, I met my sole mate, married him, moved four times and had a baby while trying to do this study so it's not surprising that it took a little longer than expected to complete.

Most of the people I am acknowledging for their help with this study have also become life long friends which I value immensely.

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I got there in the end, thanks to everyone's encouragement.

If I have missed anyone I owe you a drink.

1 Introduction

1.1 Western Australian rangelands

Rangelands are generally defined as areas where rainfall is too low or unreliable (semi-arid to arid climatic zones) and soils are too infertile to support regular cropping (Bastin 2008), therefore livestock graze on the natural vegetation in large, commercially fenced paddocks. Australian rangelands include woodlands, savannas, shrublands and grasslands in arid and semi arid temperate and tropical areas (National Land & Water Resources Audit 2001; National Resource Management Ministerial Council 2010).

The Western Australian rangelands cover 87% (908 000 km^2) of the State and consist of a vast number of diverse land systems, habitats and species (Bastin 2008). The expansiveness, ecological diversity and variable climate make livestock management, research and conservation efforts challenging. Additionally, pastoralists have been under social and government pressure to preserve the biodiversity of their land and consequently improve the sustainability of their industry (National Land & Water Resources Audit 2001). Appropriate management decisions with respect to the most appropriate grazing system are difficult due to the variable environment and lack of solid data on livestock diets in the rangelands. Assessments of nutritive values of diets consumed by animals are complex due to the highly diverse diets.

1.1.1 The Arid Shrublands of WA

The current study was set in the Arid Shrublands of WA. The Arid Shrublands stretch between Kalbarri and Exmouth through the Goldfields to the Nullarbor and cover 850,000 km^2 (Figure 1.1). Pastoralism is the main land use and occupies 85% of the area (Burnside *et al.* 1995).

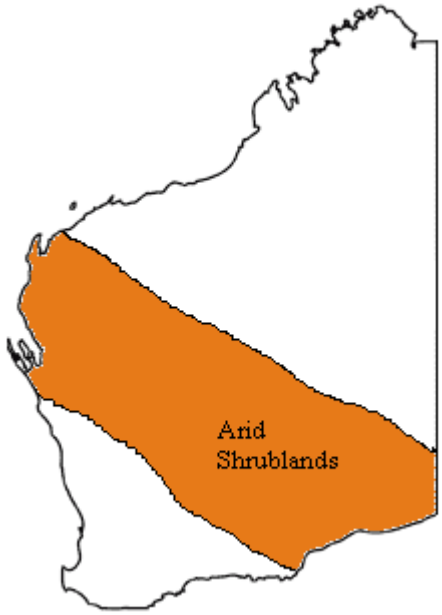


Figure 1.1 Arid Shrublands of Western Australia (Burnside *et al.* 1995)

The climate in the Arid Shrublands is semi-arid to arid with highly variable rainfall. On average the area receives approximately 250 mm annually (Burnside *et al.* 1995); however, rainfall events throughout the year are unpredictable. Winter rainfall is low in volume, but soil penetration and use by vegetation and animals is more effective than summer rainfall due to lower evaporation rates in the cooler months. Summer rainfall is heavier, less frequent and has high runoff and evaporation rates, although plants can respond quickly to warm, moist conditions when rainfall volumes are large, and frequent enough to create sub-surface moisture (Harrington *et al.* 1984b).

The highly variable climate and ancient landscape has resulted in variable land systems and soils, which are generally of low fertility but with rich areas (Williams 1973; Stafford Smith & Pickup 1990). Trees, shrubs and grasses cluster in groves and smaller patches which obstruct surface and water movements and collect rainfall, soil and plant litter that increase the fertility of the soil (Tongway & Ludwig 1990; Burnside *et al.* 1995; Ludwig & Tongway 1995). Ludwig & Tongway (1995)

found that available nitrogen and soil organic carbon content was higher in soils within groves and smaller patches compared to areas between the groves. The spatial organisation of soils with fertile patches separated by less fertile interpatches reduces overall resource loss and maximises utilisation and nutrient cycling (Tongway *et al.* 2003). However, small and mid-slope patches are more fragile and can be easily damaged by water runoff and animal trampling (Ludwig & Tongway 1995).

The patchy soil fertility and variable, low rainfall has resulted in diverse and dynamic rangeland plant communities with continually changing species compositions (Archer 1992) and standing biomass (Specht & Specht 1999). The structure and patterns of rangeland plant communities depend on topography (Wheeler & Hutchinson 1973), temperature (Williams 1973), drainage patterns (Pringle & Tinley 2003), soil types (Holm *et al.* 2002), nutrients and water availability (Holm *et al.* 2003). Changes in these factors have resulted in spatially heterogeneous plant communities; community types can change significantly in less than 100 m (Stafford Smith & Pickup 1990).

1.2 Commercial sheep management in the Western Australian rangelands

The pastoral areas of WA were opened up in the 1870s by European settlers who were initially very successful (Burnside *et al.* 1995). Sheep numbers peaked in the 1930s; however, stations were severely overstocked and unprepared for drought (Burnside *et al.* 1995; Watson 2003). Williams *et al.* (1980) reported that:

"prior to 1934 one station carried in excess of 100,000 sheep with no more than three wells and shallow soaks opened up in the river bed…"

This quote implies that the 100,000 sheep would have congregated near the low number of soaks and wells putting enormous pressure on the land and vegetation surrounding these watering points. Inevitably, a severe drought occurred in 1934 and exacerbated the severe overstocking to result in major, widespread degradation. The Murchison-Meekatharra region lost around 75% of its saltbush

(*Atriplex* spp.) and around 25% of its *Acacia* spp. (Burnside 1979). Livestock numbers generally followed dramatic boom-bust cycles reacting to changes in climate and product market values (Stafford Smith *et al.* 2007), until recommended carrying capacities were decreased to reduce overstocking and the consequent degradation (McKeon *et al.* 2004). Watson *et al.* (2007b) reported that land condition and populations of shrubs and trees have improved or stayed the same between 1992 and 1999 in many areas of the Arid Shrublands of WA.

Presently, 42% of Western Australia's rangelands are occupied by pastoral leaseholds (Bastin 2008). Land owners are currently facing many challenges including unstable, but generally low market value for wool and livestock meat (Stafford Smith *et al.* 2007), progressively drier and hotter weather that would ensue climate change (Foster 2008), loss of ruminant animals due to feral dogs (Thomson & Rose 2006), additional grazing pressures from feral and native animals (Fisher *et al.* 2005) and labour shortages (The Centre for International Economics & The Ryder Self Group 2008). Most pastoral properties consist of 1-3 full time labour units (husband, wife and possibly another family member or a farm hand), plus one or two farm dogs, with seasonal help from contractors and young children.

Management aimed at maintaining a reasonable flow of nutrition to livestock is difficult due to the highly variable environment and lack of solid data on livestock nutrition. Management options for pastoralists in the WA rangelands are limited to choices involving the manipulation of stocking rates and the timing of grazing. As Yalgoo is only about 100 km from the wheatbelt, managers in Yalgoo also have the option to agist their sheep onto wheatbelt properties. Managers can also choose the type of livestock most suitable for their enterprise. The Yalgoo area is mostly shrublands with little to no reliable grasslands (Payne *et al.* 1998); therefore cattle cannot be sustained in this area. Managers in Yalgoo can still choose between running goats and/or sheep and the breeds of sheep or goats. Most pastoral properties annually harvest wild goats for live export which is an important source of income. O'Connor (2002) reported that in 1999 - 2000 a number of pastoralists in Yalgoo had greater gross margins off wild goats ($11.62 per DSE) compared to sheep and wool ($8.95 per DSE). In 2000 - 2001, the gross margins for wool and

sheep were $15.27 per DSE; goats were $13.83 per DSE, while gross margins for Damara sheep were $11.92 in the Yalgoo shire (O'Connor 2002). A number of managers in the WA rangelands are running Damara and/or Dorper pure and cross breeds (Murphy 2003). These breeds are well suited to dry environments and have lower maintenance requirements (Degan & Kam 1992), however, little is known about their impact on landscapes and vegetation (Young 1995).

Despite these challenges, pastoralism is still a strong industry (Bastin 2008) and the development and improvements in new and existing technology are assisting production and management. Remote drafting systems can regulate supplements to sheep with precision and little labour requirements (Bowen *et al.* 2009). Satellite imagery and on-ground observations can allow managers to monitor vegetation and can assist in better fencing and windmill placements that minimise impacts to landscapes and maximise grazing (Pringle *et al.* 2006).

Knowledge of dynamics and resilience of rangeland communities has improved since the first settlers arrived in the late 19th century. However, with decreasing market value for products and continuing climatic uncertainty managers must find ways to improve their production outputs without adversely impacting on the land and vegetation.

1.3 Research in the rangelands

Detecting change in rangeland ecosystems can be difficult as it can be slow to emerge from the initial event(s) and hard to detect, or it can occur rapidly, before institutions and managers are prepared to react (Bastin 2008). The size of study areas, length of study period, limited extent of control over variables and the sensitivity of tools used to measure change must be considered when attempting research in Australian rangelands. Studies must also be flexible and adaptable to extreme changes in variables like climate that are likely to occur during the study.

There have been numerous studies on the effects of grazing selectivity on livestock nutrition (Provenza 1996a & b; Mitchell 1990), production (Sanderson *et al.* 2005;

Soder *et al.* 2007), plant composition (Holechek *et al.* 1989; Watson & Holm 1992) and land systems (Pringle & Landsberg 2004; Launchbaugh & Howery 2005). However, the majority of this research was conducted in small paddocks, or in very controlled trials, which do not adequately represent highly variable rangeland environments (O'Reagain & Turner 1992; Norton 1998).

Extrapolations of results from controlled studies to 'real world' variable environments are limited (Norton 1998). Vesk *et al.* (2004) found that simple methods used in subhumid environments to monitor plant responses to grazing did not work in more diverse, dry shrublands and woodlands of Australia. Research in realistic environments needs to be flexible and less traditional for results to be applicable to commercial scale situations (Laca 2009).

1.4 Study background and significance

The Arid Shrublands of WA have highly variable characteristics and are so diverse that most biodiversity issues found in other parts of the Australian rangelands can also be found here (Fisher *et al.* 2005). Land holders are charged with the custodial duty of conserving this rich biodiversity, and require assistance from government, researchers and ancient knowledge of the indigenous, original land owners, to practice more sustainable management strategies.

Research in rangelands is difficult due to high variability in all aspects of rangeland environments. However, the factors causing variability are interdependent and essential for a healthy range ecosystem, which has evolved to function with high variability. Therefore, controlled studies do not entirely represent rangeland environments and observational studies do not provide enough accuracy for strong conclusions. The best way to compensate for the high variability is to increase sampling (Stafford Smith & Pickup 1990), but this is difficult in expansive rangeland areas where time and money become limiters. Therefore, due to the importance of variability and the difficulty in achieving adequate sample sizes, the current study is considered exploratory because it cannot control major influencing factors like climate, livestock management and land systems nevertheless, they are

documented and the study attempts to incorporate them in results. Consequently some accuracy is lost, although concurrent controlled studies are used to strengthen some conclusions.

The original aim of this study was to compare rotational and continuous grazing systems in a rangeland environment. However, due to the difficult drought (refer to Chapter 4.4.3 for definition) conditions experienced during the study period, the aim of the research was altered to focus more on sheep nutrition and associated production.

Knowledge of sheep nutrition in the area is severely lacking, which reduces pastoral managers' abilities to make informed decisions about stocking rates and grazing systems. The objectives of this study were to gain more knowledge about the nutrition of sheep grazing the Arid Shrublands of WA, and to test easier and quicker ways of determining sheep nutrition with minimal interference to animals. It is hoped that the knowledge provided by this study will enlighten managers about the nutritional characteristics of common, native plants and the general nutritional status of their animals. This information may assist managers in making more informed judgements about the quality of food on offer in paddocks and enable them to manipulate stocking rates and timing of grazing to optimise production. Additionally, it is hoped that the study highlights the need for more detailed information on animal nutrition, and provides a stepping stone in further development of research tools that can be used in rangeland environments.

1.5 Research questions

Due to drought conditions that affected the stations and lack of control of many factors affecting the animals and plants, the research became an exploratory study and attempted to answer the following questions:

1) What plant species do the sheep on the two pastoral stations eat?
2) How nutritious are the target plant species (refer to Appendix 1 for the list of species tested)?

3) How variable are the individual test sheep's wool, weight and body condition scores?

4) Do blood-lines affect the test sheep's wool, live weights and body condition scores?

5) How does the diet affect the test sheep's wool, live weights and body condition scores?

6) Is the nutrition of the test sheep affected by different flock management strategies?

7) Do faecal DNA and NIRS analyses provide an accurate way to predict the nutritional status of sheep grazing expansive paddocks and broad diets?

2 Literature review

Pastoral expansion in Australia first occurred in the 1830s when squatters searched inland for grassy plains for their livestock (Peel 1973). These squatters eventually became pioneer pastoralists when their searching went further inland. In the southern rangeland of WA, pastoral expansion followed the movements of explorers, surveyors and prospectors (Webb 1993). The development and improvement of the Australian Merino sheep, better able to cope with the harsh environment (Cottle 1991), improved water boring technology (Bennett 1997) and improved sheep husbandry, including fencing (Jebb 2010) allowed for increased production in drier climates and pastoral stations became highly profitable with managers employing many people and maintained high stocking rates. However, drought, land degradation, reduced market value for meat and wool and the change in employment laws for indigenous Australians have resulted in reduced incomes for pastoralists.

Indigenous Australians were used as stock workers and domestic staff on large pastoral stations with generations of indigenous families living and working on the land, however, they received only a little money allowance and rations (Jebb 2002). By the time laws were changed to entitle indigenous workers to equal pay in 1967, stations were no longer sustaining them and they gradually moved to towns and reserves where they relied on welfare and social security for survival (Jebb 2002). As a result, pastoralists began to improve and mechanise their stations and to this day, they rely on labour saving technologies to assist their enterprise (Pearson & Lennon 2010).

A number of droughts in the 1900s coupled with overstocking resulted in significant, and in some cases, irreversible land degradation (Mabbutt *et al.* 1963; Biswas & Biswas 1980; Curry *et al.* 1994; Pringle & Tinley 2001; McKeon *et al.* 2004). The 1934 drought coupled with the great depression, resulted in pastoralist's permanently reducing their stocking rates to more sustainable numbers (McKeon *et*

al. 2004). However, the degradation caused by early pastoralists has dramatically reduced pastoral production (Burnside *et al.* 1995). Jennings *et al.* (1979) reported that carrying capacities were reduced by a third by historical overgrazing.

Within this literature the five main issues that the study addresses are reviewed. These are: 1) rangeland plant nutrient composition and the influences of sheep grazing on plants; 2) sheep nutrition and grazing behaviour in the rangelands; 3) effects of diet on sheep production; 4) effects of pastoral management on sheep diets; and 5) limitations to current methods for assessing the nutritive value of plants and the nutritional status of grazing animals, which reduce the ability of managers to make informed decisions in terms of stocking rates and grazing systems.

2.1 Rangeland vegetation

Vegetation in the Australian rangelands is highly adapted to the harsh conditions and most species are therefore endemic and important for biodiversity. The natural vegetation is also the base on which the pastoral industry in the Arid Shrublands is built, as livestock depend entirely on this natural vegetation for food.

Rangeland plants must cope with three major stresses in the rangelands; climate (Harrington *et al.* 1984a), fire (Stretch 1996) and grazing pressures (Downing 1993). A major adaptation to climate that also helps with grazing pressures is the different life cycles of rangeland plants. These plants have evolved as perennial or ephemeral. Perennial species like *Atriplex amnicola, Maireana pyramidata* and *Enchylaena tomentosa* are deep-rooted and long-lived, capable of surviving drought (Harrington *et al.* 1984b) and contribute to stabilising the landscape by protecting soils from erosion (Burnside *et al.* 1995). Perennial species also provide food for livestock during dry times when annual species have died. Ephemeral species like *Ptilotus macrocephalus, Rhodanthe chlorocephala* and *Schoenia filifolia* flower, seed and die during favourable conditions, leaving seeds that are able to persist in the soil through severe droughts (James *et al.* 2001). Many ephemerals are thought

to be highly digestible and favoured by livestock when they are in season (Mitchell & Wilcox 1994).

Rangeland plants generally have three growth phases; the dormant phase, which is generally during summer – autumn and plants become photosynthetically inactive, the growth phase, which is generally in winter – spring and photosynthetic activity is at its greatest, and post bloom, which is generally in spring – summer when seeds are developing and photosynthetic demand is high, yet temperature and soil conditions are less favourable (Harrington *et al.* 1984b; Holechek *et al.* 1989). Grazing plants in the growth and post-bloom phases can be physiologically stressful whereas grazing during the dormant phase is non-detrimental as re-growth does not occur and become exposed to defoliation (DelCurto *et al.* 2005).

The adaptations mentioned are very general and Australian rangeland plants have many other adaptations to the harsh environment. Rangeland plants are highly diverse and dynamic, therefore domestic livestock have had to adapt to a highly variable diet to maintain nutrition.

2.1.1 General description of plant nutritional components

Plant cells can be separated into two components – cell contents and cell wall constituents. Cell contents are highly digestible and consist of proteins, water-soluble carbohydrates, and to lesser extent lipids, minerals and organic acids (Lyons *et al.* 1998). Cell wall constituents consist mainly of polysaccharides (cellulose and hemi-cellulose) and non-polymers of which lignin is the most significant (Weston & Hogan 1973). The presence and concentration of lignin in cell walls affects the digestibility of plant material. Lignin bonds with cell wall polysaccharides restricting the access of digestive enzymes to the cell. Additionally, lignin contributes to cell structural strength making cells more resistant to degradation through mastication and rumination (McDonald *et al*. 2002).

The proportions of nutrients within plants depend on plant age (Huston & Pinchak 1991), plant parts (Lyons *et al.* 1998), soil fertility (Archer 1992) and season

(O'Reagain & McMeniman 2002). As plants age, the proportion of cell contents decrease while cell wall content increases (Huston & Pinchak 1991). Additionally, the amount of lignin builds up in maturing cell walls making plants increasingly indigestible (Cordova *et al.* 1978). Roots and stems have more lignin than leaves, which have more lignin than fruits and flowers (Lyons et al. 1998). Plants extract minerals from the soil, which is also the largest terrestrial source of nitrogen (N) and sulphur (S) (Archer 1992), therefore the availability of nutrients depends largely on their content in the soil. The amounts of digestible carbohydrates, protein and phosphorus (P) are highest during the growing season and decline as plants become dormant (Holechek *et al.* 1989). Overall, livestock tend to avoid parts of plants with high amounts of lignin and consequently prefer younger plant material (Hanley 1982; Harrington 1986; Atiq-Ur-Rehma *et al.* 1999).

Rangeland plant species vary largely in quality, mineral content, digestibility and secondary chemical content (O'Reagain & McMeniman 2002). Franklin-McEvoy & Jolly (2006a) found that nutritive values of plants varied between pastoral properties and season. In general, many species have been found to be low in energy content (O'Reagain & McMeniman 2002), low in digestibility (McLeod 1973), high in N (Newman 1969; Wilson 1977; McMeniman *et al.* 1986), low in P (McMeniman 1976) and high in salt, especially halophytic species (Franklin-McEvoy 2005b). Shrubs have been found to have higher crude protein (CP) content than grasses (Newman 1969).

2.1.2 Impact of grazing on plant nutrient composition

Plants have a number of general responses to grazing, which enable them to survive and stay productive while being lightly grazed. However, most plants are limited in the amount of defoliation they can survive.

2.1.2.1 Physiological response

The initial, physiological response by plants to defoliation is to produce new leaf growth, replacing material that has been removed (Beukes & Cowling 1999). The

formation of sugars, starches, proteins and new tissues are dependent on the photosynthetic process in the leaves. Therefore when leaves are removed the energy producing capacity is reduced (Chapman 1996). Consequently, energy stored in roots is initially used to grow the new material. It is generally argued that light grazing increases plant production as mature material is removed and new, more photosynthetically active material can replace it (Holechek *et al.* 1989). For example, Watson & Holm (1992) concluded that:

"light grazing of Maireana platycarpa during and post drought reduced plant mortality compared to ungrazed populations"

However, when plant re-growth is frequently defoliated there is less leaf area supplying energy to support the root system, which consequently shrinks as energy is redistributed into the leaves (DelCurto *et al.* 2005). As the roots shrink they absorb less water and nutrients and in a competitive environment or when experiencing dry-season stress, the shrunken root system eventually dies as does the plant itself (Oosthuizen & Snyman 2003).

2.1.2.2 Plant defences

To discourage grazing, many plants have evolved defence mechanisms like spines and thorns, dead stems protecting new growth, growing within the protection of less palatable plants, and producing volatile oils, tannins and poisons.

Hakea preseii, Solanum lasiophyllum and many *Acacia* species grow spines and thorns on leaves, seeds and stems (Woods 1992). Zhang *et al.* (2006) found that the density and length of thorns on *Carangana microphylla*, a Mongolian shrub, increased when grazing intensity increased. A similar defence, which almost all shrubs utilise, is growth of new leaves within the protection of dead outer stems (Holmgren & Hutchings 1972; Johnson & Norton 1980), which shield new material in the same way that spines and thorns do. Atiq-Ur-Rehma *et al.* (1999) found that sheep eating saltbush preferred young leaf material and refused to eat stems thicker

than 1.5 mm in diameter despite decreasing availability of preferred feed. Consequently the nutritional value of the saltbush did not deteriorate.

Other plants, especially many shrub species, produce volatile oils, tannins and toxins, which reduce palatability (Macheboeuf *et al.* 2008). Plants containing terpenes and tannins have strong odours and astringent taste, respectively. This makes them less palatable to livestock, which rely on taste and smell when selecting feed (Krueger *et al.* 1974; Cowan 1999). Tannins are complex polyphenolic substances that bind to proteins within the rumen making the bound protein indigestible (Makkar 2003). Tannins can reduce the rate of digestion; therefore livestock eat less food, which can reduce animal production (Launchbaugh 1996; Karabulut *et al.* 2006). However, ingesting small amounts of tannins can be beneficial. Small amounts of tannins in livestock diets can increase the efficiency of microbial protein synthesis in the rumen (Makkar *et al.* 1995; 1997) and increase the amount of essential amino acids entering the small intestine and consequently absorbed into the blood stream (Waghorn & Shelton 1997). The increased supply of non-ammonia N can lead to higher milk, meat, reproduction and wool production and less methane production (Min *et al.* 1998; Makkar 2003).

Knowledge of plant palatability, changes in nutritional content and the resilience of species to climate and grazing are important to gain a better understanding of livestock impacts on plants. The concentrations of primary and secondary compounds within plants and how they change spatially and temporally significantly influence livestock nutrition and grazing behaviour.

2.2 Sheep nutrition in the rangelands

Market value for sheep meat was generally low in the 19th and 20th century, but wool tended to fluctuate in response to international and national influences (Jebb 2010). More recently wool value has been decreasing (Table 2.1) while meat has increased in value (ABARE & MAF 2006). Between 1977/78 and 2001/02 prices for wool, mutton and lamb increased by 2.7% a year, but input costs increased by 4.8% (ABARE & MAF 2006).

Table 2.1 Gross value of sheep wool and meat from 1985 – 2006.

	1985/86	1995/96	2005/06
Wool	5544	3262	2187
Mutton	159	284	442
Lamb	587	747	1425
Live trade	348	289	257

ABARE & MAF (2006)

While sheep numbers have declined and cattle numbers increased over the last decade in the Upper Gascoyne and Murchison areas (Van Vreeswyk & Thomas 2008), sheep are still the major livestock type in the Yalgoo shire with 77,754 sheep and lambs recorded in 2006 and only 816 cattle (ABS 2010). Wool is the main enterprise in the southern Gascoyne, Murchison and Goldfields areas; however, there is also an increasing focus on meat production from Merino and sheep meat breeds, and goats (Van Vreeswyk & Thomas 2008).

2.2.1 General description of ruminant nutrition

Animals require carbon (C), N, hydrogen (H) and S for synthesis products, vitamins and minerals for cell metabolism and structure (Weston & Hogan 1973). Ruminant animals have microbial populations in the rumen that enables them to digest complex plant polysaccharides like cellulose (Hanley 1982) and synthesise essential nutrients from simple chemical compounds, including amino acids from urea (McDonald *et al.* 2002). However, the microbes also degrade nutritionally valuable substrates like water-soluble carbohydrates and essential amino acids into waste products and less efficient forms (Shirley 1986). Ruminant animals have complex requirements and must provide enough nutrition to satisfy both themselves and their rumen microbes. This is further complicated in the rangelands where animals have broad diets and nutrition is limited by availability.

Carbohydrate digestion mostly occurs in the rumen resulting in the production of volatile fatty acids (VFAs), carbon dioxide (CO_2) and methane (CH_4) (Huston &

Pinchak 1991). Water-soluble carbohydrates are readily accessible to enzymes and are rapidly digested while cell wall constituents are digested with difficulty and lignin is indigestible (Varga & Kolver 2006).

Proteins are broken down in the rumen to amino acids, which are rapidly deaminated to yield ammonia and VFAs (Weston & Hogan 1973). The presence in diets of secondary metabolites such as tannins can reduce protein digestibility in the rumen. Low concentrations of tannins in the diet may allow essential amino acids to bypass rumen digestion and be absorbed in the small intestine, thus benefiting the animal (Bhatta *et al.* 2005; Kamra 2005). However, high tannin diets can be detrimental to animals by significantly reducing microbial populations (due to inadequate N supply), inhibiting digestion and suppressing appetite (Launchbaugh 1996).

Studies suggest animals select feed in attempts to balance their energy and protein intake (Egan 1977; Provenza *et al.* 1996b). Kronberg & Malechek (1997) found that sheep selected for high CP forage material in an environment where protein was limited. Howery *et al.* (1998) discovered that lambs have a large requirement for energy but after a high energy feed their preference changes to high protein feed. Brennan *et al.* (2006) suggest that in the Arid Shrublands of WA digestible organic matter (DOM) and metabolisable energy (ME) availability are low while salt and rumen degradable protein (RDP) are high, therefore livestock must select for plants with low salt, adequate DOM and ME to satisfy their nutritional requirements. This may contribute to the decline in availability of high(er) energy content plants such as grasses and other herbaceous species in many rangelands land systems. On the other hand, it has been observed that in areas of Australian rangelands where grass and therefore energy supply, is dominant, protein has become the limited resource (Coates & Dixon 2007). This protein/energy balance is complicated by mineral and vitamin requirements and secondary metabolites (Katjiua & Ward 2006).

The nutritional requirements for rangeland sheep are obtained through the native vegetation. Sheep must be highly selective in their grazing behaviour in order to meet adequate health and production.

2.3 Grazing behaviour in the rangelands

2.3.1 Palatability and selectivity

Palatability is defined as plant characteristics or conditions which provoke a response in herbivorous animals as to whether they select or avoid a plant (Heady 1964; Stuth 1991). There are many factors influencing palatability including physiological responses from animals (Provenza 1996a), animal memory (Ring *et al.* 1985), plant age (O'Connor 1992), species (O'Reagain & McMeniman 2002), plant parts (Lyons *et al.* 1998), secondary metabolites (Degen *et al.* 2002), climate and topography (Stuth 1991) and an animal's pursuit to maintain and update rumen microflora and fauna (Rutter 2006). Important plant characteristics that influence palatability are the protein, sugar and fat contents, which make plants more palatable, and lignin, crude fibre, tannins and nitrate contents which make plants less palatable (Westoby 1974). Salt can make feed palatable or unpalatable depending on concentrations present (Thomas *et al.* 2007a) and salinity of available drinking water.

The palatability of plants influences livestock selectivity and various researchers (Squires & Low 1987; Rosiere *et al.* 1975; Howery *et al.* 1998; Degen *et al.* 2002) have shown that livestock graze preferred species when available, but will resort to less palatable species as availability declines. Studies in Australian rangelands have found that livestock mainly graze perennial shrubs when annual herbage has declined (Watson & Holm 1990). Harrington (1986) found that sheep had a succession in their diet where preferred young ephemerals and grass shoots were replaced with perennial forbs, then *Acacia aneura* (mulga), then dead perennial grass and tree litter. Similarly, Leigh *et al.* (1979) found that sheep preferred forbs and green grass when available and *Sclerolaena* spp. at other times. One of the most important consequences of selective grazing is overgrazing (Heady 1964; Hunt 1992; Funston 1993; Dowling *et al.* 2005). For example, grass death in summer increased significantly when tussocks were grazed to below 10 cm in height (Hacker

et al. 2006). Therefore monitoring of palatable species is important to avoid overgrazing and plant death (Ngwa *et al.* 2000).

The factors determining plant palatability to livestock are complex. In a study on the relationships of taste, smell, site and touch on forage selection in sheep, taste was the primary sense used by sheep when selecting forage yet taste also interacted with other senses (Krueger *et al.* 1974). Similarly, a study in New Zealand (Fenner *et al.* 1993) related the chemical composition of a grass genus (*Chionochloa*) to grazing preferences shown by sheep. The highly desired plants had high ME and CP levels. Degen *et al.* (2002) found that phenolic content was the only factor influencing livestock selectivity. This may have been in an environment where energy, protein and digestibility were not limiting. Cooper *et al.* (1988) could not find a relationship between grazing preference and single chemical factors within plants, but did find that preference was related to a combination of protein and condensed tannin concentrations. A study in south-eastern Australia found that sheep preferred female saltbush (*Atriplex vesicaria*) shrubs compared to male shrubs, although sterile shrubs were the most heavily grazed, these were immature plants where correct sex classification was obscured (Graetz 1978). Overall, ruminants select food mostly in relation to taste and post-ingestive effects of satiety and malaise, which are determined by the animal's morphology, physiology and nutritional requirements (Provenza 1995a & b; Provenza *et al.* 1996b).

Given the complexity of natural vegetation, not all plants are considered palatable to grazing animals. Squires & Low (1987) found that despite the large number of species on offer (26 – 80 herbaceous and grass species) to cattle, only 5 to 13 species in each range type of mulga shrublands, open woodlands and Mitchell grasslands contributed to their diets on any occasion, but use of species changed considerably over time. Similarly, Rosiere *et al.* (1975) found that of the 52 species of plants available in a pasture, only 20 comprised 84 - 95% of cattle diets in all seasons. These studies demonstrate that livestock graze preferentially, however, livestock are frequently limited by the availability of preferred plants.

In general, livestock prefer to eat highly digestible plants and plant parts with low amounts of tannins and lignin. Pen studies have shown that livestock will select a higher quality diet than what is offered (Avondo *et al.* 2004). However, in areas or times when choice is highly limited, for example in overgrazed areas or during drought, livestock have to resort to grazing plants that contain more indigestible components. Atiq-Ur-Rehma *et al.* (1999) found that sheep preferred to graze green leaves and fine stems; however, as summer grazing progressed they had to consume thicker stems as the availability of green leaves and fine stems declined. This ultimately leads to decreased dry matter digestibility (DMD), lower feed intake and lower animal production. Cook *et al.* (1965) found that protein, carbohydrate and energy content decreased in animal diets as grazing intensity increased, while ash, cellulose and lignin content increased.

A consequence of preferential grazing is that some plants are continuously re-grazed as livestock select the new and more palatable re-growth (Leigh *et al.* 1968; Wilson *et al.* 1969; McDaniel & Tiedeman 1981; Norton 1998; Savory & Butterfield 1999). On the other hand, some plants are never re-grazed and remain alive but stagnant because they do not need to produce new material (Dorrough *et al.* 2004). Morcombe *et al.* (1994) reported that ungrazed saltbush does not deteriorate nutritionally over time although it may develop a lower leaf to stem ratio. O'Connor (1992) found that grass tuft size and amount of previous grazing had a greater influence on livestock selectivity than plant species, location or amount of moribund material. Overall, prolonged selective grazing results in some plants being over grazed and degraded, these species are classified as decreasers, while other plants are less utilised and increase in population size (increasers) (Funston 1993; Vesk & Westoby 2001).

2.3.2 Spatially uneven grazing

Due to livestock's instinct to selectively graze, paddocks are grazed unevenly. There are many factors that influence where livestock graze including slope steepness (McDaniel & Teidman 1981), proximity to water (Hodder & Low 1978), availability of palatable vegetation (Kie & Boroski 1996), livestock selectivity (Cowley & Rogers

1995), historical grazing (Ring *et al.* 1985), wind direction and air temperature (Thomas *et al.* 2008). O'Connor (1992) suggests grazing selectivity is complex, where animal response to one variable is conditional on the level of other variables and that sward structure is more important in grazing patterns than is sward composition.

Livestock select and spend more time in habitats that provide an abundance of preferred feed (Wilson & Harrington 1984; Willms *et al.* 1988; Stuth 1991). Livestock determine which feeds are palatable by learning from their mother, peers and personal exploration (Provenza 1995b; Launchbaugh & Howery 2005). They then retain the information and use their memory and visual cues (such as pads and tracks) to find preferred areas, which they will continue to graze even if the available forage deteriorates (Ring *et al.* 1985; Funston 1993).

Squires (1976a) discovered that sheep in chenopod and grassland paddocks did not graze randomly. They chose to graze only a small portion of the paddocks, yet the choice of grazing areas changed as the dry season progressed. The sheep grazing the chenopod shrublands stayed as one flock or split into two flocks whereas the sheep grazing the grasslands stayed in small flocks of five to six individuals and came together as one large flock while watering at night. Grazing was influenced by social factors, forage availability, watering points, wind direction and shade availability. Gardiner *et al.* (1978) studied sheep grazing behaviour on short grass and halophyte communities in Meekatharra, WA and found that as pasture production decreased in dry times, sheep split into smaller mobs, which resulted in reduced ewe-ram contact and mating efficiency. Cowley & Rogers (1995) found that sheep do not graze paddocks evenly despite the paddock having uniform topography, soil type and vegetation. They found that total plant cover increased further away from water and percentage of unpalatable species was highest close to the water. The patterns in the vegetation were attributed entirely to stocking pressure, which was highest close to water.

In Australia, the most important factor influencing where livestock graze is distance from water (Wilson & Harrington 1984; Landsberg *et al.* 2003; Pringle & Landsberg

2004). Hodder & Low (1978) reported that the majority of cattle in the study grazed within a 4 km radius from water in good seasons on abundant feed and within 8 km in dry seasons. The extent of grazing and consequent degradation due to animal impacts decreases further away from watering points as grazing pressures dissipate. However, the degradation gradient, known as the piosphere, is again uneven with some areas close to water left untouched or lightly used (Lange 1969; Graetz 1978; Orr 1980; Scott & Sutherland 1981; Senft *et al.* 1985; Kie & Boroski 1996).

Plant palatability, animal selectivity and uneven grazing within paddocks are important, complex factors influencing grazing management decisions in the rangelands. Most studies on patch formation and degradation find that the number of palatable species declines, dry matter (DM) yield decreases, soils became increasingly compacted, soil erosion increases, rainfall infiltration is reduced and overall habitat production is reduced (MacDonald 1978; Fuls 1992; Kellner & Bosch 1992).

Knowledge of how sheep meet nutritional needs in rangelands would allow managers to make better stock decisions; however, measuring diets is difficult in vast and variable rangeland environments.

2.4 Methods for determining sheep diets

Plant and animal interactions in the rangelands are complex and variable, and therefore, difficult to measure. There are many general techniques for measuring these interactions, all with weaknesses and strengths when used in rangeland environments. There are several aspects to sheep diets that contribute ultimately to animal production. These include diet quality, diet composition and feed intake.

2.4.1 Diet quality

The digestibility of food, and energy, protein, mineral and vitamin content ingested, contribute to the overall quality of animal diets. Diet quality varies seasonally,

spatially, over time and with proportions of plant species consumed (Mbatha & Ward 2006). There are a number of ways of measuring diet quality.

2.4.1.1 Chemical composition of the diet

The chemical composition of diets can be determined using either the plant material that is being grazed or digesta samples taken from (oesophageal or rumen) fistulated animals. Faecal samples can also be used. Plant collections involve cutting or plucking plant material representative of what a grazing animal would select (Holechek *et al.* 1982c). This technique is non-invasive, cheap and easy, but tedious and inaccurate in the Australian rangelands where accurate knowledge of what animals eat is limited. Using fistulated animals can be an accurate method (Arnold *et al.* 1964; Van Dyne & Heady 1965) although, fistulas are invasive, there are animal welfare implications associated with their use and are impractical in large rangeland paddocks.

Faecal analysis is non-invasive and sample collections are quick, cheap and an unlimited number of samples can be obtained. On the other hand, some accuracy is lost compared to more invasive techniques (Holechek *et al.* 1982c). Faeces of herbivorous, ruminant animals consist of undigested plant material, mainly cell wall constituents (cellulose, hemi-cellulose and lignin), microbial cells (mostly bacteria), cell walls from rumen bacteria, digestive enzymes, mucous and sloughed epithelial cells (Holechek *et al.* 1982b). Chemical analysis of faecal samples can estimate many aspects of diet quality.

The most common chemical constituent measured is faecal N, which has been found to be closely correlated to dietary N for grass-based diets (Squires & Siebert 1983). Grant *et al.* (2000) were able to use faecal N and to some extent faecal P to estimate diet quality of grazing animals in Africa. However, they did not account for effects of phenolic compounds, which reduced the accuracy of their diet quality estimates. The chemical composition of the faeces can also reflect the degree of selectivity practiced by different animals. Kaitho *et al.* (1998) discovered that sheep

that were more selective excreted fewer faeces, which contained higher N and ash levels and lower crude fibre levels.

It is important to note that variability between individual animals in choice of forage and digestion differences decreases the accuracy of faecal analysis; therefore Cordova *et al.* (1978) suggest large numbers of animals must be used. Additionally, soluble phenolic compounds can also affect results as they bond with N and consequently increase faecal N values, misleadingly suggesting the diet is high in protein (Holechek *et al.* 1982a). Care should be taken when using faecal N as a measure of diet quality with forbs and shrubs, some of which can contain phenolic compounds (Macheboeuf *et al.* 2008).

2.4.1.2 Digestibility of the diet

Digestibility provides the best practical assessment of diet quality as it represents the portion of the diet that is used by the animal (Holechek *et al.* 1982b). *In vivo* analysis is the direct measurement of the digestibility of feeds (Kitessa *et al.* 1999). This technique is accurate, but it is confined to pen studies where feed types are restricted to what can be locally grown and therefore animals have limited choice of feed and their selective behaviour is limited.

Digestibility can also be estimated by measuring the disappearance of DM during *in vitro* fermentation (Lippke 2002). However, this estimation cannot entirely account for variations in intake levels or rate of passage through the digestive tract (Stern *et al.* 1997). For example, Judkins *et al.* (1990) trialled 11 different techniques of estimating *in vivo* DMD for six diets fed to rams. They did not find a single technique that provided accurate estimates across all the diets and feeding conditions. However, some techniques were relatively accurate for specific dietary conditions and they recommended that future techniques should be selected according to the diet and one method across all diets should be avoided.

2.4.1.3 NIRS profiles of feed and faeces

Near Infra-red Reflectance Spectrophotometry (NIRS) estimates the chemical composition of solid samples including plant and faecal material, and has the potential for estimating digestible matter, protein degradation in the rumen and botanical composition of diets (Stern *et al.* 1997; Coates & Dixon 2007).

Near-infrared radiation (750-2500 nm) is absorbed mostly by organic compounds namely C-H, N-H and O-H bonds; therefore, chemical bonds are reflected with the spectrum of light. The organic compounds that are absorbed are detected and analysed for structure and composition (Foley *et al.* 1998). Statistical procedure is then used to develop and quantify relations between the NIR reflectance spectra and forage quality measurements that are determined by chemical procedures (McIlwee *et al.* 2001). When effective formulas are developed, analysis can be very accurate (Lyons & Stuth 1992).

NIRS is an accurate technique for predicting diet quality; however, it relies on known *in vivo* values of feed which is laborious and slow to obtain (Kitessa *et al.* 1999). Once calibrations of feed have been achieved NIRS is a quick, cheap and accurate analysis of diet quality. Lundberg (2004) concluded that NIRS can be used to estimate CP, neutral detergent fibre (NDF), acid detergent fibre (ADF) and fat in diets but did not recommend the use of NIRS to derive ash nor *in vitro* digestible NDF.

The accuracy of NIRS calibrations is constantly being improved and while studies have concluded that some applications of NIRS are equal to or less accurate than conventional methods (Mburuja *et al.* 1995; Boval *et al.* 2004; Lundberg 2004), NIRS is regarded as being more cost-effective and has the potential to be better than conventional methods (Walker *et al.* 1998; Garnsworthy & Unal 2004).

2.4.2 Diet composition

There are several methods for determining the botanical composition of the diet in relatively non-complex situations.

2.4.2.1 Direct observation of grazing animals

The most basic method for determining animal diets is to observe grazing behaviour and determine intake rate from time spent grazing and/or number of bites per unit time (Holechek *et al.* 1982b). This technique is simple and straightforward; however, it has a number of disadvantages and issues with accuracy. First, it may be unclear if an observer's presence will inadvertently affect animal behaviour. Second, observations from a distance have limited accuracy to identify material grazed and bite size, which can vary considerably, third, observational time periods can vary (Mayes & Dove 2000). Additionally, in rangeland paddocks, which are vast in size, it can be difficult to locate the sheep.

2.4.2.2 Measuring plant biomass in the paddock

Plant biomass measurements can estimate the amount of material consumed from different species and can therefore determine which plants are preferred (Dowling *et al.* 2005). O'Connor (1992) analysed diet composition and grazing selectivity by measuring grass tuft biomass, proportions of moribund material, tuft height, number of reproductive culms, basal circumference and grass species. Plant biomass measurements can occur over any sized area as long as the position of sampling units, frequency of sampling and size of quadrats is appropriate, as these factors can have a significant influence over results ('t Mannatji 2000). Plant biomass in the rangelands is determined mainly by rainfall and grazing (Torpy *et al.* 1992). It can be difficult to monitor plant biomass removed by all grazing animals in the rangelands, which include sheep, goats, cattle, rabbits, kangaroos, horses and camels.

2.4.2.3 Collection and identification of grazed material via oesophageal cannulation of grazing animals

The collection and identification of grazed material found in oesophageal cannulated grazing animals is a more specific method compared to measuring plant biomass (Squires & Siebert 1983; Squires & Low 1987). This technique can be very accurate for animals limited to a small paddock (McInnis *et al.* 1983). Having cannulated animals in a rangeland environment is impractical as animals graze on broad diets over large areas. Additionally, fistula collections are carried out over a short period when animals are hungry; therefore, the samples may not represent true grazing as fistulated animals may graze differently to un-fistulated animals (Mayes & Dove 2000).

2.4.2.4 Sampling of rumen fluid and microscopic examination and identification of plant material

The identification of grazed material through microscopic examination of rumen contents (Mayes & Dove 2000) or faecal matter (Holechek *et al.* 1989) is widely used. The sampling of rumen contents requires cannulated animals, which is undesirable due to a variety of reasons, including animal welfare, non-representative samples and identifying a species from fragment material, which makes the method unreliable for quantitative estimation. Rosiere *et al.* (1975) encountered difficulty in identifying a number of species and some plants observed to be grazed were not identified in the samples. McInnis *et al.* (1983) found that diets determined by examination of rumen and faecal material did not accurately estimate intake of grasses and forbs.

2.4.2.5 Comparison of plant alkanes and faecal alkanes

Plant alkanes are found in wax cuticles of many plants and can be used to identify plants by proportions of total alkanes and ratios of even and odd-chain alkanes (Dove & Mayes 1991). Proportions of species in diets can be estimated by using odd-chain alkanes as internal markers in conjunction with dosed even-chain alkanes as faecal output markers (Lippke 2002). This allows the measurements of intake

and output at the same time, reducing error, and also removes the need for fistulated animals (Mayes & Dove 2000). However, this technique has somewhat limited field application, especially in the rangelands, Validations of the alkane method has mainly been confined to grasses or grass/legume association (Valiente *et al.* 2003). Plant alkanes (for determining diet composition) work best in a temperate, sown pasture containing a low number of different plant species. When the pasture is species rich there is a chance that many plants will have a similar alkane concentration pattern therefore making it difficult to distinguish the different plants in faecal samples (Smith *et al.* 2001).

2.4.2.6 DNA profiles (fingerprints) of feed and faeces.

DNA can be extracted from animal faeces and determine such information as the defecator species, gender and individual identity and diet (Wilson *et al.* 2003). DNA sequences unique to a plant species are an effective way of identifying, from faeces, botanical compositions in animal diets and are being effectively used for many wild animals (Jarman *et al.* 2004). Deagle *et al.* (2005) analysed the faecal DNA (*f*DNA) of sea lions to test the reliability of DNA identification of prey species from scats. They found the analysis was successful in identifying 100% of the prey eaten by some sea lions and the major diet component of other sea lions; however, minor prey was missed in some scats.

There are some potential disadvantages or sources of error associated with *f*DNA. Genetic material (DNA) can suffer degradation by environmental conditions, making it desirable to collect faeces as soon as possible after voiding (Wilson *et al.* 2003). Low DNA content can make amplification difficult causing potentially erroneous results (Morin *et al.* 2001).

An important requirement for using *f*DNA to determine diet composition in grazing animals is a DNA library of unique primers of the plants that are potentially grazed in any grazing system. This may be a major issue in the Arid Shrublands of WA where: (1) there are a large number of plant species; (2) livestock eat very diverse diets; and (3) there is little conclusive evidence about what exactly livestock consume.

2.4.2.7 Faecal NIRS analysis

Applications of NIRS include measuring the botanical composition of different plant communities (Walker *et al.* 1998; Dixon & Coates 2008), determination of plant nutrients (Garnsworthy & Unal 2004), mineral elements, plant secondary metabolites and anti-nutritional components and prediction of functional attributes including animal performance (Foley *et al.* 1998; Smith & Jeffery 2006; Coates & Dixon 2008).

Coates & Dixon (2007) tested the effectiveness of faecal (*f*) NIRS to distinguish C3 and C4 plants in the diets of cattle grazing tropical Australian rangeland pastures. C3 and C4 plants differ in structure and photosynthetic pathways (Susmel & Filacorda 1996). In general C4 plants are more efficient at water and N use compared to C3 plants, while C3 plants can tolerate high atmospheric CO_2 (Wolfson & Tainton 1999). They concluded that *f*NIRS was an accurate, low cost and easy tool to use and effectively distinguished C3 and C4 plants. They were then able to track the annual changes in cattle diets under the assumption that C4 plants were mostly grass species and C3 plants were mostly non-grass species. Unfortunately, in the southern rangelands of Australia there are C3 grasses and C4 non-grasses, therefore this technique cannot be used in this region.

2.4.3 Feed intake

Feed intake measurements predict the total quantity and quality of food that animals ingest. In many ways it is the most difficult to predict in the field due to the complex digestive system and grazing behaviour of ruminants (McDonald *et al.* 2002). Feed intake is also a very important measurement as a highly nutritious diet can still be inadequate if feed intake in insufficient. Breed (Kronberg & Malechek 1997), physiological status (Allison 1985), diet (Adams *et al.* 2002), forage availability (Allden & Whittaker 1970) and grazing management (Mbatha & Ward 2006) are factors that affect feed intake. Most predictions of feed intake are inferred from measures of diet composition and quality (McMeniman 1997).

2.4.3.1 Direct measure of feed intake

Feed intake can be measured directly by giving livestock known quantities of feed and measuring the amount left behind. The feed offered to animals can be analysed for quality through standard techniques (refer to 2.5.2). This involves pen trials and is the most accurate way to measure feed intake, but is intensive and inhibits animal grazing behaviour.

2.4.3.2 Total faecal output

Measuring total faecal output via faecal collection bags attached to the animals allows the animals to graze, although this technique is most useful where the animals are grazing on small paddocks. The known quality of the pasture and faecal output quality and quantity can then be used to estimate feed intake (Nunez-Hernandez *et al.* 1992). This is one of the most accurate techniques for measuring intake although animal behaviour and the determination of diet composition and quality can reduce precision (Nastis & Cordesse 1996). Holechek *et al.* (1986) trialled the method and found that faecal quality results differed significantly from actual forage intake quality for six out of nine forages offered to livestock. They suggested that the inaccuracy was caused more by the methods of determining digestibility, which in their case, was a gas fermentation technique by Tilley & Terry (1963).

2.4.3.3 Diet composition and diet quality techniques

Feed intake can be predicted by measures of plant biomass (McMeniman 1997), bite size and quantity (Gordon 1995), cannula contents (Van Dyne & Heady 1965), alkanes (Nastis & Cordesse 1996), chemical composition (Holechek *et al.* 1982c) and digestibility (Kitessa *et al.* 1999) which are also measures of diet composition and quality. Refer to 2.4.1 and 2.4.2 for advantages and disadvantages of these techniques.

Methods for predicting dietary intake are generally laborious and have relatively low accuracy and precision (Nastis & Cordesse 1996). In fact, measuring animal diets can be difficult and no method is entirely accurate. However, animal production is highly influenced by diet; therefore dietary knowledge is essential.

2.5 Effects of diets on sheep production

The quality of and quantity of the feed available to sheep dictates the success of production parameters such as live weight (Arnold *et al.* 1964), reproduction rates (Lekatz *et al.* 2009) and wool production (Friend & Robards 2006). A low quality diet will reduce wool growth, result in higher variability in wool strength along the staple, and reduce live weight gain (Holm *et al.* 2005). Therefore measuring sheep production parameters will provide an indication of the quality of animal diets.

Measurements of production parameters will also provide information about sheep genetics, age, pregnancy, lactation, climate and season, which are all factors influencing animal and wool production. Weston (1959) found wool production and growth efficiency was related to body weight and sheep strain, where the strong wool strain produced more wool than the fine wool strain. Arnold *et al.* (1964) suggested that seasonal changes in live weight and wool growth reflect changes in nutritional conditions; they found that the digestibility of sheep diet was highest in spring and autumn and as pasture matured digestibility rapidly declined, which corresponded to the decline in animal production. Wilson & Leigh (1970) compared wool and body weights of sheep grazing different rangeland communities on the Riverine plain in south-eastern Australia and found that the grasslands (*Danthonia caespitosa*) were able to sustain the sheep without being significantly damaged compared to the saltbush (*Atriplex vesicaria*) community. They found that most variation in sheep productivity occurred during summer when rainfall was unreliable. They also found that sheep grazing *Stipa variabilis* grasslands on sandy soils had poorer wool growth and body weight gain compared to grasslands on clay soils.

2.5.1 Live weights and body condition scores

Live weights are the most effective way of measuring animal condition and production, except during late pregnancy or when gut fill varies between weighings, in which case body condition scoring is the most accurate alternative (Suiter 1994). Sheep nutrition is an important component of pastoralism as the quality and quantity of the plants sheep eat affects production. Arnold *et al.* (1964) found seasonal changes in sheep live weights reflected changes in nutritional conditions. Squires & Low (1987) and Squires & Siebert (1983) both found live weight change in cattle was highly correlated with OMD and dietary N content.

Salt is a significant issue in the rangelands as many palatable plant species are halophytic. High salt diets can decrease feed intake, digestibility and live weight gain (Riaz *et al.* 1999; Masters *et al.* 2005). However, a low to moderate salt diet with ample fresh water supply can be beneficial. Atiq-Ur-Rehma *et al.* (1994) found that the addition of saltbush to a wheat straw diet for sheep resulted in improved voluntary food intake, digestibility, N intake and N retention. Secondary metabolites in diets can also affect animal live weights. High tannin diets can reduce live weights (Barry 1985), whereas low tannin diets can positively affect live weights (Ramirez-Restrepo *et al.* 2005)

2.5.1.1 Wool

Wool length, strength and fibre diameter are highly related to diet (Sharkey *et al.* 1962; Nagorcka 1977) and are influenced by the partitioning of available C, N, H, oxygen (O) and S elements to wool follicles (Brown & Crook 2005). High quality diets with high concentrations of digestible protein will increase wool production (Li *et al.* 2007). The protein is also used to supply ME therefore both the composition of the protein and the supply of ME influence the rate of wool growth (Allden 1979; Williams 1991; Reis & Sahlu 1994). Reis *et al.* (1992) studied the effects of increased protein and energy intake on wool production and found that increasing protein in diets resulted in increased wool growth, although increased energy only increased wool growth when protein intake was high. This study demonstrates the

overriding importance of protein for wool growth compared to energy (Black *et al.* 1973; Luque *et al.* 2000). Adams *et al.* (2002) studied relationships among variability in wool growth, live weight loss and body composition in sheep fed poor quality feed to understand the partitioning of nutrients between wool and body when forage is limited. They found that the ability to increase feed intake when feed quality increased was a major factor affecting wool growth responsiveness.

Fibre diameter is considered the most important wool property for processing over strength, length and yield (Chapman *et al.* 1973). Fibre diameter is related to follicle size (Hynd 1994; Hynd *et al.* 1997) and number and varies within a staple, along the fibre, position on the sheep, and between animals (Teasdale 1998). Variation within the staple is mostly due to the variability of secondary follicles as they are more sensitive to nutrition (Lyne 1964). Therefore, ratios of primary to secondary follicles affect diameter and sensitivity to the environment (Brown & Crook 2005). Variation in diameter along the fibre is mostly due to nutrition, pregnancy, lactation and disease (Li *et al.* 2007).

Salt and tannins can also affect wool growth. Salt increases the efficiency of converting OM intake to wool (Hemsley 1975). Thomas *et al.* (2007a) found wool growth increased as salt content in diets increased up to 21%, while feed digestibility decreased with salt content of more than 14%. Masters *et al.* (2005) found that feed intake, digestibility, live weight gain and wool growth decreased with increasing salt content in diets; however, wool growth per unit of OM intake increased at high salt intakes and fibre diameter decreased. Low tannin diets increase the absorption of essential amino acids in the small intestine, avoiding degradation in the rumen (McNabb *et al.* 1993). Luque *et al.* (2000) found that sheep fed *Lotus corniculatus*, a tannin-containing plant, had increased wool growth and reproduction due to improved efficiency of food utilisation. However, high tannin diets can reduce wool production due to lowered N absorption (Barry 1985).

Overall, a high quality diet has significantly positive effects of clean fleece weight, wool growth, staple strength, staple length, variance of fibre diameter and variance of diameter along fibre (Friend & Robards 2006). Therefore pastoral management

should be aimed to maximise diet quality and quantity for animals without negatively affecting biodiversity.

2.6 Grazing management for livestock production

Due to the limited rainfall, pastoral stations are much larger than their counterparts in agricultural regions and stocking rates are lower. The average size of pastoral stations is 250,000 ha with individual paddocks often being 6,000 ha or more, with stocking rates varying 5 – 40 ha/DSE (dry sheep equivalent) depending on the condition of paddocks (Mitchell & Wilcox 1988). The large paddock and station sizes combined with highly variable climate and vegetation makes management on rangeland properties very complex (Watson 2003). Yet on most stations managerial input into livestock is low, handling the animals only once or twice a year (Burnside 1979). Maintaining a reasonable flow of nutrition to animals in an environment with limited resources and an uncertain climate is challenging. The only mechanisms available to managers are to manipulate the number of animals per unit area and the timing of grazing.

2.6.1 Stocking rate

Stocking rate is the amount of land allocated to each animal for the entire grazable period per year and is considered the most influential management decision affecting livestock, vegetation, biodiversity and economic returns (Wilson *et al.* 1984a). A correct stocking rate should optimise production and minimise damage to resources (Stafford Smith 1996). Holst *et al.* (2006) concluded that sheep production parameters could be maximised irrespective of pasture type as long as the stocking rate matched food availability.

Stocking rates can either be flexible or fixed. Flexible stocking rates aim to keep a relatively constant ratio between forage available and livestock production. Flexible stocking rates are dynamic, and assessed and adjusted regularly, especially in variable rangeland conditions (Stafford Smith 1992). It may be difficult and expensive to maintain a successful flexible stocking rate in the rangelands, again

due to the variable conditions and large size of paddocks (Tainton *et al.* 1996). Fixed stocking is a more stable alternative with less risk and management input. The more constant a manager wants to be with stocking rates, the lower the stocking rate must be to maintain ecological sustainability (Stafford Smith 1992). Most managers using fixed stocking rates aim for a rate that can safely carry animals through the dry season without affecting plant or animal production. As a consequence, for much of the year the station may be considered under-stocked (Burrows 1990).

Research and pastoral experience has found that high stocking rates are detrimental to both the land and animals (Leigh *et al.* 1979; Orr 1980; Fletcher 1991; Du Toit *et al.* 2003). Mpiti-Shakhane *et al.* (2002) found that under high stocking rates Merino ewe live weights, wool length and wool production declined as did lamb performances. Leigh *et al.* (1968) found that in a continuously managed system, sheep grazed cotton bush (*Kochia aphylla*) more often during dry times and when stocked at high (0.75 sheep/acre) compared to low (0.375 sheep/acre) rates. The sheep had more seasonally variable wool growth at the high stocking rate compared to the low stocking rate. Wilson *et al.* (1969) found that under high stocking rates and continuous grazing, *Atriplex vesicaria* shrubs were heavily grazed (mostly during autumn) and were unable to recover from complete defoliation. Additionally, sheep productivity could not be maintained at the high stocking rates during the 3 year study. Watson *et al.* (1997) compared grazing effects on two shrub species *Eremophila maitlandii* and *Eremophila forrestii* and found that stocking rate did not affect *E. forrestii* but did negatively affect the more palatable *E. maitlandii* at high stocking rates. They concluded that effects of high stocking rates and low rainfall were additive. Historically, pastoralists used high stocking rates, as their aim was to maximise profit (McCosker 2000). Unfortunately, the combination of overstocking and prolonged drought resulted in extensive, long-term damage to the landscape (Peel 1973). Consequently, it is now generally agreed that light to moderate stocking rates are better for forage and livestock production (Watson & Holm 1992).

Research has found that, over long periods, moderate to light grazing can still lead to losses of palatable plants (Bartle 2002), especially in those parts of a paddock

that receive heavy use due to habitual grazing behaviours (Mueggler 1965; Hodder & Low 1978; Scott & Sutherland 1981; Kie & Boroski 1996). Fletcher (1991) found that light grazing decreased desirable plant species recruitment. Overall, lowering stocking rates may reduce overgrazing but does not entirely control it (Norton 1998).

2.6.2 Grazing systems

There are two main forms of grazing management, continuous and rotational or cell grazing.

Continuous grazing is the common form of management used in the Australian rangelands and has been since European settlement (Downing 1993). It is a simple form of management where livestock are left in paddocks for most, if not all of the year and plants are continuously exposed to livestock grazing (Woods 1992). In theory, animals are distributed evenly over the land and are able to select the most nutritious plants while grazing pressures on all areas are low (Wilson *et al.* 1984a). During the growing season annual grasses and forbs are preferentially grazed while perennial species are naturally saved from grazing until the availability of annuals declines (Wilson *et al.* 1984a). In practice, livestock do not graze paddocks evenly (Refer to Chapter 2.3.2) and palatable species can be eliminated when continuously grazed long-term (Wilson *et al.* 1984a; Willms *et al.* 1988; Teague *et al.* 2009). Continuous grazing favours annual grasses and forbs more so than perennials as populations of perennials are slow to establish and are more vulnerable to heavy grazing (Wilson *et al.* 1984a). Therefore a continuous grazing system may be effective in areas where growth of annuals is reliable.

Rotational grazing management was introduced into Australian rangelands in 1989 (McCosker 2000) but acceptance by pastoralists as an equal if not better alternative to continuous grazing is low and it is still not widely acknowledged in the scientific communities (Norton 1998). Rotational grazing systems entail the amalgamation of livestock into one paddock, which is stocked at high rates for a short time before the stock is moved into another paddock. In theory, the livestock amalgamation and regular movements allow the majority of the paddocks a long rest period, where

vegetation can recover from the grazing (Earl & Jones 1996; Bartle 2002). Also, the short grazing period at high stocking rates ensures that vegetation is grazed more evenly and the possibility of livestock establishing familiar grazing patches is reduced (Savory & Butterfield 1999). Wilson (1986) outlined a number of rules to assist pastoralists in deciding if rotational grazing would suit their range types and these are: (1) a grazing system must either increase the density of desirable species or replace an undesirable species by a desirable one; (2) grazing systems are more likely to lead to a useful change in botanical composition when the vegetation contains perennial grasses; (3) as mentioned above, rotational grazing systems favour perennial species and continuous grazing favours annual species; (4) the advantages of rotational grazing requires many years to become evident as perennial species are slow to respond; and (5) adoption of grazing systems requires additional costs in fencing and stock movement.

Comparisons between rotational and continuous grazing systems have been frequently explored experimentally with most research concluding that there is little difference in plant or animal production between the two management techniques (Bryant *et al.* 1989; Hart *et al.* 1993; Heitschmidt 1986; Taylor 1989; Pinchak *et al.* 1991; Heitschmidt, Klement & Haferkamp 2005; Briske *et al.* 2008). However, many of the studies have been controlled and small scale with limited scope of fairly resilient and highly variable landscapes (Norton 1998; Teague *et al.* 2009). The majority of managers that use rotational grazing for their commercial enterprise generally agree that it is a more productive alternative to continuous grazing (Howell 1978; Funston 1993; Teague *et al.* 2009).

Currently, most managers in the arid shrublands of WA use a combination of continuous grazing and 'spelling' where sheep are removed when paddock conditions deteriorate. Yan *et al.* (1996) compared the effects continuous grazing to no grazing, a 6 month spell and 12 month spell on plant dynamics in the WA arid shrublands. They found that moderate, continuous grazing did not have any discernable effects on community species composition and population size of major perennial shrub species compared to no grazing over the 8 year period and there was no discernable difference between spelling and continuous grazing. They

concluded that the major shrub species studied (including *Maireana georgeii* and *Maireana pyramidata*) responded to seasonal conditions rather than management. However, the authors also point out that chenopod shrubs are most important during drought when food availability is low (Graetz & Wilson 1984). Rainfall was average to above average for most years during the study; therefore sheep may not have been grazing on the perennial shrubs as much. The population density of the highly palatable *M. georgeii* seemed to be decreasing in the continuously grazed treatment and increasing in the ungrazed treatment for the last half of the study period when rainfall was mostly average. Therefore, continuous grazing may have been having a negative effect on more palatable species.

To apply a correct stocking rate and grazing system, managers must know the quality and quantity of feed within paddocks and when they change throughout the years. The majority of pastoralists generally rely on their long-term observed knowledge to judge condition of their paddocks. However, calculating the quality and quantity of feed in large and variable paddocks is difficult.

2.7 Management tools

Managing livestock to maximise animal production and minimise negative impacts on landscapes can be challenging in such large properties. Management tools to assist in making decisions must be simple and require low labour inputs to be easily applied to large and numerous paddocks.

2.7.1 Monitoring

Plant monitoring in the rangelands provides important information about the long-term effects of management on the land (Wilson *et al.* 1984b). Monitoring the presence and absence of indicator species and exotic weeds gives indications of how healthy a land system is and how intense grazing pressures are in some areas (Tauss 1992; Landsberg & Crowley 2004). Monitoring techniques are quick and easy to conduct, but only provide indications of range condition (Pringle & Landsberg 2004).

The presence or absence of plants that are highly sensitive to grazing is used as indicators of range condition and grazing intensity. “Decreaser” species decline under grazing, as they are highly palatable and preferred by livestock. Presence of these plants indicates low grazing pressure in the area (Landsberg & Crowley 2004). On the other hand, there are plants that thrive under heavy grazing, known as “increaser” species. Presence of these species indicates high grazing pressure (Kirkman 2002) as they are usually less palatable and replace overgrazed decreaser species (Landsberg *et al.* 2003). Lastly, there are plants that can survive heavy grazing and therefore are not good indicators of grazing pressures. Most monitoring techniques involve regular assessments of plant presence or absence, especially of indicator species. Fletcher (1991) studied goat and sheep grazing in WA shrublands and found that *Maireana georgeii* decreased under light grazing and was a sensitive indicator while *Eremophila forrestii* only decreased under heavy grazing and *Ptilotus obovatus* responded moderately to grazing making it the best single indicator. Fletcher (1991) concluded that monitoring of all these three species would give good indications of grazing pressures.

WARMS (Western Australian Rangeland Monitoring System) is a state-wide monitoring system managed by the Department of Agriculture and Food WA (Dalton & Bright 2003). The objectives of WARMS are to track long-term change in vegetation and soil, track ecological change, operate across all vegetation types, provide regional-scale information and facilitate change (Watson *et al.* 2007a). WARMS involves monitoring over 1500 sites set up on many pastoral stations, every 5 years. Additionally, some pastoral owners have set up private monitoring sites in areas they believe are significant, to monitor grazing impacts.

WARMS monitoring sites are set up 1.5 km from watering points in seven broad vegetation types: Spinifex grasslands, short bunchgrass savannas, chenopod shrublands, Acacia low woodlands, Nullarbor, Mulga woodlands and shrublands, and Eucalypt woodlands and shrublands (Holm 1993; Watson *et al.* 2007a). Sites comprise of a photo plot and three parallel belt transects and monitoring involves recording species diversity, location, frequency and plant width and height along these transects (Watson *et al.* 2007a). Land function analysis and soil surface

conditions are also assessed. Other monitoring techniques used include exclosures, which exclude livestock, wild and feral grazers from small areas, photographic sites where photos are taken to monitor plants visually (Tauss 1992) and satellite imagery to monitor changes over extensive areas.

A major short-coming of monitoring in the rangelands is that ground-based techniques are limited spatially (Wilson *et al.* 1984b), which reduces the ability to detect change quickly (Watson *et al.* 2007a). It is impossible to set up and monitor enough sites to get accurate and comprehensive information in the rangelands. Additionally, there is a severe lack of benchmark sites (areas with little historical or present interference from humans, livestock, feral and wild grazers), therefore there is a lack of knowledge as to what is "good condition" (Landsberg & Gillieson 1995; Landsberg & Crowley 2004). Nonetheless, the techniques are quick and easy to conduct and provide an indication of the condition of sites and land systems.

2.7.2 NDVI (Normalised Difference Vegetation Index)

Monitoring via satellite images has become increasingly popular to compliment ground-based techniques (Wilson *et al.* 1984b; Gherardi *et al.* 2006). NDVI uses satellite images to assess plant photosynthetic activity over a large area. This monitoring technique can provide historical information about range condition in paddocks, stations and regions (Funston 1993; Palmer & Fortescue 2004), which can then be used to predict stocking rates and carrying capacities more accurately (Oesterheld *et al.* 1998, Hamilton *et al.* 2008).

NDVI is the algorithm used to estimate green vegetation cover from images taken by the National Oceanic and Atmospheric Administration (NOAA) satellite (Cridland *et al.* 1993). The satellite sensor measures light reflectance in visible red and near-infrared portion of the electromagnetic spectrum and as leaf chlorophyll pigment (green) absorbs red light, and radiation in the NIR portion is scattered by internal spongy mesophyll, the satellite can detect areas of green vegetation (McVicar & Jupp 1998; Todd *et al.* 1998). Therefore, the satellite detects the photosynthetically active material, which can then be used as a indicator of growing material, effective

rainfall and foliage projective cover (Pickup 1989; Specht & Specht 1999; Ramsey *et al.* 2003). However, data must be corrected for light scattering as it passes through the atmosphere and cloud cover (Holben 1986).

The advantage of the NOAA satellite used to take the images is that it passes WA every day, giving greenness values every square kilometre (not obscured by cloud) and can therefore provide comprehensive data about day-to-day changes in the vegetation (Cridland *et al.* 1993). Most studies on NDVI have found that it is a good indicator of quality of season at a regional scale (Roderick *et al.* 1999), but the story becomes more complex at a paddock scale (Cridland *et al.* 1995; Lind *et al.* 2003). This is due to spatially and temporally variable vegetation and soil types typical of the Australian rangelands resulting in each 1 km, 2 pixel covering multiple vegetation types (Wallace *et al.* 2004). Yet as long as corrections are made for differing vegetation types, NDVI can still provide comprehensive information about changes in greenness and effectiveness of rainfall at small scales (Cridland *et al.* 1995). Blanco *et al.* (2009) found that NDVI was able to detect differences in ecosystems that were grazed either continuously or rotationally. They considered it an important step for monitoring vegetation and making informed management decisions on stocking systems.

Rangeland vegetation is resilient to most environmental impacts, including grazing, and can be a sufficient source of feed for livestock. However, livestock are capable of grazing species to extinction, therefore regular monitoring of plants and livestock is important input to management decisions to ensure the persistence of good forage supply. The persistence of palatable species will also ensure that livestock receive adequate nourishment from the forage available.

2.8 Conclusion

Rangeland vegetation is dynamic with constantly changing nutritional content in response to the variable environment. Sheep diets need to satisfy both their rumen microbes and their own nutritional requirements. Therefore their grazing behaviour in rangeland environments is complex, influenced by their changing nutritional

needs and the varying availability of plants. Pastoral management of livestock to maximise production while being sustainable is challenging as information about sheep and plant nutrition in the rangelands is limited. Tools to assist managers and researchers must be easy and cost effective to be able to apply frequent sampling over large and varying landscapes.

3 Materials and methods

3.1 Experimental location

The animal study, satellite and plant collections occurred on two stations near Yalgoo (28º18'S 116º38'E) in Western Australia. The study was conducted from November 2005 to December 2007. Approval for the animal study from the Curtin Animal Experimentation Ethics Committee was obtained at the commencement of the study and reviewed annually, although station management was independent of the study.

3.1.1 Climate and water

Both stations lie within the semi-arid, Mediterranean climatic region, which is characterised by 9 to 11 dry months, mild wet winters and hot dry summers with occasional summer storms. Yalgoo receives an average 250 mm of rainfall annually; however, rainfall is highly variable and 57% of the annual rainfall is below average, balanced out with occasional wet years. Both stations have a moderate to high risk of drought (Payne *et al.* 1998).

As rainwater is unreliable, the majority of drinking water is supplied by underground aquifers. The water is brackish and varies in salt concentrations from less than 1000 mg/L TDS, which is considered fresh ground water, to greater than 7000 mg/L TDS which is saline and unsuitable for consumption by people or livestock (Johnson 1998).

3.1.2 Geology and land systems

The stations are predominantly found on the Archaean aged (> 2500 Ma) Yilgarn block, which is comprised of greenstone belts, where gold and other minerals lie, held between granitoid rocks. The landscape is generally low relief with large lakes,

alluvial valleys and breakaways (Johnson 1998). Refer to Chapter 3.2.2 for further details of land systems found on the study sites.

3.1.3 General soil and vegetation types

There are three main vegetation types on both stations – Mulga shrublands, chenopod shrublands and sandplains.

Soils in Mulga shrublands are non-saline, shallow and uniform with low fertility, susceptible to track erosion. The vegetation, dominated by Mulga (*Acacia aneura*) shrubs, develops most commonly as grove communities where water and nutrients accumulate (sink zones) between patches where water and nutrients move (source zones). Mulga shrublands are generally considered as moderate to good grazing country with a moderate number of palatable species such as *Rhagodia eremaea, Ptilotus obovatus, Maireana convexa* and *Sida calyxhymenia*, which are usually found under Mulga shrubs and in very stable ecosystems (Stafford Smith & Pickup 1990; Burnside *et al.* 1995).

Chenopod shrublands consist of saltbush (*Atriplex*) and bluebush (*Maireana*) species, including *Atriplex amnicola, Atriplex bunburyana, Maireana georgei* and *Maireana tomentosa*, which are halophytic. These shrublands are considered prime livestock grazing country, especially if fresh water is located nearby. Chenopod shrublands are located below breakaways, on level plains, river and lake frontages. Most chenopod shrublands are fragile and have been subject to many years of overgrazing and consequent degradation (Burnside *et al.* 1995). Both stations have historic overgrazing degradation but managers have worked hard in recent years to improve their shrubland areas.

Dominant plants on sand plains include Wanderrie grasses and Bowgada (*Acacia linophylla and Acacia ramulosa*). Wanderrie grasses, also known as tussock grasses, are a valuable grazing resource and can include many palatable grasses such as *Eragrostis eriopoda, Eragrostis lanipes, Monachather paradoxa* and *Thyridolepis multiculmis* and shrubs such as *Maireana convexa, Rhagodia eremaea,*

Sida calyxhymenia and *Ptilotus obovatus*. Bowgada trees form thickets, suppressing smaller shrubs, and provide few palatable species for livestock grazing, although Bowgada seeds are thought to be a nutritious feed when available (Burnside *et al.* 1995)

Details of the soils and vegetation characteristics of the land systems found on the study sites are presented in Appendix 3.

3.2 Animal study

3.2.1 Grazing management

Station management was independent of this study; however, decisions about sheep movements were documented. Throughout the study the management systems were referred to as rotational grazing system (RGS), Continuous grazing system (CGS), continuous grazing system - good land system (CGS-G) and continuous grazing system - poor land system (CGS-P).

Station 1 (RGS) was chosen for the study because it had relatively detailed stocking rate and observational data, which assisted in interpreting study results. Station 2 (CGS) was chosen for the study because of its close proximity to Station 1 and its continuous grazing regime generally represented the majority of pastoral stations in the Arid Shrublands.

Both stations use motorbikes, aircraft and self-mustering yards to gather livestock when they need to be handled for animal husbandry practices, sales and shearing. Self-mustering yards are holding compounds which enclose watering points. They have a one-way gate which can be set by the manager when livestock need to be caught.

Managers estimate that kangaroos and feral goats apply 20 - 30% of total grazing pressures on each of the stations. After shearing in 2007 both stations reduced stock numbers considerably.

3.2.1.1 Station 1 (RGS)

Station 1 (28º37'S, 116º16'E) covers 178,029 ha of which 138,001 ha is used for livestock grazing, while the remaining 33,455 ha is officially reserved for conservation purposes. The recommended carrying capacity is 9,207 DSE and the potential carrying capacity is 10,310 DSE (Van Vreeswyk & Godden 1998). Much of the station is in good rangeland condition with 65% of the perennial vegetation rated as good, 25% fair and 10% poor (Vreeswyk & Godden 1998). The station is predominantly a Merino wool and meat enterprise, although the flock has a growing mixture of Dorper and Suffolk cross.

Station 1 uses a flexible rotational grazing system (RGS) where sheep, amalgamated into flocks varying in size from 2,500 to 5,000 head, are regularly moved throughout the year. The owners aim was to graze paddocks for 2 – 3 months and rest them for 30 – 48 months to allow pasture plants to recover and give palatable perennial species ample opportunity for effective recruitment. In general, paddocks with saltbush floodplains are grazed during summer and stony hardplains, wanderrie sandplains and mulga hardpans are utilised during winter. Movement between paddocks are conducted using mostly self-mustering yards and motorbikes. Most paddocks have 2 – 3 watering points with an average grazing distance of 3 km. Shearing occurs once a year when most other animal husbandry practices are also undertaken.

During the study, 2,500 – 5,000 sheep were moved every 3 – 6 weeks through a choice of 21 paddocks ranging in size from 2,500 ha to 10,000 ha (Table 3.1). The sheep lambed in winter (June - August) both years. Movement of sheep during lambing was minimised, however, neighbouring paddocks were opened to allow sheep to have free range of paddocks. RGS reduced its stock numbers and began supplementing their sheep with wheat at the rate of approximately 1.5 kg/head/week from August 2006 until agistment in January 2007. In 2007, they removed their sheep and agisted them on a failed wheat crop from the 25th January until the 30th

May 2007 when they brought the sheep back. Approximately 1.5 kg/head/week of wheat was then spread in paddocks until June 2007.

The recommended carrying capacities (RCC) of the paddocks used are shown in Table 3.1. The RCC is the number of sheep that the paddock can carry sustainably over summer following an average winter (Van Vreeswyk & Godden 1998). The RCC is a guideline and is a conservative estimate.

Table 3.1 Movements of sheep on RGS during the study and recommended carrying capacities (RCC) of paddocks.

Date	Paddock	Period (days)	Paddock size (ha)	RCC*
28-Nov-05	Shearing Yards	n/a	n/a	n/a
29-Nov-05	Yalgoora	56	8,800	522.2
24-Jan-06	Woodita	31	4,400	316.5
24-Feb-06	Ederga	41	6,696	385.7
6-Apr-06	Cagacaroon	33	4,056	279.3
10-May-06	Cattle Station	103	2,760	163.0
21-Aug-06	Buddadoo-Widgulia-Edamurta	59	17,000	1200.8
19-Oct-06	Shearing Yards	n/a	n/a	n/a
20-Oct-06	Yallanbyne-Murdalyou	98	6,920	349.0
25-Jan-07	Morawa (agistment)	125	2,000	
30-May-07	Yewin	19	1,500	117.4
18-Jun-07	Edamurta	114	6,000	406.0
10-Sep-07	Yewin-Buddadoo	61	12,800	783.1
10-Dec-07	Shearing Yards	n/a	n/a	n/a

*RCC based on suggested carrying capacities (SCC) for the total area of the land systems found on the station (Van vreeswyk & Godden 1998). Land system size (ha)/SCC gave the number of ha per 1 DSE for each land system. The number of ha/1 DSE for each land system within a paddock was then averaged. The average was then divided into the size (ha) of the paddocks.

3.2.1.2 Station 2 (CGS)

Station 2 (28º16'S, 116º43'E) is much smaller than Station 1 comprising of 60,117 ha. It has a recommended carrying capacity of 3,770 DSE and potential carrying capacity of 4,290 DSE (Blood 2001). A large portion of the station is in moderate rangeland condition with 35% of the perennial vegetation rated as good, 57% fair and 8% poor (Vreeswyk & Godden 1998). The station is a Merino wool enterprise producing good lines of medium to broad wool. It also musters and sells goats once a year and commercially harvests kangaroos. The station uses a flexible, continuous grazing management system where small mobs (≤500 sheep) stay in paddocks all year, until shearing, which occurs once a year. The station regularly transports its ewes away to be mated on nearby agricultural stubbles returning in autumn for lambing, however, the test sheep were not moved from their paddocks during the study. Paddock size ranges from 1,500 to 7,500 ha with watering points generally less than 4 km apart. Stocking rates are generally set during shearing time when an assessment of available forage is made. Set stocking rates are based on the feed estimate, perceived range condition and livestock performance objectives.

During the study CGS started the trial with approximately 400 sheep in the poor condition paddock (CGS-P) and 500 sheep in the good condition paddock (CGS-G). These numbers were reduced to 220 in the CGS-P in 2007, and stayed about the same for CGS-G (540 sheep). One large bale of cereal hay was provided for the sheep on CGS-G in October 2007. This amount of supplementary feeding was considered insignificant by the owners. The ewes were not mated in 2006, but were in 2007, with winter lambing.

Based on paddock size and suggested carrying capacities for land systems on the entire station (Van Vreeswyk & Godden 1998), the recommended carrying capacities for CGS-G and CGS-P are 341.9 and 305.6, respectively (Refer to Table 3.1 for calculation). Recommended carrying capacities are for paddocks over summer, following an effective winter season. Therefore, CGS-G was overstocked during the entire study and CGS-P was overstocked during 2006.

3.2.2 Sheep location

3.2.2.1 Station 1 (RGS)

Paddocks on RGS were studied as sheep entered and left them during the rotation. Table 3.3 outlines the paddocks used during the study.

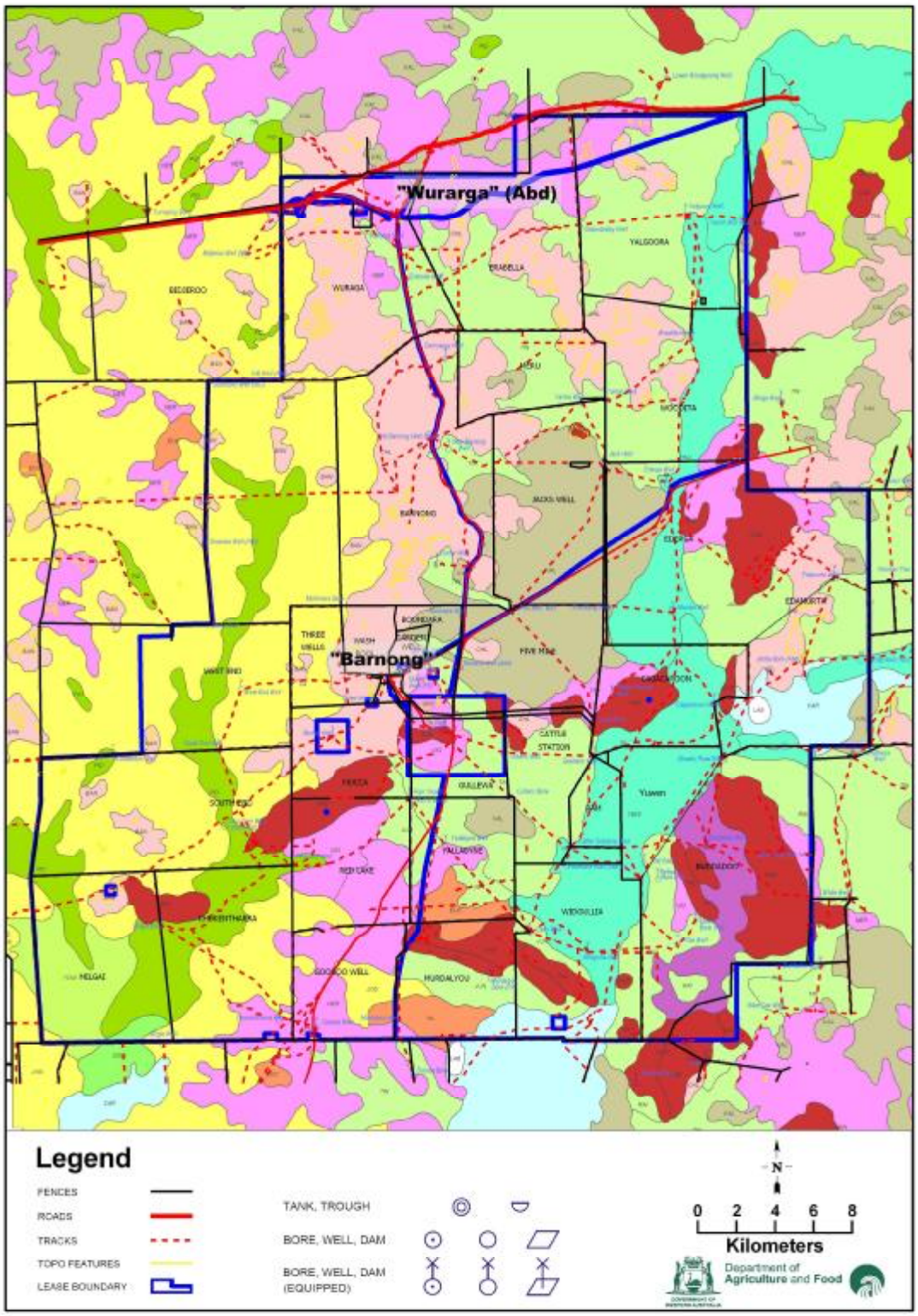
Table 3.2 lists the land systems present in the paddocks grazed during the study in order of dominance.

Table 3.2 Land systems of RGS paddocks grazed during the study.

Paddock	Land systems (listed in order of dominance)
Yalgoora	Tindalarra, Ero, Nerramyne and Challenge
Woodita	Tindalarra, Challenge and Ero
Ederga	Ero, Gabanintha, Kalli, Jundee, Violet, Challenge and Tindalarra
Cagacaroon	Yewin, Gabanintha, Violet, Ero, Challenge, Jundee and Carnegie
Cattle Station	Tindalarra, Gabanintha, Challenge, Kalli, Violet and Yewin
Edamurta	Carnegie, Challenge, Tindalarra, Mileura, Kalli, Lake bed, and Jundee
Widgulia	Yewin and Carnegie
Buddadoo	Wiluna, Gabanintha, Rainbow, Violet, Tallering, Yewin, Watson, Jundee and Tindalarra
Yallanbyne	Tindalarra, Jundee, Violet, Euchre, Kalli and Yewin
Murdalyou	Jundee, Yilgangi, Watson, Carnegie, Euchre, Tallering and Joseph
Yewin	Yewin, Rainbow and Wiluna

Plate 3.1 shows the land systems present on Station 1, and the paddocks used during the study.

Plate 3.1 Land system map of Station 1 (Refer to Appendix 2 for legend).



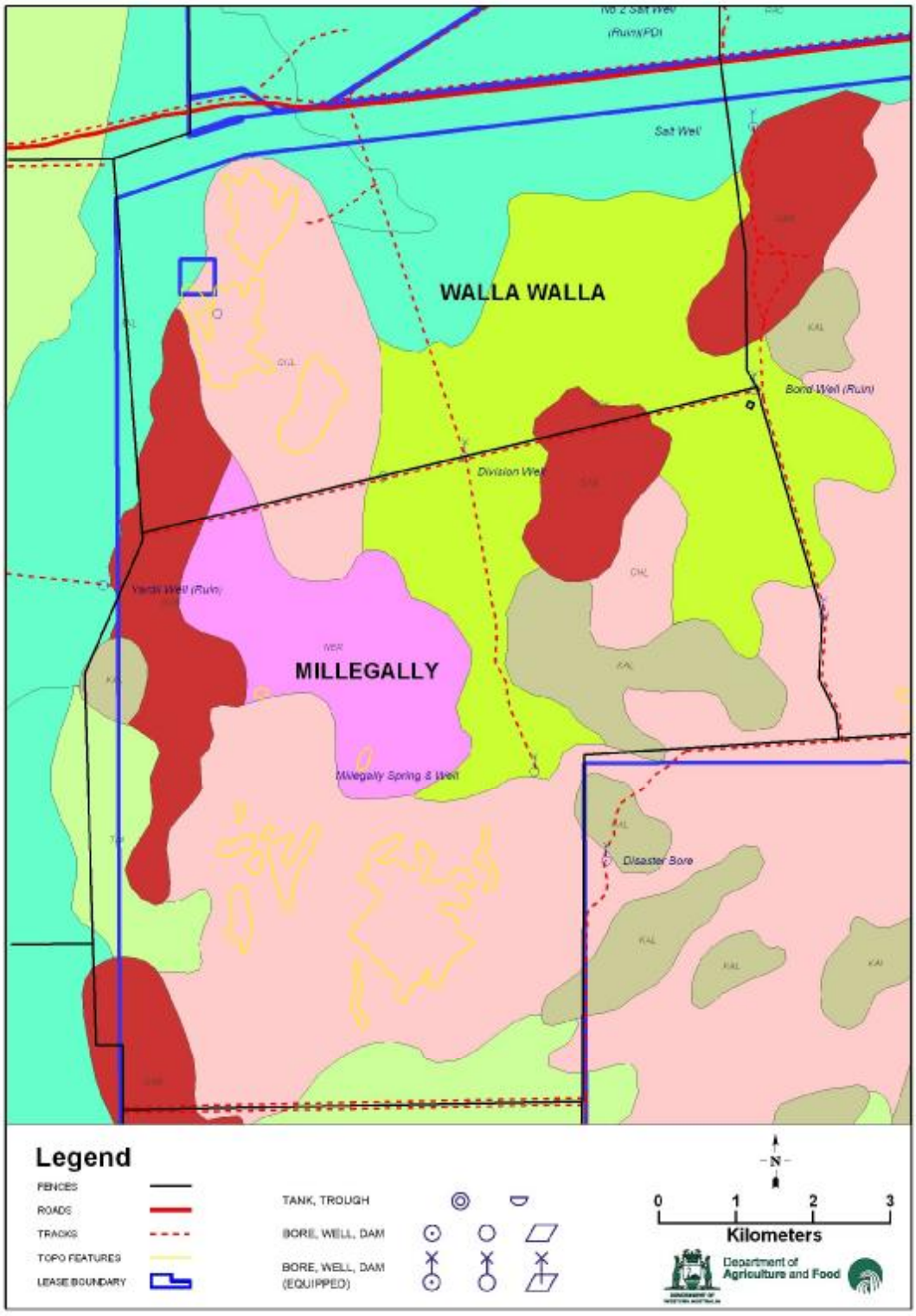
3.2.2.2 Station 2 (CGS)

Two paddocks on CGS were chosen to represent paddocks with relatively high (CGS-G) and low (CGS-P) feed value (Plate 3.2).

CGS-G was approximately 5,575 ha and contained four watering points. The paddock represented high feed value, dominated by the highly productive Racecourse land system with chenopod shrublands and mulga groves. The paddock comprises of six land systems listed in order of dominance: 1) Racecourse; 2) Monk; 3) Challenge; 4) Mileura; 5) Gabanintha; and 6) Nerramyne.

CGS-P was approximately 5,831 ha and contained two watering points. The paddock represented low feed value, dominated by the less productive Challenge and Tindalarra land systems, with mulga woodlands. The paddock comprises of six different land systems (listed in order of dominance): 1) Challenge; 2) Nerramyne; 3) Monk; 4) Kalli; 5) Gabanintha; and 6) Tindalarra.

Plate 3.2 Map of CGS-G (Walla walla) and CGS-P (Millegally) (Refer to Appendix 2 for description of land systems).



3.2.3 Animal selection

A total of 300 Merino hogget (18 month old) ewes were randomly selected from the stations for the study. One hundred and fifty sheep from each station were selected and separated into three comparable mobs of 50 sheep by stratifying live weights. The selected sheep were double ear tagged and mixed with station sheep in the two paddocks on CGS and the single rotating mob on RGS. Therefore there were a total of 100 trial sheep, 50 from each station, on RGS, CGS-G and CGS-P. Creating a balance of sheep from both stations within the three test mobs was necessary to account for variable bloodlines between the stations.

3.2.4 Live weights and body condition scores

The sheep on RGS were weighed, using portable, electronic sheep scales (AG500 03), body condition score (BCS) and wet/dry (lactating/non lactating) assessed every time they moved paddocks. On CGS they were similarly weighed, BCS and wet/dry assessed every 4-6 months, depending on opportunity for trapping and approval by station owners. As far as possible, the same person carried out BCS assessment each time to minimise judgement error. Estimated clean fleece weights (see 3.5.6) were subtracted from live weights (for each recorded weighing) to determine fleece-free body weight.

3.2.5 Wool dye-banding

All the study sheep were dye-banded at least once during each year, coinciding with trapping for live weights and BCS assessment. In 2006 they were dye-banded twice, however, one dye-band failed. Dye-banding (Plate 3.3) involved applying a fine vertical line (5 -10 cm) of blue-black or red-black permanent hair dye (McCloghry 1997) at skin level on the right mid-side of each animal (Chapman & Wheeler 1963; Williams & Chapman 1966). Brown dye was applied during shearing in 2006 (October/November), but it was found that the dye was indistinguishable from the colour of dirt found in wool. Consequently, brown dye colour was avoided there after. The dye was applied using 10 mL syringes with modified 20 gauge needles

where the tips were ground on a diagonal to widen the opening and make application easier. Care was taken to not apply excessive amounts or dye, which can burn the wool; however, this did occur occasionally.

After trialling two methods of removing the dye-banded wool – on the wool table after the sheep were shorn and using portable shears to remove the patches before the sheep were shorn, it was decided that removal of a mid-side patch using the portable shears was the easiest and quickest method.

Plate 3.3 Applying dye-band to midside of sheep

3.2.6 Clean fleece weights

A mid side patch of wool containing the dye-bands (refer to 3.5.5) was removed from each test sheep immediately before shearing each year. Additionally, sheep fleeces, including the belly, were weighed immediately after shearing. Once dye-bands were removed for analysis, the remaining wool from the midside patch clipping was analysed for clean fleece weight. The samples (10 – 30 g) were

weighed, washed (see 3.8.1) and left to dry overnight before being re-weighed to determine clean fleece yield (%). The clean fleece yields were used to determine clean fleece weights using greasy fleece weights collected at shearing.

3.2.7 Faecal collections

Faecal samples were collected from trap yards at watering points within paddocks every 3 - 4 months on CGS and either during or immediately after sheep left paddocks on RGS. Watering points were the chosen places for collections as these were the most likely places to find fresh dung from a large number of sheep. Dung was also opportunistically collected along tracks when it was visibly fresh.

Sampling frequency on CGS was increased to once a month from July 2007 until shearing in October/November 2007.

3.2.8 Near infrared reflectance spectrophotometry

Dietary CP, ME and OMD (dCP, dME and dOMD) were estimated from faecal samples using NIRS calibration equations developed with data from controlled feeding experiments (K. Mahipala, Curtin University of Technology, unpublished data).

3.3 Plant study

Leaf material from selected native species varying in palatability was collected from the two paddocks on Station 2 every 3 - 4 months and as sheep entered new paddocks during the rotation on Station 1. A Scientific or Other Prescribed Purposes (SOPP) flora licence was obtained from the Department of Environment and Conservation at the start of the study and reviewed annually.

Approximately 100 g of new leaf material was collected from the ends of branches over the entire plant; however, if new leaf material was not present older material was collected. Stems, flowers and fruit were avoided.

3.3.1 Selection of plants for evaluation of nutritive value

The plant species targeted for collection were known to be palatable based on pastoralists' observations of livestock (Merino sheep) grazing, evidence of utilisation observed in the field and information stated in Mitchell and Wilcox (1994) and Russell and Fletcher (2004). Species collected depended on those available for forage in paddocks being grazed. Because of the drought conditions, some plants disappeared (died or grazed out) from the paddocks during the study. Many of the perennial shrub species chosen for analysis were common on both stations in the aim that they could be sampled regularly. Additionally, most of the species were chosen because they were easy to identify.

3.3.2 DNA profiling of selected indicator plants

3.3.2.1 Plant selection

Eighteen indicator perennial species were selected for DNA profiling and sampling during the study. The species ranged in palatability from highly palatable and sought after by livestock to low palatability, only eaten in dry times. Categorisation of these species' palatability in Table 3.3 was obtained from a ranking compiled by Russell & Fletcher (2003) and information from Mitchell & Wilcox (1994). Faecal DNA analysis enabled determination of when these plants appeared and disappeared in sheep diets.

The species chosen for DNA profiling are common across the Arid Shrublands of WA and are relatively easy to identify. Correct identification of plant species is critical for accurate DNA profiling. Therefore species that were difficult to identify, including short lived species, were not considered for DNA analysis. Species common to the Arid Shrublands were targeted as concurrent (S. van Wyngaarden, Masters student, Curtin University of Technology) and future studies can occur in different areas of WA.

Table 3.3 Plant species for which DNA fingerprints have been developed, together with the relative palatability ratings of these species.

Scientific name	Common name	Relative palatability rating
Grasses:		
Aristida contorta F. Muell	Wind grass	Moderate
Austrostipa elegantissima Labill	Silver speargrass	High
Enneapogon caerulescens (Gaudich)	Limestone grass	High
Browse:		
Acacia hemiteles Benth	Tan wattle	Very low
Acacia saligna		Moderate
Atriplex bunburyana F Muell.	Silver saltbush	Moderate
Atriplex vesicaria Benth	Bladder saltbush	Moderate
Enchylaena tomentosa R.Br.	Ruby saltbush	Moderate
Eremophila forrestii F Muell.	Wilcox bush	Variable
Eremophila maculata subsp. brevifolia (Ker Gawl.) F.Muell.	Emu bush	High-moderate
Frankenia setosa L	Frankenia	Moderate
Maireana georgei (Diels) Paul G.Wilson	George's bluebush	Very high
Maireana pyramidata (Benth.) Paul G.Wilson	Sago bush	Moderate-low
Maireana sedifolia (F.Muell.) Paul G.Wilson	Pearl bluebush	Moderate-low
Ptilotus obovatus (Gaudich.) F.Muell.	Cotton bush	Moderate
Rhagodia eremaea Paul G. Wilson	Tall saltbush	Moderate
Scaevola spinescens R.Br.	Current bush	Moderate
Solanum lasiophyllum Poir	Flannel bush	Moderate

3.3.3 Isolation of plant DNA

DNA profiling was undertaken at the ChemCentre according to the method of Ho *et al.* (2009). The first requirement was the establishment of a DNA reference data bank for the selected plant species. DNA was isolated from the plants' chloroplast and subjected to PCR amplification (as described below). DNA restriction site screening was then performed on respective PCR-amplified DNA to which the resultant restriction profiles were used to assign the reference plants. Using the same procedures, DNA was isolated from the faecal samples and PCR-amplified using the same primer pairs as used for the reference plant material.

The dried faecal samples were individually milled, sieved through a 0.5 mm in a Retsch Model SK-100 (1,100 Watt) cross-beater mill. Each sample was decanted into a plastic sample bottle, labelled and stored at room temperature until subsequently used for DNA analysis. To further minimise the risk of cross-over contamination, the entire mill was thoroughly cleaned in-between samples using compressed air and then wiped down with tissues.

Genomic DNA was isolated from milled faecal samples using the QIAGEN DNeasy Plant kit (QIAGEN), with modifications. Each sample was analysed in triplicate. The 25 mg sub-sample was combined with 1.2 mL of Lysis buffer (Buffer AP1) and 12 µL RNase A stock solution (100 mg/mL). The mixture was incubated for 10 min at 65°C after which 390 µL of Buffer AP2 was added, mixed and the lysate placed on ice for 5 min. The lysate was centrifuged for 5 min at 20,000 x g and 560 µL from the supernatant was used for DNA isolation according to the manufacturer's instructions, without alteration.

For the reference plants, dried leaves were placed in a plastic bag and manually ground into smaller fragments using a bottle as a rolling pin. The three 25 mg samples were taken for DNA isolation using the QIAGEN DNeasy Plant kit. A new bag was used for each reference plant. All genomic DNA were eluted to a final volume of 100 µL AE Buffer (QIAGEN) and stored at -20°C.

3.3.4 PCR amplification

DNA was screened for suitability for PCR by amplifying each isolate over a 2-fold serial dilution range. The best performing range of titres for each DNA preparation were those which produced a single and most intensely-stained DNA band (DNA concentration ranging from 5 - 25 ng was optimal for PCR-amplification) and these were used for subsequent studies. PCR amplifications were performed on 5.0 µL of DNA isolate in a final reaction volume of 20 µL containing 10 mM Tris-HCl, 1.5 mM $MgCl_2$, 50 mM KCl (pH 8.3), 0.25 µM Primers, 250 µM dNTPs and 0.75 Units of Kapa Taq DNA polymerase (Kapa Biosystems). The primer pairs used were CH 37/39 (*trn*L and *rpl*2m1) and CH 53/55 (*trn*L exon 1 and 2) (see Table 3.4). DNA was denatured at 94°C for 2 min, followed by 7 cycles of 94°C for 15 s (denaturation) and 72°C for 1 min (extension), in which the annealing temperature was touch-downed in 1 degree decrements, from 65°C to 58°C. This was followed by 28 – 30 cycles of amplification in which the annealing temperature was held at 58°C and before a final extension of 72°C for 10 min. The presence of PCR-amplified products were confirmed by UV transillumination following horizontal gel electrophoresis on a 2% agarose (Bio.Rad) and then accurately sized using the Agilent 2100 bioanalyzer (Agilent Technologies) according to the manufacturer's instructions.

Table 3.4 Primer pairs used.

Primer	Sequence 5' – 3' (priming region)	Reference
CH 37 F	TGA ATG GTT AAA GCG CCC AAC T (*trn*L)	Heinze (2007)
CH 39 R	TTC TAT GGT TAC GAT TCT ACC ATA TAT GTC (*rpl*2m1)	Heinze (2007)
CH 53 F	CGA AAT CGG TAG ACG CTA CG (*trn*L exon 1)	Taberlet *et al.* (1991)
CH 55 R	GGG GAT AGA GGG ACT TGA AC (*trn*L exon 2)	Taberlet *et al.* (1991)

F, forward primer; R, reverse primer.

3.3.5 Restriction enzyme analysis

Up to 10 µL of amplified DNA (250-500 ng) was digested with restriction enzymes (Roche Diagnostics) in a final volume of 18 µL for 4 h at 37°C. A panel of 24 different restriction enzymes were used to generate restriction profiles from which DNA fingerprints diagnostic for each plant species were identified. The presence of restriction fragments was confirmed by UV transillumination following horizontal gel electrophoresis on 4% agarose MS (Roche Diagnostics) and the fragments were accurately sized using the Agilent 2100 bioanalyzer (Agilent Technologies) according to the manufacturer's protocol.

3.4 Additional

Additional factors that can influence the plant and animal study were monitored, including NDVI and rainfall. Rainfall data was collected from station homesteads, individual paddocks and from Yalgoo township.

3.4.1 Normalised difference vegetation index (NDVI)

The paddocks that the sheep on RGS and CGS occupied were GPS mapped to pinpoint NDVI satellite data. Dr Shane Cridland (Department of Environment, Canberra) analysed and calibrated the data. The NDVI data was extracted fortnightly over the study period to show changes in "greenness" (photosynthetic active material) over time, which is related to forage availability and quality.

NDVI is calculated as:

(NIR-Red)/(NIR+Red)

where:
NIR is the near infrared reflection of green vegetation
Red is the reflection of green vegetation in the red wavelengths

3.5 Analytical procedures

3.5.1 Wool profiles

Dye-banded wool samples were analysed at CSIRO in Floreat, Western Australia. Small samples of approximately 10,000 – 20,000 fibres were washed with petroleum ether then left to dry and stabilise in a climate controlled room at 19°C and 60% relative humidity for 24 h. The samples were thinly spread on a fibreglass (5 mm steps) slide then scanned with the ODFA 2000 (Baxter 2000; IWTO 2001), which automatically profiles the wool.

After weighing and measuring total length of the samples, they were cut at the beginning of each dye-band and each section re-weighed and measured for length to determine proportions of growth between dye-bands (Chapman & Wheeler 1963; Williams & Chapman 1966).

Additional, wool samples of between 10 g – 30 g were weighed, washed, dried and reweighed to determine yields (see 3.5.6) at Australian Fibre Testing Western Australia.

3.5.2 Dry matter content

Plant and faecal samples collected in the field were stored in an esky during transport to the laboratory (a 2 - 4 h journey). The samples were then dried at 60°C in a forced-air oven (Contherm Thermotec 2000), after which they were ground through a 0.5 mm screen and stored at -18°C. Prior to chemical analyses the samples of known weight (approx. 1 g) were again dried in clean sintered glass crucibles (Pyrex, Crown Scientific, Cat # 3650/08, 10 mL, porosity 4) at 70°C until constant weight to determine laboratory DM content.

3.5.3 Ash

Dried and ground plant and faecal samples of known weights (approximately 1 g) were placed in sintered glass crucibles and ignited in a muffle furnace at 480°C for 6 h to determine ash content.

3.5.4 Crude protein

Crude protein (CP) content was determined for plant and faecal samples. Total N was determined using the Kjeldahl oxidation procedure (Mossberg 1979). The resulting N content was multiplied by 6.25 to give the CP content, expressed as a percentage of the DM.

3.5.5 Neutral detergent fibre

Neutral detergent fibre (NDF) measures the combined cellulose, hemi-cellulose and lignin content and was determined for plant and faecal samples. For each sample, approximately 1 g (known weight) of ground material was weighed into a conical flask to which 100 mL of neutral-detergent solution was added. Samples were heated to boiling then simmered on a hot plate for 1 h before filtering on coarse, sintered glass crucibles (which had been previously weighed). Samples were washed with boiling demineralised water until there was no foam. The crucibles were then dried for 12 h at 105°C and re-weighed (AOAC 2005).

3.5.6 Acid detergent fibre and lignin

Acid detergent fibre (ADF) measures the combined cellulose and lignin content and was determined for plant and faecal samples. For each sample, approximately 1.0 g (known weight) of ground material was weighed into a conical flask to which 100 mL of CTAB/sulphuric acid solution was added. The samples were heated to boiling, simmered on a hot plate for 1 h and then filtered on coarse, sintered glass crucibles (which had previously been weighed). The samples were washed with boiling, de-

mineralised water until there was no foam. The crucibles were then dried for 12 h at 105°C before being re-weighed.

To determine acid detergent lignin (ADL) content, crucibles containing the ADF residue were placed in 50 mL beakers and filled with sulphuric acid. Stirring with a glass rod occurred hourly to break up the fibre. After 3 h the crucibles were filtered and washed with hot water until all the acid was removed. The crucibles were then dried at 100°C for 12 h and weighed (AOAC 2005).

3.5.7 Plant elements – Phosphorus (P), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), sulphur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn)

Macro and trace element contents of plant samples were determined using the ICP-AES method (CCWA 1994). Organic matter is destroyed and mineral components are digested by heating with nitric and perchloric acids. Results were quantified against known standards (CCWA 1994).

3.5.8 In vitro organic matter digestibility (OMD) and metabolisable energy (ME) content

The OMD and ME content of the plant samples were determined using the *in vitro* gas fermentation technique (Menke *et al.* 1979; Makkar 2004).

Approximately 200 mg (known weight) of the ground samples (0.5 mm sieve) were transferred into 100 mL calibrated, gas-tight glass syringes that had a length of silicon tubing and clip attached (see Plate 3.4). These were prepared the day before and maintained at 39°C in a forced-air oven until ready for incubation. Samples were incubated in triplicate. Duplicate syringes were prepared as blanks (ruminal fluid and buffer mixture only) and standards (Hohenheim hay standard) and were also incubated. The Hohenheim hay standard used produces 44.16 mL gas over 24 h.

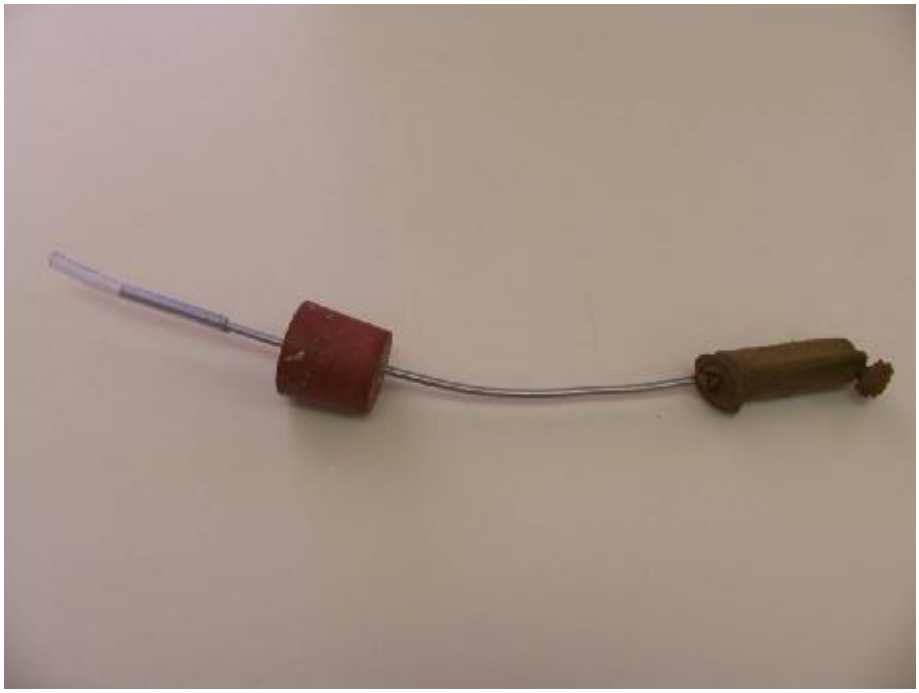
Three, rumen fistulated, Merino wethers were used as ruminal fluid donors. The sheep were individually housed in raised, timber slatted pens, 2.5 m^2 in size and each fitted with feed and water troughs.

The sheep were fed a maintenance, roughage-based diet (Makkar, 2003), consisting of 70% steam-cut oaten chaff, 17% lucerne hay chaff and 13% lupins, for at least 10 d prior to (i.e. adaptation period) and during the period of ruminal fluid collection. The sheep had *ad libitum* access to clean, fresh water.

About an hour before the morning feed, ruminal fluid was collected from each of the donor animals and transferred into a pre-warmed (39°C) thermos flask that has been flushed with CO_2. The ruminal fluid was obtained by suction using a probe, which consisted of a metal frame (5 cm x 1 cm x 1 cm) covered with a double layer of nylon stocking material (Plate 3.5). The probe was attached to a curved stainless steel metal tube (about 25 cm long) and placed in a caudal position in the ventral sac of the rumen and held in this position by its tight fit through the rubber stopper in the cannula.

Plate 3.4 Gas-tight, glass syringes used for the gas fermentation procedure

Plate 3.5 Sampling probe used for the collection of ruminal fluid



Prior to the collection of the ruminal fluid, the reagents were prepared and respective volumes were mixed to be adequate to fill the required number of syringes per batch (Table 3.5). Bicarbonate buffer solution, macro and micro-mineral solutions, resazurine and distilled water were mixed (in that order) in a 3 L wolffe flask, which was suspended in a water bath at 39°C and continuously flushed with CO_2 gas. After 5 min, 40 mL of reducing solution was added. Once the mixture was reduced 440 mL of rumen fluid was added. The mixture was then stirred and flushed with CO_2 for a further 10 min. Forty mL of the rumen mixture was then dispensed into the glass syringes. Gas bubbles were removed and the plastic clips on the silicon tubing were closed. The position of the piston was recorded and the syringes were then suspended in a waterbath (Plate 3.6) for incubation.

Plate 3.6 Incubation of gas syringes in water bath

Table 3.6 Preparation of in vitro rumen fermentation buffer solution.

Reagent	Volume (mL)
Bicarbonate buffer solution: Dissolve 35 g sodium bicarbonate (Na_2HCO_3) & 4 g ammonium carbonate (NH_4HCO_3) in about 500 mL distilled water. Make up to 1 L volume (in volumetric flask) with distilled water.	420.00
Macro mineral solution: Dissolve 6.2 g potassium dihydrogen phosphate (KH_2PO_4), 5.7 g disodium hydrogen phosphate (Na_2HPO_4), & 0.6 g of magnesium sulphate ($MgSO_4.7H_2O$) in about 500 mL of distilled water. Make to volume (1 L) with distilled water.	210.00
Micro mineral solution: Dissolve 10 g manganese chloride ($MnCl_2.4H_2O$), 13.2 g calcium chloride ($CaCl_2.2H_2O$), 1g cobalt chloride ($CoCl_2.6H_2O$), 8 g ferric chloride ($FeCl_3.6H_2O$) in about 50 mL of distilled water. Make to volume (100 mL) with distilled water.	0.10
Resazurine (store in refrigerator): Dissolved 0.1 g resazurine in 100 mL distilled water.	1.07
Reducing solution (i.e. freshly prepared): Dissolve 996 mg sodium sulphide ($Na_2S.9H_2O$) in 94 mL distilled water & then add 6 mL of 1N sodium hydroxide (NaOH) solution.	40.00
Distilled water	630.00
Ruminal fluid (i.e. filtered, homogenised):	440.00

The volume is adequate to fill 40 syringes plus 10% extra.

The suspended syringes were shaken every 1 h for the first 4 h, then every 2 h until 12 h, then left untouched until the 24 h was completed. Measurements of gas production were taken at 0, 2, 4, 6, 8, 10, 12 and 24 h.

3.6 Calculations

3.6.1 Net gas production

The net gas (Gn) produced by the fermentation of the 200 mg plant sample was calculated from gas produced after 24 h, taking into consideration the gas produced by the hay standard and that of the blank. The variation due to ruminal fluid was corrected by using gas produced by the hay standard.

The mean gas production of blank tests (Gb0) was subtracted from the gas production of samples and standards measured with the same batch of ruminal fluid. This net gas production was then corrected for differences in sample weight (W. mg DM) when different from 200 mg DM.

Gas production (Gn) is defined as the total increase in volume (V24 – V0) minus the blank (Gb0), multiplied by the sample weight correction factor (200/W) and by the mean standard correction factor (FH). It was thus calculated as:

Gn (mL per 200 mg DM, 24 h) = [(V24 – V0 – Gb0) * 200 * FH]/W

where:
V0 = position of the piston at the beginning of the incubation
V24 = position of the piston after 24 h of incubation
Gb0 = mean gas production after 24 h incubation of ruminal fluid and medium mixture without substrate (blank)
FH = 44.16 / (GbH – Gb0); roughage correction factor with Hohenheim hay standard (GbH)
W = weight of the test sample (mg DM)

3.6.2 In vitro OMD and ME content

In vitro OMD and ME content of the plant samples were predicted from net gas production of the samples, together with CP and ash contents of the respective plants (Menke *et al.* 1979).

OMD (%) and ME, (MJ/kg DM) were calculated, according to Makkar (2004), as follows:

OMD (%) = 14.88 + 0.889 Gn + 0.45 CP + 0.0651 XA

ME (MJ/kg DM) = 2.20 + 0.136 Gn + 0.57 CP

where:
Gn = Net gas production by 200 mg of the sample (mL)
CP = Crude protein content of the sample (%)
XA = Ash content of the sample (%)

3.7 Statistical analysis

Treatment means for all parameters were compared using analysis of variance performed by the statistical analysis package Genstat. For all analysis $P<0.05$ was regarded significant.

Analysis of animal study data occurred as a nested design where original sources of sheep (Station 1 and Station 2) were compared within management systems (RGS, CGS-G and CGS-P), which were compared within years (2006 and 2007).

4 Study sites: Rainfall and normalised difference vegetation index (NDVI)

4.1 Introduction

Rainfall is highly variable and one of the most dominant factors affecting Australian rangeland environments, including plant production (Harrington *et al.* 1984b). Plant production in response to rainfall can be effectively monitored by NDVI, using satellite data, which regularly records the photosynthetic activity of a defined area (Cridland *et al.* 1995). Climate and plant production are factors that cannot be controlled therefore they were monitored by recording rainfall and NDVI for the trial sites over the study period.

4.2 Materials and methods

4.2.1 Rainfall

Both Yalgoo town, which is within 10 km of CGS sites, and the RGS site have official Bureau of Meteorology (BOM) weather stations. The rainfall data was derived primarily from these records with Yalgoo town records used as the rainfall data for the CGS sites.

RGS also had rain gauges at numerous watering points (mills) and monitoring sites within paddocks, which were regularly checked after rain events.

4.2.2 NDVI

Refer to Chapter 3.7 for details of the NDVI methodology. Due to the movements of the sheep in the rotational grazing system, the NDVI for the study period involved using the NDVI for the specific paddock the sheep were occupying each month.
The NDVI was plotted as a time series, as described by Cridland *et al.* (1995).

The green flush was calculated as:

Flush = NDVImax – NDVIbaseline

where:

NDVImax is the maximum NDVI for the year
NDVIbaseline is the minimum NDVI from the previous year.

The annual green flush (Flushyear x) relative to the absolute flush over total time period (Max Flushpopulation) was calculated as:

% NDVI Flush = (Flushyear x / Max Flushpopulation)*100

NDVI data for the stations was collected from April 1991 to November 2007.

4.3 Results

4.3.1.1 Rainfall

The average annual rainfall for Yalgoo Shire is 258 mm. In 2006, RGS received below-average rainfall (193.6 mm), while CGS received above-average rainfall (274.4 mm). In 2007, all sites received below-average rainfall (196.6 mm for RGS; 199.4 mm for CGS). Additionally, the winter of 2006 was the lowest rainfall on record for the Shire (BOM 2006).

As shown in Figure 4.1, the sites experienced some large rainfall events in summer and early autumn of 2006, and again in 2007, due to cyclonic rain-bearing depressions. The RGS site experienced above-average rainfall in January, February and April of 2006, and January, February and April of 2007. The CGS sites had above-average rainfall in January, February, April and September of 2006, and April, July, November and December of 2007.

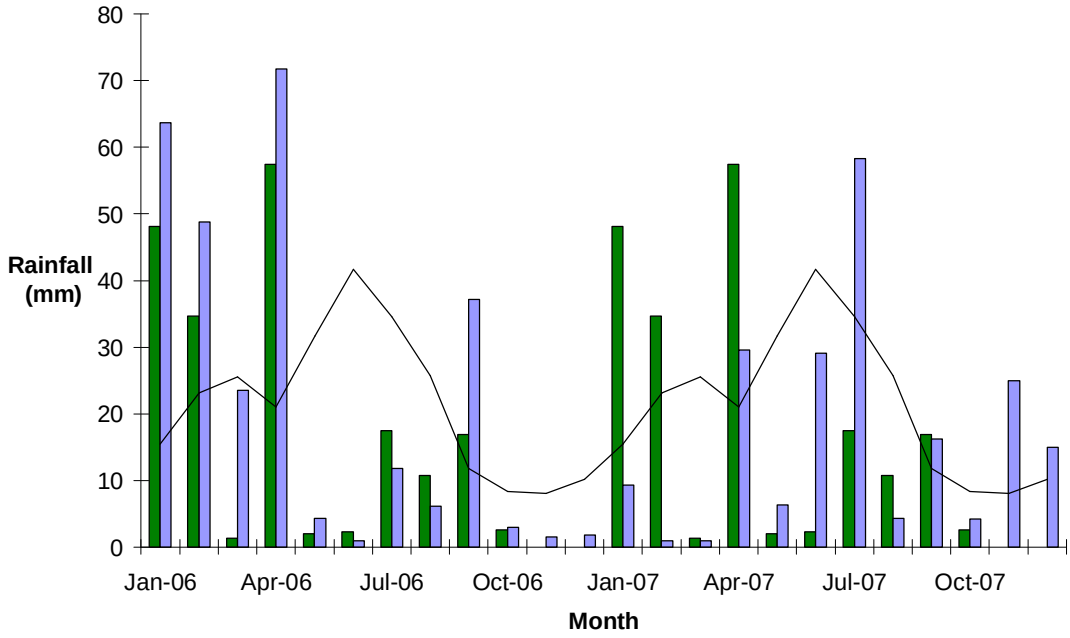


Figure 4.1 Rainfall from December 2005 to December 2007 at RGS site (green), Yalgoo (blue, representing CGS sites) and 108 years average (line) (BOM unpublished data).

The variability in rainfall at different sites within the RGS in 2006 is shown in Figure 4.2. The average annual rainfall for the Station is 275 mm, calculated from historical station records. The homestead received below-average rainfall (208.6 mm) for the year (2006). Yallanbyne Mill (276 mm), Ederga Mill (388 mm), Edamurta Site 1 (288 mm) and Yallanbyne Site (290 mm) received above-average rainfall for the year (2006). In contrast, West End Mill, Gooroowell Site and Murdalyou Site received no rainfall during 2006, according to station rain gauge records.

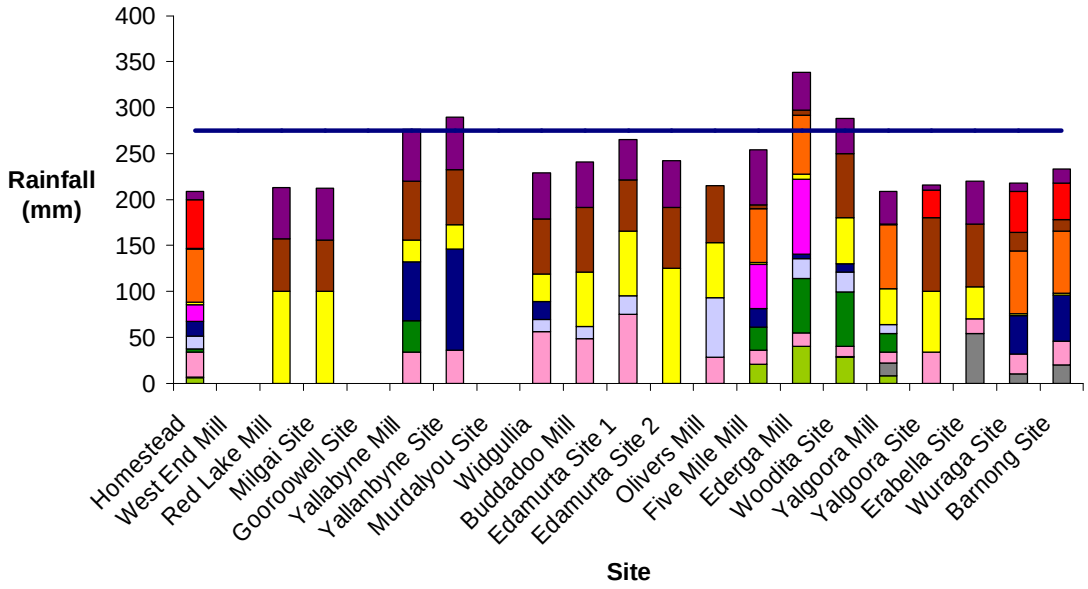


Figure 4.2 Rainfall at different sites within the RGS during 2006. Solid blue line, average annual rainfall; light green, 6th Jan; grey, 8th Jan; light pink, 14th Jan; dark green, 25th Jan; light blue, 31st Jan; dark blue, 12th Feb; dark pink, 23rd Feb; yellow, 4th Mar; orange, 2nd Apr; brown, 12th May; red, 18th Oct; purple, 31st Dec.

4.3.2 NDVI

In 2006, the photosynthetic activity (NDVI) on the study sites increased from January (0.12 - 0.13) to May/June (0.17 - 0.22) before decreasing (Fig 4.3). During 2007, the photosynthetic activity fluctuated between 0.07 - 0.16. The photosynthetic activity within the RGS was generally intermediate to the two sites within the CGS, apart from October-January 2006 and November 2007, when NDVI was lower. CGS-G had higher photosynthetic activity compared to CGS-P, which one would expect.

During the study period, the maximum NDVI within the RGS was in June 2006 (0.21) and the minimum (0.07) occurred in November, 2007. For CGS-G the maximum (0.22) was also in June 2006, while the minimum (0.12) was in January

2007. For CGS-P, the maximum (0.17) was April to June 2006, and the minimum (0.10) in January 2007.

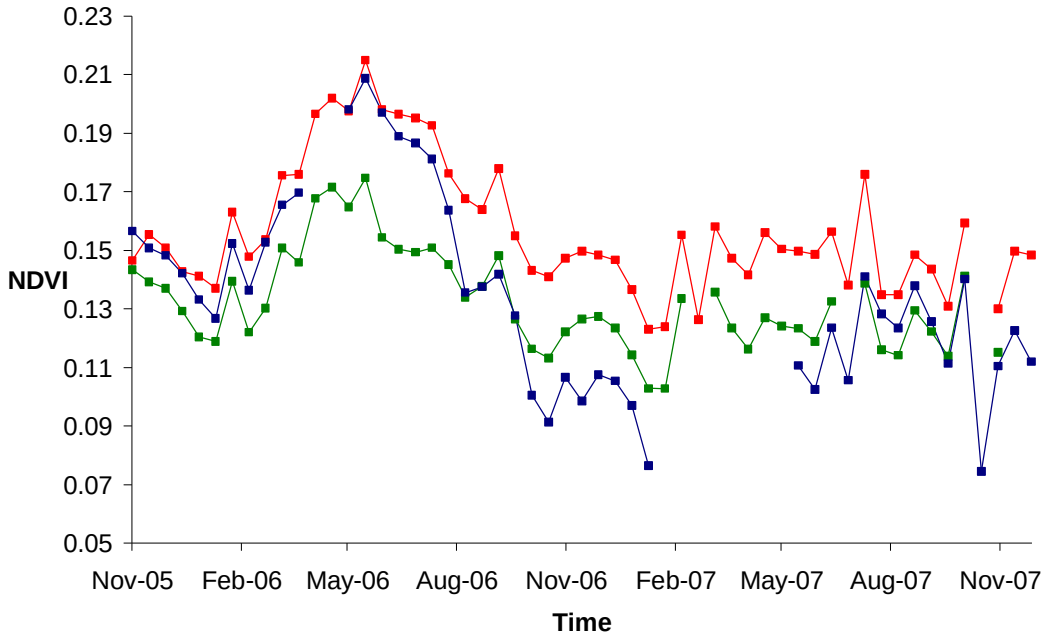


Figure 4.3 NDVI of the sites over the study period. RGS (blue), CGS-G (red) and CGS-P (green).

The overall monthly averages of NDVI from 1991 to 2007 are shown in Figure 4.4. NDVI peaks in winter months (June - August), although the standard deviations are also highest during these months.

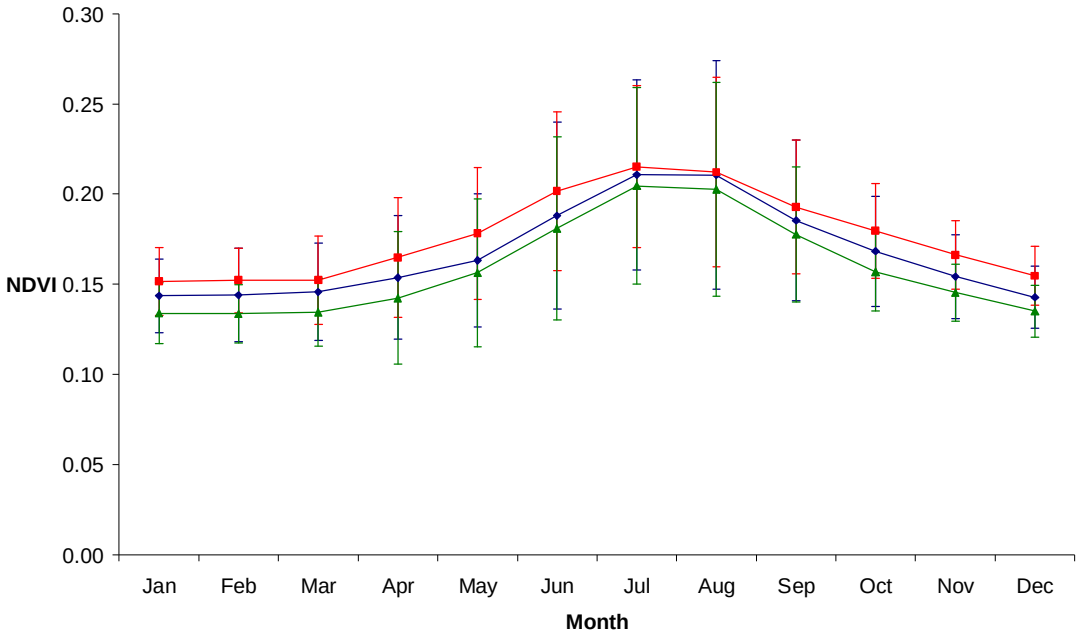


Figure 4.4 Overall monthly average NDVI (±SD) from 1991 to 2007.

The long-term (1991-2007) NDVI for the study sites are shown in Figure 4.5 Generally, peaks occurred in winter months (June - August), while troughs generally occurred in summer and autumn (December - April).

From 1991 to 2007 the maximum NDVI within the RGS was in February 1999 (0.38) and the minimum (0.04) occurred in March 2000. Within CGS-G the maximum occurred in July and August 1998 (0.32) and the minimum (0.09) in September 2007. In CGS-P the maximum (0.031) also occurred in July and August of 1998 but the minimum (0.09) occurred during March and April 2003.

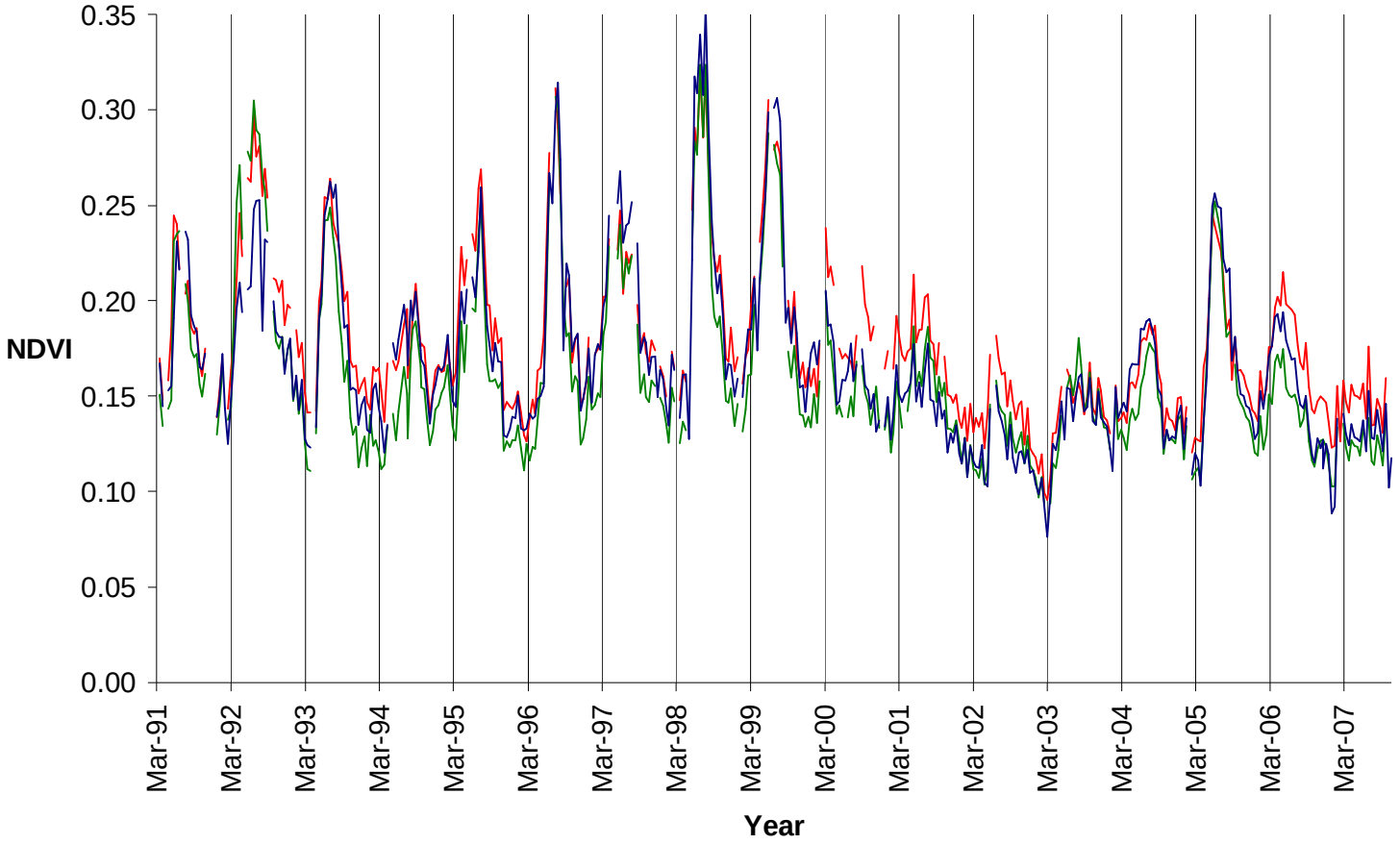


Figure 4.5 NDVI of study sites from March 1991 to December 2007. RGS (blue), CGS-G (red) and CGS-P (green).

All three study sites had low green flushes in 2006 and 2007, compared to the previous years (Fig 4.6). In both 2006 and 2007, RGS experienced its lowest flush (14%) during the 16 years of NDVI record; its greatest flush (72.1%) occurred in 1999. CGS-G experienced low flushes in 2006 and 2007 (36.4% and 27.3%, respectively), but these were not the lowest during the 16 years (22.7% in 2001). As occurred with RGS, CSG-P experienced its lowest flushes during the 16 years in 2006 (21.7%) and 2007 (17.4%). Both sites within CGS experienced their greatest flushes in 1996 (81.8% for CGS-G and 87% for CGS-P).

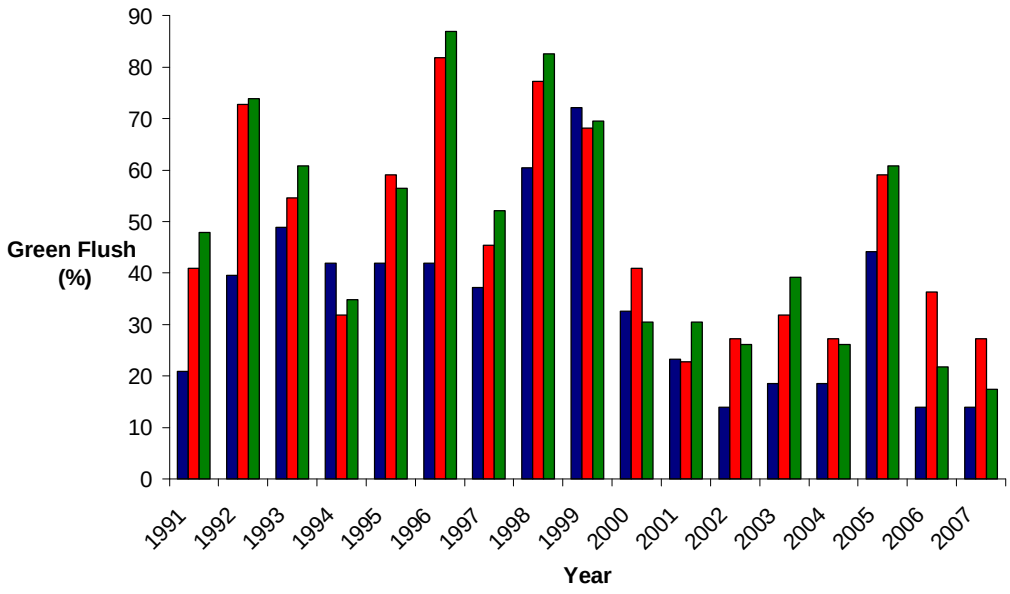


Figure 4.6 Green flush of stations over the test period. RGS (blue), CGS-G (red) and CGS-P (green).

4.4 Discussion

During the majority of the study rainfall was below average and in 2006, Yalgoo experienced its lowest winter rainfall on record (BOM 2006). These dry conditions were experienced in most of the Gascoyne and Murchison regions, but conditions in Northampton, Shark Bay, Yalgoo and Murchison shires was particularly poor (Van Vreeswyk & Thomas 2008). The dry conditions influenced NDVI, plant nutrition, sheep diets and production.

4.4.1 NDVI and rainfall relationships

4.4.1.1 Rainfall effects on NDVI

Studies have shown that rainfall and vegetation greenness are highly correlated in semi-arid and arid environments (Liu & Kogan 1996; Zhang *et al.* 2005; Chamaille-Jammes *et al.* 2006; Pennington & Collins 2007). The results on this study also indicate a good relationship between rainfall and NDVI.

As shown in Figure 4.7, NDVI increased from mid to late January to late May - early June 2006 in response to the high summer rain that fell in January to April. Therefore, there was little delay in the vegetation's initial response to January rainfall, and the NDVI continued to increase one month after the rainfall stopped. NDVI decreased from June 2006 to January/February 2007 in response to the low rainfall from May to December 2006 and generally there was a one-month lag response time.

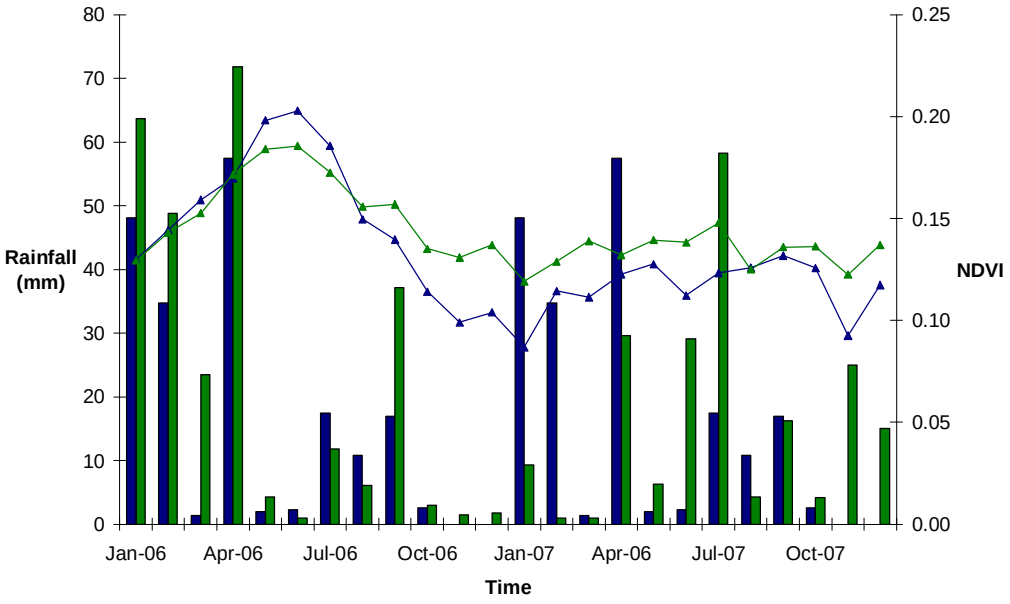


Figure 4.7 Average monthly NDVI (line) and total monthly rainfall for RGS (blue) and CGS (green).

Plant response to the decrease in rainfall during 2006 is illustrated in Plates 4.1, 4.2 and 4.3. *Solanum lasiophyllum* collected in May was lush and green. By October the *Solanum* sp. had dried, and by December, the leaves had shed from the plants, although Plate 4.3 shows that there was some regeneration which occurred after a summer rainfall event.

Plate 4.1 *Solanum lasiophyllum* collected in May 2006

Plate 4.2 *Solanum lasiophyllum* collected in October 2006

Plate 4.3 *Solanum lasiophyllum* collected in December 2006

The results indicate that vegetation responds within weeks of a rainfall event and has approximately one month lag time in response to dry times. Other studies have also reported a one month lag time in NDVI response to rainfall (Chamaille-Jammes *et al.* 2006; Liu & Kogan 1996). Additionally, Pennington & Collins (2007) reported a rapid response of vegetation to rainfall after drought.

Vegetation responses to rainfall are affected by season, ambient temperature, existing surface and sub-surface moisture and variations in plant physiological abilities to harness water. Summer rainfall is considered to be less effective than winter rainfall in Australian rangelands due to reduced reliability and lower infiltrations rates (Harrington *et al.* 1984b). Lower infiltration rates are due to high evaporation caused by higher ambient temperatures, and high runoff is caused by heavier rainfall (Johns *et al.* 1984). Annual grasses respond better to effective summer rainfall due to the combination of warm temperatures, increased moisture, and increased light (Wolfson & Tainton 1999), whereas annual herbs respond to effective winter rainfall (Morrisey 1984). Annual herbs and grasses rely heavily on surface moisture for growth, whereas perennial shrubs, forbs and grasses have larger root systems which are able to use subsurface moisture (Burnside *et al.*

1995). Perennial plants vary in their response to rainfall and temperatures due to the reduced reliance on surface moisture, although periods of high activity usually occur in winter when water infiltration is more effective due to lower temperatures and lighter, but more reliable rainfall events (Holechek *et al.* 1989). Plant species also have adaptations to maximise water uptake. For example, many large shrub species like Acacia have leaf and trunk structures that channel water to the base of the trunk and roots below (Johns *et al.* 1984). The effects of seasons, land systems and soil moisture on plant photosynthetic activity (NDVI) are reviewed later in this chapter.

Figure 4.2 illustrates the variability in rainfall that can occur within and between paddocks. While most paddocks received below-average rainfall, three paddocks received above-average rainfall and another three paddocks recorded zero rainfall. There were also slight differences in rainfall received by different sites within paddocks. This spatial variability affects the photosynthetic activity of plants within paddocks and therefore affects NDVI paddock results. The rainfall results in this study were collected only at weather stations, and do not account for patchy rain within and between paddocks. However, general trends and relationships between rainfall and NDVI are still observed in the results.

Management decisions for stocking rates based on rainfall monitoring are unreliable due to the variability in rainfall within and between paddocks. Therefore, other monitoring tools like NDVI, observations of indicator plants, and food on offer (FOO) assessments, must also be regularly used in addition to rainfall observations. FOO assessments visually estimate the amount of palatable food available to livestock within paddocks (Thompson & Curnow 2008). However, due to the high plant diversity within and between paddocks, FOO assessments alone are also unreliable in rangeland environments (Grossman *et al.* 1999). NDVI can monitor large areas of land more accurately than on-ground techniques (Wilson *et al.* 1984b). However, NDVI cannot provide information about the plant species being grazed; therefore regular monitoring of indicator plants must also occur.

4.4.1.2 Seasonal effects on NDVI

NDVI results from 1991 to 2007 (Fig 4.4 and 4.5), show seasonal changes, with peaks occurring in winter months (June - August), and troughs generally occurring in summer and autumn (December - April). The winter peak in NDVI corresponds to the main peak in monthly rainfall (Fig 4.1), although the rainfall also shows a smaller peak in February/March due to summer rainfall caused by remnant cyclones.

The short gap between troughs and peaks from April to June indicates that vegetation responds quickly to winter rainfall. However, the short period in winter when peaks occur indicates the vegetation has only a short period of high activity (Fig 4.5). The longer gap between peaks and troughs from August to December indicates that the vegetation reduces activity slowly in response to the drier, warmer months. This is typical of Australian rangeland perennial plants that can respond quickly to rainfall and can draw soil moisture from great depth, prolonging the response to rain. The long period when troughs occur indicates that the vegetation has long periods of low photosynthetic activity during dry, hot months, when both surface and sub-surface moisture are depleted. During low rainfall periods, perennial plants allow leaves to die and/or shed to conserve energy (Harrington *et al.* 1984b).

Chamaille-Jammes *et al.* (2006) found that rainfall has a stronger effect on NDVI at an inter-annual short-term time scale rather than long-term seasonal time scale. The long- and short-term NDVI results in this study indicate that both rainfall and season affected NDVI.

4.4.2 Spatial effects on NDVI and rainfall

Spatially and temporally variable vegetation and soil types typical of the Australian rangelands, resulting in each 1 km^2 pixel covering multiple vegetation types (Wallace *et al.* 2004). The results in this study show that there were differences in photosynthetic activity of the study sites.

CGS-G consistently had greater photosynthetic activity compared to RGS and CGS-P (Fig 4.3 and 4.4) during the study period. It seems that CGS-G has generally higher photosynthetic activity in times of low production as shown in Figure 4.5 around March 1994, March 2000 – March 2003 and March 2006 – present. Conversely, RGS generally has higher NDVI in high production years compared to CGS as shown in Figure 4.5 between March 1996-1997 and March 1999-2000. There were a number of land systems present in the sites (as discussed below), which are likely to have contributed to NDVI differences.

4.4.2.1 Land system productivity

Land productivity is determined by the cover and composition of vegetation, where land with high vegetation cover and a high number of palatable plants is more productive than land with low vegetation cover and low numbers of palatable species (Van Vreeswyk & Godden 1998). More productive land systems can endure more grazing from animals and therefore can have higher carrying capacities.

CGS-G is dominated by Racecourse (approximately 40% of the paddock) and Tindalarra (approximately 40% of the paddock) land systems. Racecourse is a highly productive land system, with wide drainage tracts and alluvial plains. It can support 1 DSE/7.6 ha. Tindalarra consist of mostly hardpan plains, and can support 1 DSE/14 ha (Payne *et al.* 1998). CGS-P has a mixture of land systems, but is mostly dominated by Challenge land system. Challenge consists of a mixture of landforms including gritty-surface plains, and stony plains that can support 1 DSE/17.7 ha (Payne *et al.* 1998). RGS has a broad mix of land systems as sheep rotate through paddocks. The most common land systems in the paddocks that sheep grazed during the study included Tindalarra, Challenge and Yewin land systems. Yewin land system consists of saline flood plains, which can support 1 DSE/7.4 ha. Tindalarra land system on Station 1 can support 1 DSE/14.1 ha and Challenge can support 1 DSE/8.2 ha (Payne *et al.* 1998). Refer to Table 3.1, 3.2 and 3.3 for further descriptions of land systems grazed during the study period, and their carrying capacities.

The land system carrying capacities indicate that Racecourse is the most productive land system, followed by Yewin. Challenge land system on RGS is more productive than the same land system found on CGS. This is due to differences in soils, vegetation and grazing history (Payne *et al.* 1998). Challenge and Tindalarra land systems are less productive compared to Racecourse and Yewin. According to the land systems within each study site, CGS-G is the most productive, closely followed by RGS, with CGS-P the least productive. This ranking follows the same rankings of the sites for the NDVI (Fig 4.3).

4.4.2.2 Soil variability effects on NDVI

The availability of soil moisture is the driving force in plant growth in the rangelands (Harrington *et al.* 1984b; Van Vreeswyk & Godden 1998). NDVI fluctuated in 2007, with peaks occurring in February-March, July, October and November corresponding to high rainfall events that occurred in January (RGS), February (RGS), April (RGS & CGS), June-July (CGS), September (RGS & CGS) and November (CGS) (Fig 4.7). However, the peaks in photosynthetic activity were often followed by dips. This may be a result of low subsurface moisture due to the drought conditions. The vegetation could respond instantly to the rainfall events, but without subsurface moisture the vegetation could not maintain the higher photosynthetic activity. New leaf material was often observed days after rain but plants quickly dried out weeks after rain.

The amount of water that soils can store depends on the rainfall, soil permeability, evaporation from bare soil and transpiration by vegetation (Johns *et al.* 1984). Racecourse land system has deep duplex and clay soils; Challenge has shallow coarse red clayey sands, and stony plains with shallow red earths; Tindalarra has deep red earths or shallow hardpan loams; and Yewin land system has shallow duplex soils (Payne *et al.* 1998). Of the land systems, the deep duplex and clay soils on Racecourse are most likely the best soils for holding moisture. The deep red earth on some Tindalarra land systems would also be effective at holding moisture. However, the shallow hardpan loams also found in Tindalarra land systems would not be as effective at holding water. The shallow soils on Challenge and Yewin

would not have as good moisture retention, especially the sands on Challenge land system.

The soil depths indicate that CGS-G with a predominant Racecourse land system is able to retain more soil moisture than CGS-P and RGS. However, it is likely that during 2007, soil moisture was very low due to the continuing drought. Therefore rainfall infiltration was also likely to be a strong influence on the vegetation's capacity to use rainfall effectively. Water infiltration into sandy soils, like those found in Challenge land systems, is faster than for more clay soils, which can result in better correspondence in peaks of rainfall and NDVI (Nicholson & Farrar 1994) and quicker growth response from vegetation in dry climates (Kumar *et al*. 2002). Challenge land system dominates CGS-P, and may explain why this paddock has greater flush responses to rain compared to RGS (Fig 4.6). However, it is difficult to determine if this is a reason as RGS and CGS-P have a number of different land systems influencing the NDVI and water infiltration into soils is also affected by vegetation interception and runoff/run-on water movements (Johns *et al.* 1984), which were not assessed during the study.

4.4.3 NDVI, rainfall and drought

Drought can be defined in four ways (1) Meteorological drought: a period of months to years where rainfall is low. (2) Agricultural drought: short term dryness in soils at critical times in the growing season. (3) Hydrological drought: prolonged moisture deficits that affect surface or subsurface water supply. (4) Socio-economic drought: the effects of the above droughts on supply and demand of economic goods and human well-being (American Meteorological Society 1997; Hennessy *et al.* 2008). The stations experienced a meteorological drought from May 2006 to the end of the study period with below average rainfall (Fig. 4.1). In October, 2006 the Australian Government declared parts of the southern rangelands pastoral region eligible for EC (Exceptional circumstances) payments until September 2008 (Van Vreeswyk & Thomas 2008). To meet the EC assistance criteria an event must (1) be rare, occurring no more than once on average, every 20-25 years (2) result in a rare and severe downturn in farm income over a prolonged (greater than 12 months) period

(3) be a discrete event that's not part of long term structural adjustment processes of normal fluctuations in commodity prices (Department of Agriculture Fisheries and Forestry 2009).

The dry conditions affected the photosynthetic activity of the stations, and during 2007 all the study sites had very low NDVI and green flush results that did not improve during the year (Fig 4.3 and 4.6). A comparison of Figure 4.3 and 4.5 shows that in 2007 there was no winter peak in NDVI, common to most years since 1991. The maximum NDVI during the study for RGS (0.21) was 17 units below the overall maximum since 1991 (0.38). The maximum (0.22) NDVI for CGS-G was 10 units below the overall maximum (0.32), and the maximum NDVI for CGS-P was 14 units below the overall maximum (0.31).

The fluctuating but generally low NDVI results in 2007 may indicate that the plants were operating at minimal photosynthetic activity, to conserve life. Minimum NDVI values vary annually due to soil reflectance and the influence of evergreen cover (McVicar & Jupp 1998, Roderick *et al.* 1999). NDVI for the study sites was lowest in September and December 2007, and highest in April 2006. CGS-G experienced its lowest NDVI on record (1991 - 2007) during September 2007, while RGS was three units above (0.07), its lowest on record (0.04), and CGS-P was only one unit above (0.10), its lowest on record (0.09).

Low rainfall is a common occurrence in the rangelands, therefore knowledge of its effects on plants and animals is important for managers to judge when to change their management plans to ensure the survival of land productivity and biodiversity. Pennington & Collins (2007) found that drought reduced vegetation greenness, but vegetation greenness increased rapidly when drought conditions ended. Drought effects on vegetation vary between areas determined by differing land cover types (Vincente-Serrano 2007).

4.4.4 Grazing pressures on NDVI results

Plant health and productivity is reduced by overgrazing (MacDonald 1978; Fuls 1992; Kellner & Bosch 1992; Chapman 1996; Oosthuizen & Snyman 2003; DelCurto *et al.* 2005). NDVI can be related to stocking rates (Archer 2004; Blanco *et al.* 2008; Roder *et al.* 2008), and grazing intensity may have affected results in this study; however, total grazing pressure from goats, kangaroos and livestock was not recorded during the study. Therefore it was not possible to distinguish any grazing effects on vegetation.

As discussed in Chapters 6 and 7, NDVI relates to sheep production and diets. These relationships re-iterate the importance of the natural vegetation to grazing animal nutrition and production in the rangelands.

4.5 Conclusion

The NDVI and rainfall seem to be well correlated with vegetative photosynthetic activity (NDVI), increasing quickly after rainfall and beginning to decrease approximately one month after rainfall. NDVI was also affected by seasonal influences with greater photosynthetic activity in winter. Winter rainfall in Yalgoo is generally more reliable than summer rainfall and is also more effective for vegetation growth due to the lower temperatures and evaporation rates. The drought conditions affected the response of vegetation to rainfall in 2007, resulting in fluctuating, low NDVI.

Spatial variability resulted in differences in NDVI between the study sites. CGS-G consistently had greater NDVI results compared to RGS and CGS-P during the study. This is likely due to the more productive land system (Racecourse) found on CGS-G that can retain moisture effectively during dry times. Due to the large number of land systems found on RGS and CGS-P, it was difficult to distinguish influences of land systems and soil types.
Rainfall and NDVI also affected plant nutrition, animal diets and animal production, as explained in the following chapters.

5 Plant nutritional profiles

5.1 Introduction

It is generally accepted that a combination of plant species provide livestock with adequate nutrition rather that one species alone, and livestock will select the most nutritious dietary mix from species available (Heady 1964; Franklin-McEvoy & Jolly 2006a). However, little is known about the nutritional content of plants in the Arid Shrubland of WA and knowledge of palatability and nutritional value is limited to one popular source (Mitchell & Wilcox 1994) as well as anecdotal observations of livestock grazing (Franklin-McEvoy & Jolly 2006b). Native plants are the primary food source for rangeland livestock. Therefore, information about the nutritive value of these plants is important for more accurate estimates of food on offer and thus potential animal performance of grazing livestock.

5.2 Materials and methods

General information relating to the collection, analyses and related calculations are found in Chapter 3, Sections 3.6.1, 3.8.2 - 3.8.8 and 3.9. All results for nutritive value are reported on a DM basis.

5.2.1 Assessment of nutritive value of individual plant species

The date and place of collection of the plants analysed is shown in Appendix 1. Selection of these plants was based on their presence and availability in paddocks and their palatability, as previously described in Chapter 3, Section 3.6.1.

Individual plants were analysed for CP, ash, NDF, ADF and ADL according to the methods described in Chapter 3, Sections 3.8.3 - 3.8.6. P, K, Na, Ca, Mg, S, B, Cu, Fe, Mn and Zn contents of the plants were determined according to the methods described in Chapter 3, Section 3.8.7. *In vitro* OMD and ME were determined according to the procedures described in Chapter 3, Sections 3.8.8 and 3.9.

5.2.2 Composite plant samples

Composite samples (Table 5.1) were created to imitate a varied diet as sheep are more likely to consume a number of plant species while grazing. These composite samples were analysed for CP and ash contents, according to the methods described in Chapter 3, Sections 3.8.3 and 3.8.4. Average 24 h gas production (GP) and OMD and ME of the composite plant samples were determined according to the procedures described in 3.8.8 and 3.9.2.

Three to five plant species, collected on the same day and from roughly the same location, were chosen for the composite samples. The composite sample consisted of an equal ratio (1:1:1 etc) of the individual plant species. The species chosen for the composite samples ranged in palatability from low (e.g. *Acacia* spp.) to high (e.g. *Maireana convexa*), depending on what was collected at the time and location. Composite 12 consisted of wheat stubble heads and stems, which were collected while sheep from RGS were agisted onto a failed wheat crop.

Table 5.1 Plant species combined for composite analysis for RGS, CGS-G and CGS-P management systems.

Composite	Collection date	System	Species collected
1	22-Feb-06	CGS-G	*Atriplex bunburyana , Ptilotus obovatus, Rhagodia drummondii, Rhagodia eremaea, Scaevola spinescens*
2	22-Feb-06	CGS-P	*Acacia grasbyi, Acacia tetragonophylla, R. drummondii*
3	26-Feb-06	RGS	*Atriplex amnicola, Maireana planifolia, Monachather paradoxus, P. obovatus, R. drummondii*
4	2-May-06	RGS	*Enchylaena tomentosa, Maireana villosa, M. paradoxus, P. obovatus, R. eremaea*
5	2-May-06	CGS-G	*A. bunburyana, Cratystylis subspinescens, Eremophila forrestii, P. obovatus, Solanum lasiophyllum*
6	2-May-06	CGS-P	*E. forrestii, M. villosa, P. obovatus, R. eremaea, S. lasiophyllum*
7	14-Jun-06	RGS	*A. bunburyana, E. tomentosa, Ptilotus macrocephalus, P. obovatus, R. drummondii*
8	22-Aug-06	CGS-G	*A. amnicola, A. bunburyana, E. tomentosa, Maireana tomentosa, R. eremaea*
9	22-Aug-06	CGS-P	*E. forrestii, Maireana convexa, P. obovatus, R. eremaea, S. lasiophyllum*
10	20-Oct-06	RGS	*A. bunburyana, E. tomentosa, M. convexa, Maireana thesioides, P. obovatus*
11	6-Dec-06	CGS-G	*A. amnicola, A. bunburyana, Maireana pyramidata, M. tomentosa, R. eremaea*
12	16-Feb-07	RGS	Wheat stubble heads, Wheat stubble stems
13	1-May-07	CGS-G	*A. amnicola, A. bunburyana, E. tomentosa, E. forrestii, M. pyramidata*
14	27-Aug-07	CGS-G	*A. amnicola, A. bunburyana, E. tomentosa, M. convexa, R. eremaea*

Table 5.1 cont

Composite	Collection date	System	Species collected
15	27-Aug-07	CGS-P	*E. forrestii, P. obovatus, R. eremaea, S. lasiophyllum*
16	7-Sep-07	RGS	*A. amnicola, A. bunburyana, R. eremaea, Schoenia filifolia, Sida calyxhymenia*
17	27-Sep-07	CGS-G	A. amnicola, A. bunburyana, E. tomentosa, E. forrestii, M. pyramidata
18	30-Oct-07	Cp	*A. grasbyi, A. tetragonophylla, E. forrestii, P. obovatus*
19	7-Dec-07	R	*A. amnicola, A. bunburyana, M. convexa, R. eremaea, S. calyxhymenia*

5.2.3 Cumulative gas production

The cumulative gas production of 178 plant samples and 19 composite samples was measured at 0, 2, 4, 6, 8, 10, 12 and 24 h. The gas production data was then fitted to two models developed by previous studies (Orskov & McDonald 1979; Groot *et al.* 1996) to analyse the rate of gas production.

Model 1 by Groot *et al.* (1996) is a re-parameterisation of the logistic regression

$$Y = a + \frac{c}{[1 + e^{-b(X-m)}]}$$

Where: Y = G, c = 0, c = A, em = B, b = C, eX = t.
It was fitted as a standard curve in Genstat with X = loget.

$$G = \frac{A}{1 + \frac{B^C}{t^C}}$$

where:
G = gas production (mL/0.2 g)
t = incubation time (h)
A = asymptotic gas production (mL/g)
B = time after incubation at which half of the asymptotic gas has been formed (h)
C = constant indicating the sharpness of the switching characteristic of the profile

Model 2 is an exponential curve by Orskov & McDonald (1979). It was also fitted as a standard curve in Genstat.

$$G = A + B(1 - e^{-Ct})$$

where:
G = gas production (mL/0.2 g)
t = incubation time (h)
A = gas production from the immediately soluble fraction (mL)
B = gas production from the insoluble fraction (mL)
C = gas production rate constant for the insoluble fraction (B)

Both models were fitted to the data with parameters allowed to vary with standard number.

5.3 Results

5.3.1 Analysis of individual plant species

A total of 29 plant species were collected during the study (Appendix 1). These included one tree, three annual forbs, six grasses and 21 shrub species.

5.3.1.1 Cumulative gas production

The logistic regression was fitted and 92.9% of the variance in gas production was accounted for by the model and the residual standard deviation (RSD: standard deviation of difference between actual and fitted gas production) was 1.83 according to Genstat. The exponential regression accounted for 91.7% of the variance in gas production with a RSD of 1.99 according to Genstat. Therefore there is little difference between the models; however, an examination of the estimated model parameters for each plant (Tables 5.2 - 5.4, and Figures 5.1 and 5.2) indicates that coefficients for the logistic regression model were more consistent than those for the exponential model.

Acacia spp. (13.1 mL for *A. grasbyi*; 12.6 mL for *A. tetragonophylla*), *Maireana planifolia* (11.6 mL), *Maireana pyramidata* (11.2 mL) and *Scaevola spinescens* (10.8 mL) produced the least amount of gas over the 24 h fermentation. Whereas, wheat stubble heads (34.5 mL) produced the greatest amount of gas, followed by *Sida calyxhymenia* (29.6 mL), *Rhodanthe chlorocephala* (28.5 mL) and *Ptilotus macrocephalus* (28.1 mL) over the 24 h fermentation.

Table 5.2 Total 24 h gas production (mean ± SD) and parameters estimated for the logistic and exponential models from the gas production of shrub and tree species.

Species	Gas (mL)	Logistic model			Exponential model		
		A	B	C	A	B	C
Acacia grasbyi	13.1±3.1	18.3	16.7	2.3	-1.0	-70.0	-0.01
Acacia tetragonophylla	12.6±4.6	20.4	20.4	2.3	-0.4	-10.9	-0.03
Atriplex amnicola	23.9±3.7	27.9	14.0	3.1	-1.5	-80.2	-0.01
Atriplex bunburyana	25.2±3.3	30.3	14.3	2.9	-1.0	-138.0	-0.01
Cratystylis subspinescens	22.5±0.1	28.9	14.7	2.4	-1.0	338.0	0.00
Enchylaena tomentosa	17.2±4.2	32.1	23.5	2.4	-0.5	-6.9	-0.05
Eremophila forrestii	23.8±2.6	27.5	12.8	2.8	-1.5	107.8	0.01
Maireana convexa	20.6±2.6	31.9	19.6	2.4	-0.8	-17.4	-0.03
Maireana planifolia	11.6	30.0	29.7	2.7	-0.2	-1.3	-0.10
Maireana pyramidata	11.2±6.4	32.0	33.0	2.2	-0.3	-2.8	-0.07
Maireana thesioides	18.6±7.8	20.9	13.5	3.5	-2.0	-56.0	-0.01
Maireana tomentosa	19.7±3.0	35.6	22.8	2.3	-0.6	-11.5	-0.04
Maireana triptera	17.2±1.6	32.0	23.6	2.6	-0.5	-5.0	-0.07
Maireana villosa	18.4±1.2	28.2	19.7	2.6	-0.7	-9.6	-0.05
Ptilotus obovatus	22.9±3.4	30.9	16.5	2.5	-1.0	-43.9	-0.02
Rhagodia drummondii	21.4±3.7	28.1	16.1	2.7	-1.0	-37.1	-0.02
Rhagodia eremaea	20.5±5.4	27.2	16.3	2.6	-1.0	-37.0	-0.02
Scaevola spinescens	10.8	13.7	15.9	2.9	-0.6	-13.4	-0.03
Sida calyxhymenia	29.6±4.4	35.7	14.5	2.9	-1.0	-97.0	-0.01
Solanum lasiophyllum	15.7±5.2	19.1	15.2	2.5	-1.0	-208.0	0.00
Melaleuca sp. (Tree)	22.3	28.6	15.9	2.8	-1.2	-32.8	-0.02

Table 5.3 Total 24 h gas production (mean ±SD) and parameters estimated for the logistic and exponential models from the gas production of grass species.

Species	Gas (mL)	Logistic model			Exponential model		
		A	B	C	A	B	C
Aristida contorta	22.4±1.3	33.3	19.4	2.8	-0.8	-8.7	-0.06
Cymbopogon ambiguous	18.9	24.5	17.0	3.1	-0.9	-9.2	-0.05
Enneapogon sp.	18.9	26.7	19.0	3.2	-0.7	-4.4	-0.07
Eragrostis sp.	19.7	25.3	17.6	3.6	-0.8	-4.5	-0.07
Monachather paradoxus	26.4±2.6	41.2	20.3	2.7	-0.9	-9.6	-0.06
Stipa scabra	25.4	42.0	21.5	2.8	-0.8	-6.5	-0.07

Table 5.4 Total 24 h gas production (mean ±SD) and parameters estimated for the logistic and exponential models from the gas production of annual forb species.

Species	Gas (mL)	Logistic model			Exponential model		
		A	B	C	A	B	C
Ptilotus macrocephalus	28.1±0.2	33.1	13.7	2.9	-2.0	-1286.0	0.0
Rhodanthe chlorocephala	28.5	39.7	17.0	2.4	-1.3	-57.7	-0.02
Schoenia filifolia	21.4	32.8	18.4	2.0	-1.0	-211.0	0.00

Table 5.5 Total 24 h gas production (mean ± SD) and parameters estimated for the logistic and exponential models from the gas production of agistment pastures.

Plant Type	Gas (mL)	Logistic model			Exponential model		
		A	B	C	A	B	C
Wheat stubble heads	34.5	39.5	13.8	3.2	-2.0	-114.0	-0.01
Wheat stubble stems	15.5	23.0	19.6	3.1	-0.5	-3.7	-0.07

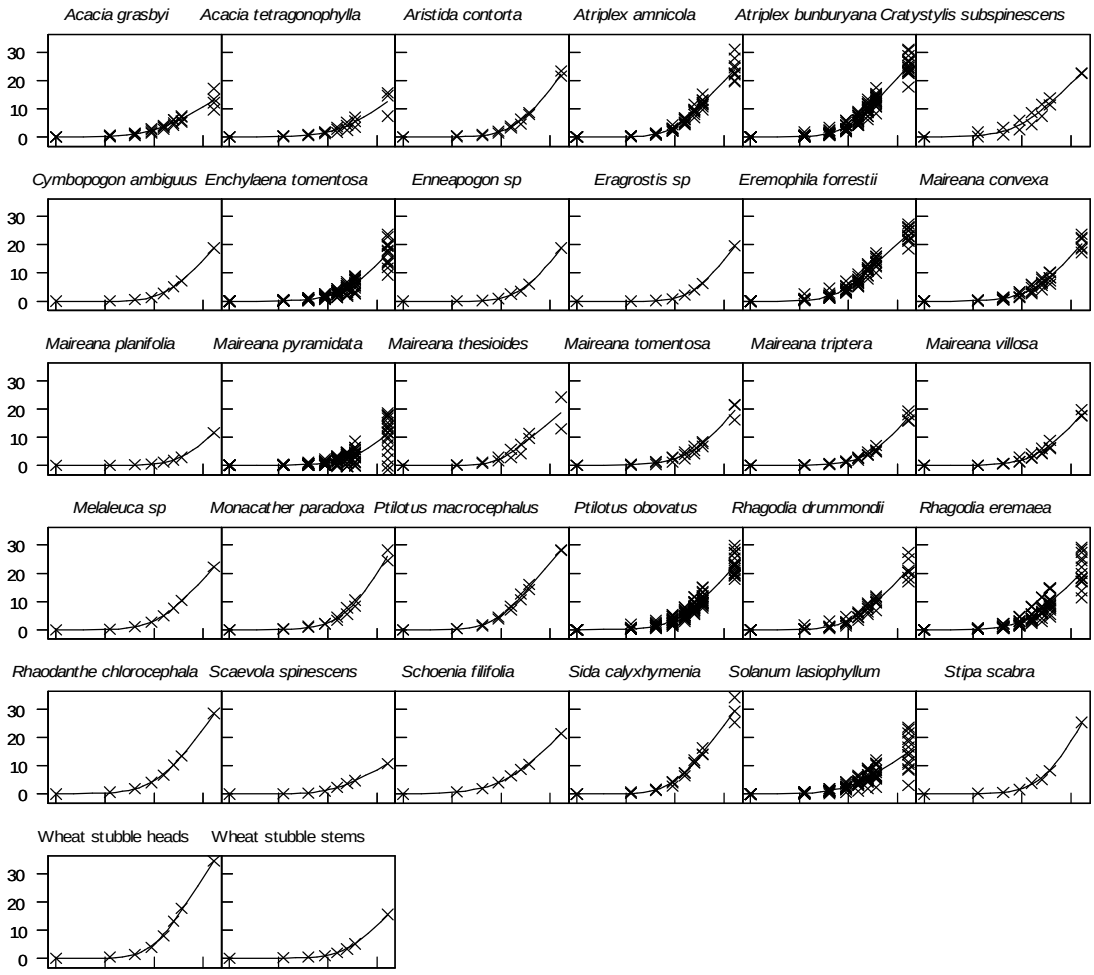


Figure 5.1 Genstat logistic curves of plant gas production (mL), (y axis) over 24 h (x axis).

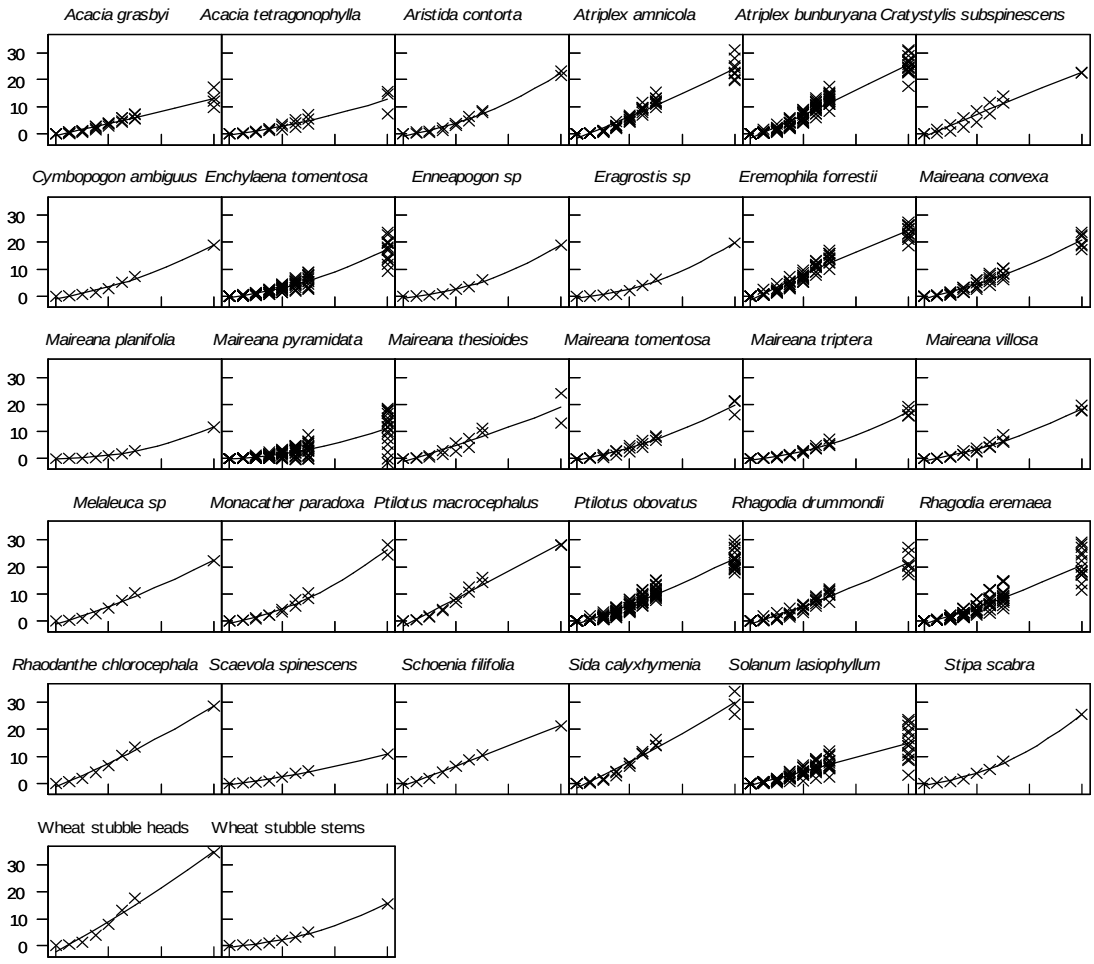


Figure 5.2 Genstat exponential curves of plant gas production (mL), (y axis) over 24 h (x axis).

As shown in Tables 5.2 - 5.5 and Figures 5.1 and 5.2, there was high variability in gas production for Acacia spp., Atriplex spp., Enchylaena tomentosa, Eremophila forrestii, Maireana pyramidata, Maireana thesioides, Maireana tomentosa, Ptilotus obovatus, Rhagodia spp., Sida calyxhymenia and Solanum lasiophyllum.

Figure 5.3 illustrates that the plants are digested by the rumen microbes at different rates during 0 – 6 h, 6 – 12 h and 12 – 24 h of the 24 h of fermentation. An average of 2.4±1.2 mL of gas was produced from 0 – 6 h of incubation. *Maireana planifolia* (0.5 mL), *Eragrostis* spp. (0.8 mL), *Maireana pyramidata* (0.9 mL), wheat stubble stems (0.9 mL), *Enneapogon* spp. (0.9 mL), and *Scaevola subspinescens* (1.0 mL) had well below-average gas production in the first 6 h. Conversely, *Eremophila forrestii* (4.3 mL), *Cratystylis subspinescens* (4.2 mL), *Ptilotus macrocephalus* (4.1 mL), *Rhodanthe chlorocephala* (4.1 mL), *Schoenia filifolia* (4.1 mL), wheat stubble heads (3.8 mL) and *Sida calyxhymenia* (3.8 mL) had above-average gas production in the first 6 h, from 58 to 79% greater than the mean.

Between 6 – 12 h of incubation an average of 6.7±2.6 mL of gas was produced by the plants. *Maireana planifolia* (2.4 mL), *Maireana pyramidata* (2.6 mL), *Acacia tetragonophylla* (3.7 mL) and *Scaevola subspinescens* (3.7 mL) had below-average gas production, whereas, wheat stubble heads (13.8 mL), *Sida calyxhymenia* (11.1 mL), *Ptilotus macrocephalus* (11.0 mL), *Eremophila forrestii* (9.8 mL), *Atriplex bunburyana* (9.6 mL), *Rhodanthe chlorocephala* (9.4 mL) and *Atriplex amnicola* (9.3 mL) had above-average gas production.

Between 12 – 24 h of incubations an average of 11.5±2.9 mL of gas was produced. *Scaevola subspinescens* (6.0 mL), *Acacia grasbyi* (6.7 mL), *Acacia tetragonophylla* (7.3 mL), *Solanum lasiophyllum* (7.7 mL), *Maireana pyramidata* (7.7 mL) and *Maireana thesioides* (8.2 mL) produced below the average gas volume. *Stipa scabra* (17.1 mL), *Monachather paradoxus* (17.0 mL), wheat stubble heads (16.9 mL), *Rhodanthe chlorocephala* (15.0 mL) and *Sida calyxhymenia* (14.8 mL) had above-average gas production.

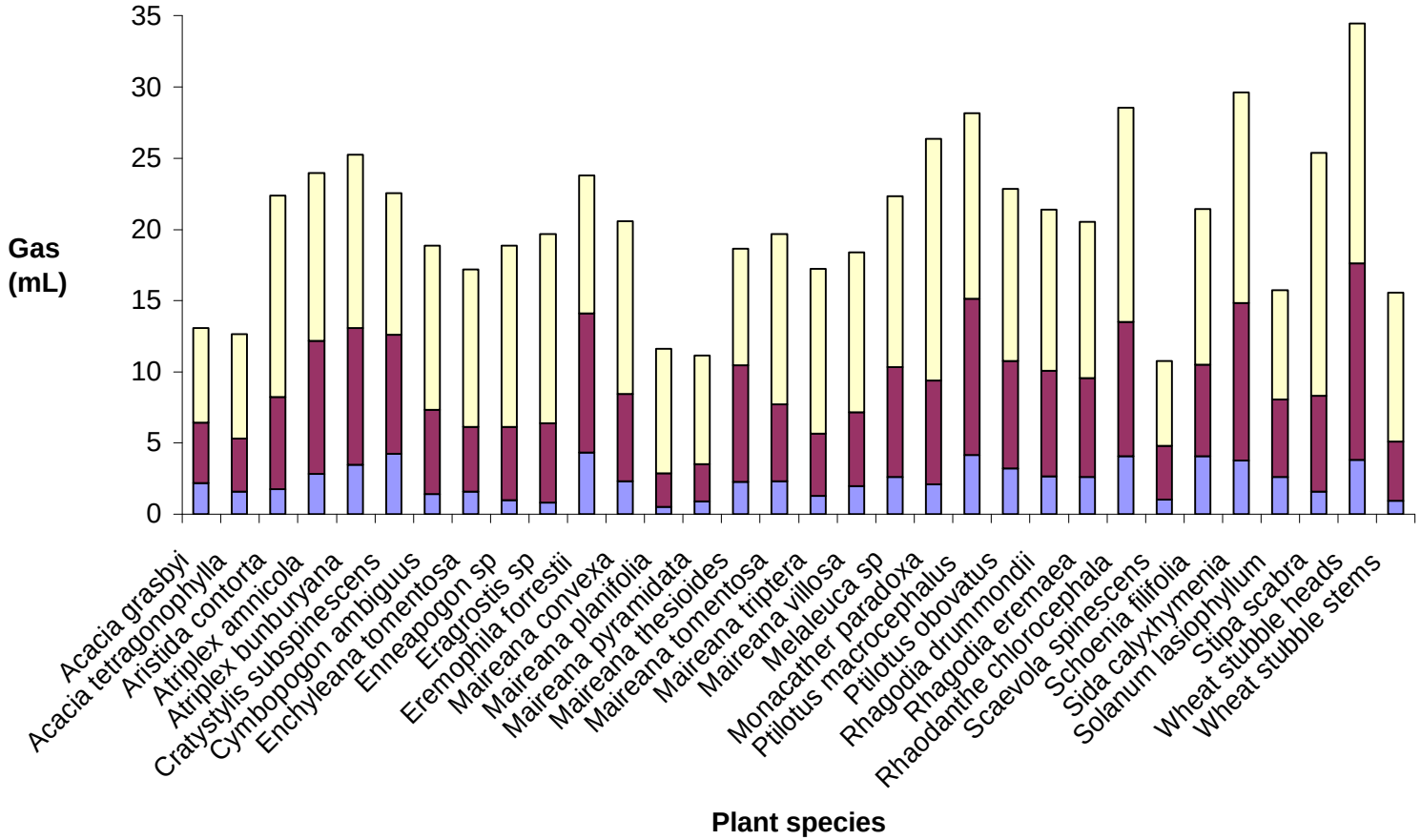


Figure 5.3 Gas produced by various plant species at 0 - 6 h (blue), 6 - 12 h (red) and 12 - 14 h (yellow) of incubation.

5.3.1.2 Nutritional profiles

There was high variability in all nutritional parameters among and between species. The forage values of the selected plants are presented in Tables 5.6 - 5.9.

The shrubs had variable OMD and ME; however, all had relatively high CP content (11.9 - 26.9%) with the exception of *Scaevola spinescens* (9.2%) and *Acacia* spp. (<10%). Shrub species generally higher in ME (>5.7 MJ/kg) and OMD (>40%) included *Atriplex* spp*., Sida calyxhymenia, Eremophila forrestii, Cratystylis subspinescens, Maireana tomentosa, Maireana convexa, Maireana planifolia, Maireana triptera, Maireana villosa* and *Ptilotus obovatus*. Shrubs low in OMD (<40%) and ME (<5 MJ/kg) included *Maireana pyramidata, Solanum lasiophyllum, Scaevola spinescens* and *Acacia* spp. These were largely chenopod shrubs, which together had a mean ash content of 23.6%. However, *Sida calyxhymenia, Solanum lasiophyllum*, the larger shrubs (*Acacia* spp*., Eremophila* spp.) as well as the selected tree (*Melaleuca* spp.), all contained less than 10% ash.

Acacia grasbyi, Maireana planifolia and *Solanum lasiophyllum* had the highest NDF contents (>60%), whilst *Maireana thesioides* and *Rhagodia eremaea* had the lowest NDF contents (<30%) compared to the other shrubs. *Scaevola spinescens, Acacia* spp., *Eremophila forrestii* and *Melaleuca* sp. had the highest ADF (>40%) contents whilst *Maireana thesioides* had the lowest ADF content (<10%). The larger shrubs *Acacia* spp., *Eremophila forrestii* and *Melaleuca* sp, the woody shrubs Cratystylis *subspinescens* and *Scaevola spinescens* as well as *Atriplex* spp. all had high lignin contents (>10%).

Compared to the shrubs, the grass species had relatively moderate to low OMD (31.7 - 42.3%) and ME (5.1 - 6.2 MJ/kg) and lower CP (5.6 - 9.6%) and ash (<10%) contents, with the exception of *Monachather paradoxus* collected in February, which has higher OMD (45.5%), ME (6.6 MJ/kg) and CP (14.8%) contents compared to the other grass species collected. The grasses had very high NDF (78.0 - 85.9%), high ADF (39.0 - 49.4%) and low ADL (2.8 - 5.6%) contents compared to the shrub species.

The annuals *Rhodanthe chlorocephala* and *Ptilotus macrocephalus* had relatively high OMD (40.4 - 51.5%), ME (6.8 - 7.3 MJ/kg) and CP (11.9 - 22.3%) contents. *Schoenia filifolia* had low OMD (38.9%), ME (5.7 MJ/kg) and CP (10.2%). *Rhodanthe chlorocephala* and *Schoenia filifolia* had moderate ash contents (6.2 - 6.7%), while *Ptilotus macrocephalus* contained relatively high levels of ash (22.3%). In general, the annual species had moderate NDF (31.0 - 53.1%), and low ADF (16.5 - 36.6%) and lignin (2.3 - 6.8%) compared to most of the shrub species analysed.

The wheat stubble heads had high OMD (51.8%), ME (7.6 MJ/kg) and CP (12.9%) contents. Wheat stubble stems had low OMD (31.1%), ME (4.5 MJ/kg) and CP (3.7%). The wheat stubble heads had moderate NDF (53.5%), low ADF (24.4%) and ADL (2.8%) content compared to the shrubs, while the stems had high NDF (74.6%), ADF (52.7%) and low ADL (5.0%).

Table 5.6 Nutritional composition (mean ± SD) of shrub and tree species.

Species	*In vitro* OMD (%)	ME (MJ/kg)	CP (%)	Ash (%)	NDF (%)	ADF (%)	ADL (%)
Acacia grasbyi	31.0±2.6	4.5±0.4	9.4±0.5	3.9±0.6	63.8±5.5	50.8±8.0	22.0±6.2
Acacia tetragonophylla	30.7±4.2	4.5±0.6	9.6±0.6	5.0±0.3	52.0±1.1	41.2±2.3	21.8±2.4
Atriplex amnicola	44.3±3.0	6.2±0.5	12.4±2.8	31.0±2.5	36.6±9.2	17.5±5.9	7.1±1.5
Atriplex bunburyana	44.6±3.0	6.3±0.5	12.1±2.2	28.1±2.7	43.5±3.1	22.1±2.1	11.8±1.6
Cratystylis subspinescens	40.4±0.2	5.9±0.0	11.9±0.2	11.8±0.4	41.5±1.9	30.9±0.1	13.7±1.2
Enchylaena tomentosa	39.5±3.3	5.6±0.5	21.8±5.3	21.3±4.2	55.8±8.1	25.5±5.7	5.6±1.7
Eremophila forrestii	41.7±3.2	6.1±0.5	13.9±3.8	7.0±0.7	56.0±14.1	42.5±6.1	22.0±7.7
Maireana convexa	42.9±1.7	6.0±0.3	22.7±5.9	27.9±6.3	46.3±11.1	20.1±3.8	5.1±1.7
Maireana planifolia	34.6	4.9	21.9	13.6	68.0	35.3	9.8
Maireana pyramidata	34.3±4.9	4.7±0.8	23.6±4.4	28.8±4.2	54.5±7.2	23.8±6.2	7.1±3.6
Maireana thesioides	40.0±4.5	5.6±0.7	21.5±2.0	30.2±1.6	35.7±2.7	11.7±1.6	3.6±0.5
Maireana tomentosa	40.0±3.0	5.4±0.5	17.6±1.3	21.1±3.8	57.2±1.3	29.2±1.6	4.6±1.6
Maireana triptera	40.1±1.9	5.6±0.3	24.6±2.6	25.9±7.6	50.0±6.2	19.5±7.8	9.5±4.1
Maireana villosa	43.9±2.8	6.2±0.4	26.9±2.9	19.7±1.3	56.3±4.3	28.1±7.0	9.2±4.0
Ptilotus obovatus	43.0±11.5	6.2±1.7	17.9±7.3	11.7±9.7	57.4±17.1	29.9±11.9	3.9±6.8
Rhagodia drummondii	41.2±2.8	5.9±0.4	17.5±3.6	17.4±3.1	43.9±6.9	17.5±3.8	5.0±1.8

Table 5.6 (cont.)

Species	*In vitro* OMD (%)	ME (MJ/kg)	CP (%)	Ash (%)	NDF (%)	ADF (%)	ADL (%)
Rhagodia eremaea	43.1±4.0	6.1±0.6	22.1±5.7	18.4±3.9	37.7±6.3	16.1±5.0	4.4±1.6
Scaevola spinescens	28.8	4.1	9.2	10.6	59.6	43.0	15.6
Sida calyxhymenia	48.4±3.8	7.1±0.6	16.3±3.4	8.3±2.0	53.7±4.3	36.0±1.6	5.5±0.8
Solanum lasiophyllum	35.2±7.2	5.0±1.1	17.0±5.3	8.3±1.9	62.7±7.4	38.8±6.9	5.0±1.7
Melaleuca sp. (Tree)	38.5	5.7	8.1	6.0	41.5	31.6	21.7

Table 5.7 Nutritional composition (mean ± SD) of grass species.

Species	*In vitro* OMD (%)	ME (MJ/kg)	CP (%)	Ash (%)	NDF (%)	ADF (%)	ADL (%)
Aristida contorta	38.6±1.0	5.6±0.2	7.8±0.3	9.5±0.8	85.9±0.1	44.4±2.8	5.2±1.2
Cymbopogon ambiguus	34.9	5.1	6.6	8.3	78.0	41.6	5.4
Enneapogon sp.	34.5	5.1	5.6	7.7	82.4	46.7	5.3
Eragrostis sp.	36.1	5.3	7.7	8.1	85.9	49.4	5.6
Monachather paradoxus	45.0±5.1	6.6±0.7	14.8±6.8	8.4±0.6	78.9±1.5	49.4±6.5	5.2±1.0
Stipa scabra	41.9	6.1	9.6	9.1	78.7	39.0	2.8

Table 5.8 Nutritional composition (mean ± SD) of annual herb species.

Species	*In vitro* OMD (%)	ME (MJ/kg)	CP (%)	Ash (%)	NDF (%)	ADF (%)	ADL (%)
Ptilotus macrocephalus	49.2±0.4	7.3±0.0	22.3±1.6	22.3±0.8	31.0±7.4	16.5±2.7	2.3±0.8
Rhodanthe chlorocephala	46.7	6.8	11.9	6.7	53.1	36.6	2.6
Schoenia filifolia	38.6	5.7	10.2	6.2	43.0	29.1	6.8

Table 5.9 Nutritional composition of wheat stubble from agistment pastures for sheep rotationally managed.

Plant Type	*In vitro* OMD (%)	ME (MJ/kg)	CP (%)	Ash (%)	NDF (%)	ADF (%)	ADL (%)
Wheat stubble heads	51.8	7.6	12.9	7.2	53.5	24.4	2.8
Wheat stubble stems	31.1	4.5	3.7	11.2	74.6	52.7	5.0

5.3.1.3 Macro mineral content

In general, macro mineral content of the plants (Tables 5.10 - 5.13) was acceptable to high in terms of meeting sheep maintenance requirements (Table 5.10), apart from P.

P content was generally below acceptable levels (for meeting sheep maintenance requirements) apart from *Sida calyxhymenia* (0.17%), and the annuals *Rhodanthe chlorocephala* (0.20%) and *Schoenia filifolia* (0.17%).

K content in plants was acceptable to high; apart from wheat stubble heads (0.43%) and stems (0.20%), which had below acceptable content. Na content varied depending on the types of plants, where halophyte plants had very high content and non-halophyte plants had very low content. Ca content in plants was acceptable to high apart from wheat stubble heads (0.13%) and stems (0.17%), which had below acceptable content. The wheat stubble heads (0.11%) and stems (0.05%) also had below acceptable levels of Mg, as did *Eragrostis* spp. (0.11%), while the other plants had acceptable to high Mg content. *Acacia* spp. (0.13% for *A. grasbyi* and 0.12% for *A. tetragonophylla*), *Aristida contorta* (0.12%), *Cymbopogon ambiguus* (0.10%), *Enneapogon* spp. (0.08%) and wheat stubble stems (0.05%) had below acceptable levels of S, while the other species had acceptable to high S content.

In general the grass species had lower K, Na, Ca, Mg and S content compared to the other species. The herb species had lower Mg content compared to the shrub species. Generally, the wheat stubble had lower mineral content compared to the other plants, particularly the stems.

Table 5.10 Average (mean ± SD) macro mineral content (%) of shrub and tree species, and approximate concentrations required in livestock for maintenance requirements.

Species	P	K	Na	Ca	Mg	S
Maintenance levels for sheep[1]	0.16-0.4	0.5-0.8	0.1-0.2	0.2-0.8	0.12-0.2	0.14-0.26
Acacia grasbyi	0.06±0.0	0.83±0.1	0.11±0.1	0.92±0.2	0.24±0.0	0.13±0.0
Acacia tetragonophylla	0.06±0.0	0.86±0.2	0.17±0.1	1.48±0.3	0.27±0.0	0.12±0.0
Atriplex amnicola	0.12±0.0	3.11±0.7	7.73±0.7	1.24±0.5	1.37±0.4	0.66±0.1
Atriplex bunburyana	0.09±0.0	3.32±0.6	7.20±1.3	1.01±0.3	0.74±0.2	0.47±0.1
Cratystylis subspinescens	0.10±0.0	1.04±0.1	2.21±0.1	0.95±0.0	0.41±0.0	1.05±0.1
Enchylaena tomentosa	0.10±0.0	2.57±0.8	6.22±1.8	0.65±0.2	0.39±0.1	0.31±0.1
Eremophila forrestii	0.10±0.0	1.75±0.4	0.04±0.0	0.82±0.2	0.23±0.1	0.25±0.1
Maireana convexa	0.10±0.1	3.80±2.2	7.63±4.0	0.81±0.1	0.49±0.1	0.28±0.0
Maireana planifolia	0.10	5.98	0.50	0.73	0.53	0.25
Maireana pyramidata	0.08±0.0	2.65±0.7	9.17±1.8	0.73±0.3	0.58±0.1	0.30±0.0
Maireana thesioides	0.05±0.0	3.12±0.2	11.16±1.1	0.43±0.1	0.42±0.1	0.44±0.1
Maireana tomentosa	0.06±0.0	2.87±0.5	5.03±0.5	0.82±0.3	0.41±0.1	0.23±0.0
Maireana triptera	0.09±0.0	3.16±0.8	7.21±5.1	2.09±3.0	0.33±0.1	0.29±0.1
Maireana villosa	0.12±0.0	8.77±0.6	0.23±0.1	0.82±0.0	0.58±0.1	0.32±0.0
Ptilotus obovatus	0.12±0.0	3.41±1.8	0.10±4.2	1.44±0.7	0.88±0.3	0.21±0.1

Table 5.10 cont.

Species	P	K	Na	Ca	Mg	S
Rhagodia drummondii	0.09±0.0	4.45±0.7	1.84±1.0	1.19±0.3	0.91±0.2	0.56±0.2
Rhagodia eremaea	0.12±0.0	5.53±1.2	1.38±1.2	1.31±0.4	0.89±0.2	0.40±0.1
Scaevola spinescens	0.07	1.88	2.50	0.96	0.68	0.50
Sida calyxhymenia	0.17±0.1	2.40±0.5	0.05±0.0	1.30±0.3	0.39±0.0	0.28±0.0
Solanum lasiophyllum	0.14±0.0	1.88±0.6	0.04±0.0	1.20±0.6	0.36±0.1	0.23±0.0
Melaleuca sp. (Tree)	0.08	0.57	0.45	1.82	0.25	0.20

[1] Franklin-McEvoy (2005)

Table 5.11 Average (mean ± SD) macro mineral content (%) of grass species.

Species	P	K	Na	Ca	Mg	S
Aristida contorta	0.12±0.0	1.00±0.3	0.03±0.0	0.21±0.0	0.14±0.0	0.12±0.0
Cymbopogon ambiguus	0.09	1.00	0.10	0.24	0.16	0.10
Enneapogon sp.	0.07	1.11	0.01	0.42	0.13	0.08
Eragrostis sp.	0.07	0.96	0.02	0.29	0.11	0.14
Monachather paradoxus	0.08±0.0	2.23±1.1	0.03±0.0	0.25±0.0	0.13±0.0	0.22±0.1
Stipa scabra	0.06	1.32	0.02	0.49	0.17	0.14

Table 5.12 Average (mean ±SD) macro mineral content (%) of annual species.

Species	P	K	Na	Ca	Mg	S
Ptilotus macrocephalus	0.10±0.0	6.62±1.0	0.45±0.4	2.11±0.2	1.31±0.2	0.27±0.0
Rhodanthe chlorocephala	0.20	2.08	0.05	0.94	0.14	0.20
Schoenia filifolia	0.17	1.76	0.35	0.68	0.17	0.24

Table 5.13 Nutritional composition of wheat stubble from agistment pastures for sheep rotationally managed.

Plant type	P	K	Na	Ca	Mg	S
Wheat stubble heads	0.23	0.43	0.02	0.13	0.11	0.15
Wheat stubble stems	0.03	0.20	0.01	0.17	0.05	0.05

There were no significant relationships between mineral content and nutritional parameters (OMD, ME, CP, Ash, NDF, ADF or ADL) with the exception of Na and ash, which had a significant (P<0.001) positive correlation (r2=0.8), as shown in Figure 5.4.

Species high in salt (Na >0.5 %) were mostly the chenopod species such as Atriplex spp., Enchylaena tomentosa, Maireana pyramidata, Cratystylis subspinescens and Maireana triptera. The exceptions were Maireana planifolia and Maireana villosa, which contained high levels of ash, but their Na content was low.

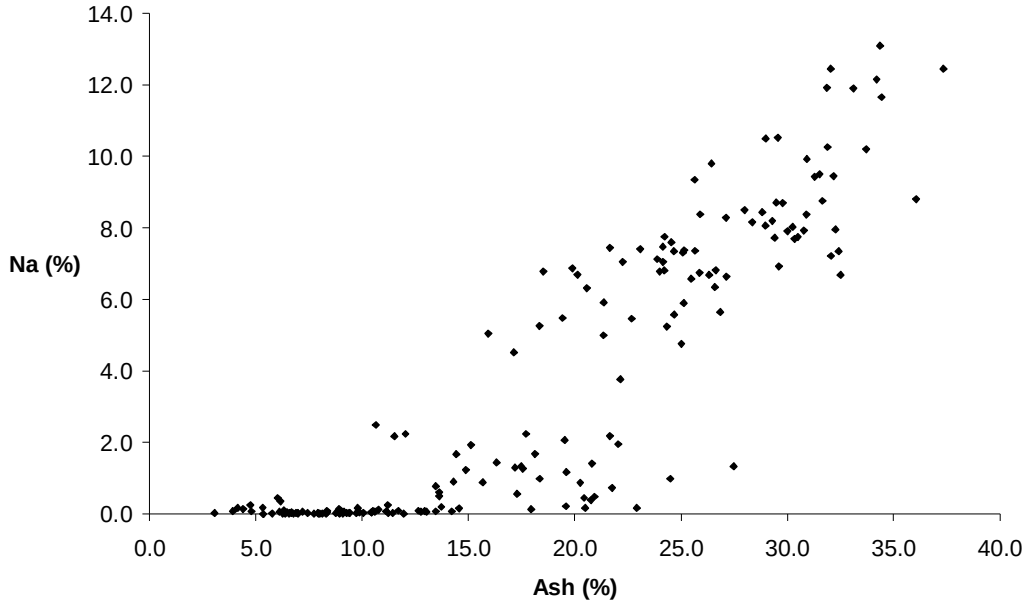


Figure 5.4 Correlation between ash and Na contents of plants.

5.3.1.4 Trace Element Content

The trace element content of the plants (Table 5.14 - 5.17) was highly variable, especially for Zn, but generally acceptable (in terms of meeting maintenance requirements for sheep, Table 5.14) for B and Cu, and acceptable to high for Fe and Mn.

Table 5.14 Average trace element content (mg/kg) ±SD in shrubs and tree species, and approximate concentrations required in livestock for maintenance requirements.

Species	B	Cu	Fe	Mn	Zn
Maintenance levels for sheep[1]	1.4-150	7-10	30-50	20-40	20-33
Acacia grasbyi	18.0±23.2	5.1±1.3	74.4±35.8	58.3±36.5	13.8±2.2
Acacia tetragonophylla	23.1±22.9	2.9±0.4	83.325.9	49.74.7	20.7±1.7
Atriplex amnicola	30.3±25.0	7.5±3.3	343.6±436.9	64.2±33.2	22.3±9.6
Atriplex bunburyana	33.2±33.5	5.5±2.6	204.3±112.4	67.2±36.5	17.1±6.0
Cratystylis subspinescens	29.4±41.6	12.6±8.5	370.4±133.7	67.2±36.5	17.1±6.0
Enchylaena tomentosa	32.3±25.2	10.5±4.2	253.4±197.3	200.8±122.2	17.5±7.5
Eremophila forrestii	23.2±22.9	10.2±4.3	613.7±828.0	413.2±347.0	28.2±16.4
Maireana convexa	36.6±31.7	11.3±6.5	684.7±1477.6	216.2±120.2	14.4±5.9
Maireana planifolia		9.3	167.8	130.5	15.8
Maireana pyramidata	27.2±23.1	6.1±3.0	233.8±214.9	121.8±98.2	14.2±7.7
Maireana thesioides	50.1±5.2	8.5±2.9	92.6±41.5	304.6±111.0	14.5±3.5
Maireana tomentosa	21.6±19.3	8.4±3.9	171.7±72.8	47.8±21.5	13.9±4.0
Maireana triptera	10.0±20.0	8.3±0.8	118.3±58.5	152.1±132.0	11.0±1.8
Maireana villosa	13.8±27.6	11.7±1.4	171.6±88.0	411.3±51.0	30.7±11.2
Ptilotus obovatus	27.6±24.3	8.2±4.0	605.2±641.2	132.7±196.8	19.6±11.4

Table 5.14 cont.

Species	B	Cu	Fe	Mn	Zn
Rhagodia drummondii	13.0±22.3	5.3±2.3	160.9±98.3	151.3±69.3	21.7±6.4
Rhagodia eremaea	34.5±37.0	7.2±4.1	600.6±1339.7	317.8±328.1	31.6±26.9
Scaevola spinescens		4.2	178.6	25.4	7.1
Sida calyxhymenia	11.3±19.5	9.4±3.4	315.5±319.3	229.6±143.8	59.0±13.9
Solanum lasiophyllum	17.3±16.2	14.0±6.3	1193.7±1350.2	116.4±167.2	36.1±27.0
Melaleuca sp. (Tree)	105.9	3.9	346.7	27.0	9.5

[1] Franklin-McEvoy (2005)

Table 5.15 Average (mg/kg) ±SD trace element content of grass species.

Species	B	Cu	Fe	Mn	Zn
Aristida contorta		4.2±0.3	96.6±10.4	66.8±39.2	26.8±22.2
Cymbopogon ambiguous	23.5	9.9	632.2	424.5	28.0
Enneapogon sp.		4.4	133.8	17.2	20.1
Eragrostis sp.		5.3	87.2	92.0	24.9
Monachather paradoxus		7.5±2.3	87.9±36.0	165.3±100.0	41.6±12.1
Stipa scabra		3.8	89.9	62.1	13.4

Table 5.16 Average (mg/kg) ±SD trace element content of annual species.

Species	B	Cu	Fe	Mn	Zn
Ptilotus macrocephalus	41.0±14.4	6.3±1.3	186.9±33.2	87.0±5.3	35.0±21.1
Rhodanthe chlorocephala	21.0	8.0	1005.4	28.3	26.5
Schoenia filifolia	39.8	9.9	225.9	135.5	11.7

Table 5.17 Nutritional composition of wheat stubble from agistment pastures for sheep rotationally managed.

Species	B	Cu	Fe	Mn	Zn
Wheat stubble heads	27.3	12.0	741.4	588.7	36.0
Wheat stubble stems	29.1	12.9	1078.1	733.1	31.3

5.3.2 Composite samples

5.3.2.1 Cumulative gas production

The logistic regression was fitted and 99.6% of the variance in gas production was accounted for by the model and the residual standard deviation was 0.6.

An examination of the estimated model parameters for each plant composite for both models (Table 5.18, Figures 5.5 and 5.6) indicated that coefficients for the logistic model were more consistent than those for the exponential model. For example, the exponential model tended to under-estimate gas production at 12 h for all but 3 of the composites, namely, 2, 5 and 9.

Composite 2 produced the least amount of gas following 24 h incubation (12.2 mL), while composites 13 (28.1 mL) and 19 (28.2 mL) produced the most gas compared to the rest of the composite samples.

Table 5.18 Gas fermentation results of composite samples.

Sample	Gas (mL)	Logistic Model			Exponential Model		
		A	B	C	A	B	C
1	20.7	24.7	14.9	3.2	-1.2	-26.5	-0.03
2	12.2	22.0	22.9	2.4	-0.4	-5.7	-0.05
3	20.4	28.7	18.6	3.1	-0.8	-6.6	-0.06
4	24.5	31.3	16.5	3.1	-1.2	-16.6	-0.04
5	23.4	31.0	16.4	2.6	-1.3	-47.5	-0.02
6	19.4	23.2	15.3	3.3	-1.1	-17.5	-0.03
7	24.5	30.4	15.8	3.1	-1.2	-22.2	-0.03
8	24.4	29.8	15.4	3.1	-1.3	-26.3	-0.03
9	19.7	27.3	17.6	2.7	-0.9	-17.3	-0.03
10	23.5	30.1	16.4	3.0	-1.1	-18.6	-0.04
11	24.6	29.4	15.2	3.3	-1.3	-22.7	-0.03
12	26.8	37.0	18.2	3.1	-1.1	-9.8	-0.06
13	28.1	32.7	14.4	3.3	-1.5	-45.1	-0.02
14	21.9	25.3	14.6	3.5	-1.3	-22.4	-0.03
15	23.5	28.2	15.1	3.2	-1.2	-27.6	-0.03
16	27.9	32.3	14.1	3.2	-1.4	-63.3	-0.02
17	25.2	29.4	14.5	3.3	-1.5	-37.9	-0.02
18	21.2	24.5	13.8	3.1	-1.0	-89.0	-0.01
19	28.2	31.6	13.4	3.4	-2.0	-105.0	-0.01

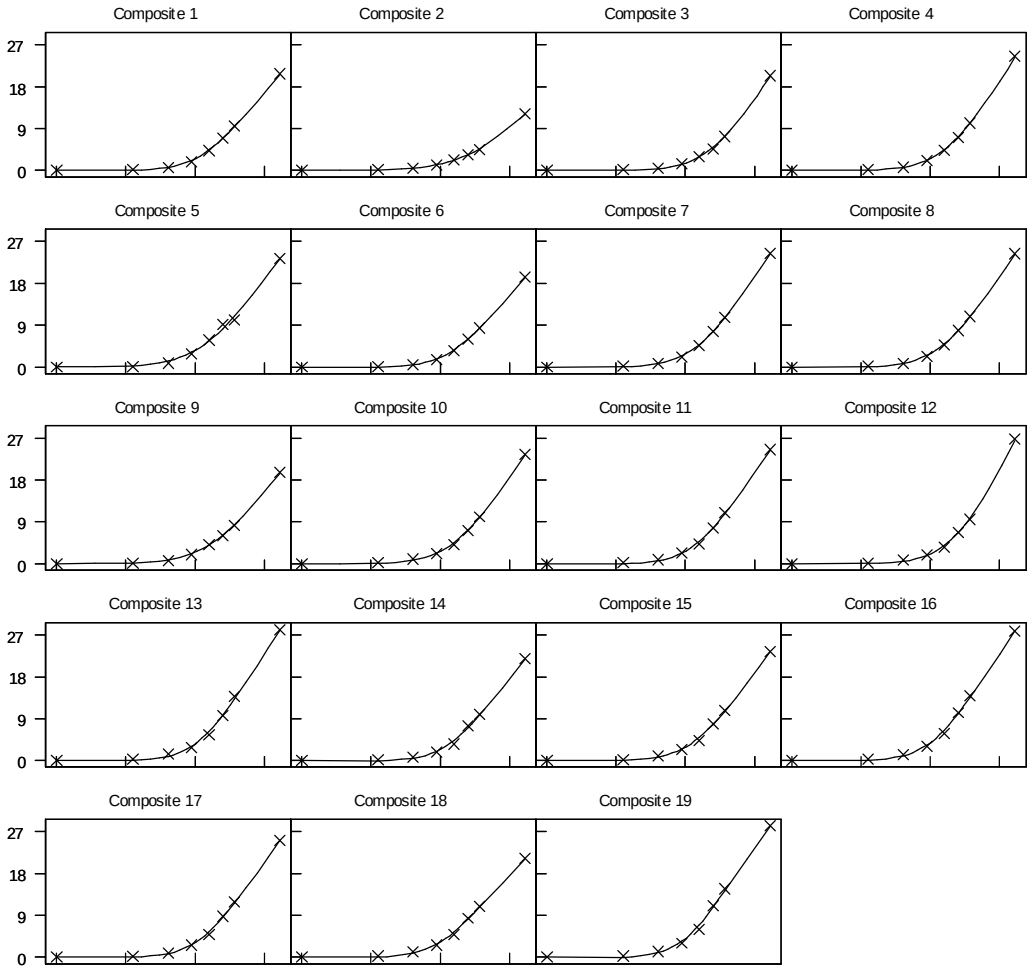


Figure 5.5 Genstat logistic curves of composite plant gas production (mL), (y axis) over 24h (x axis).

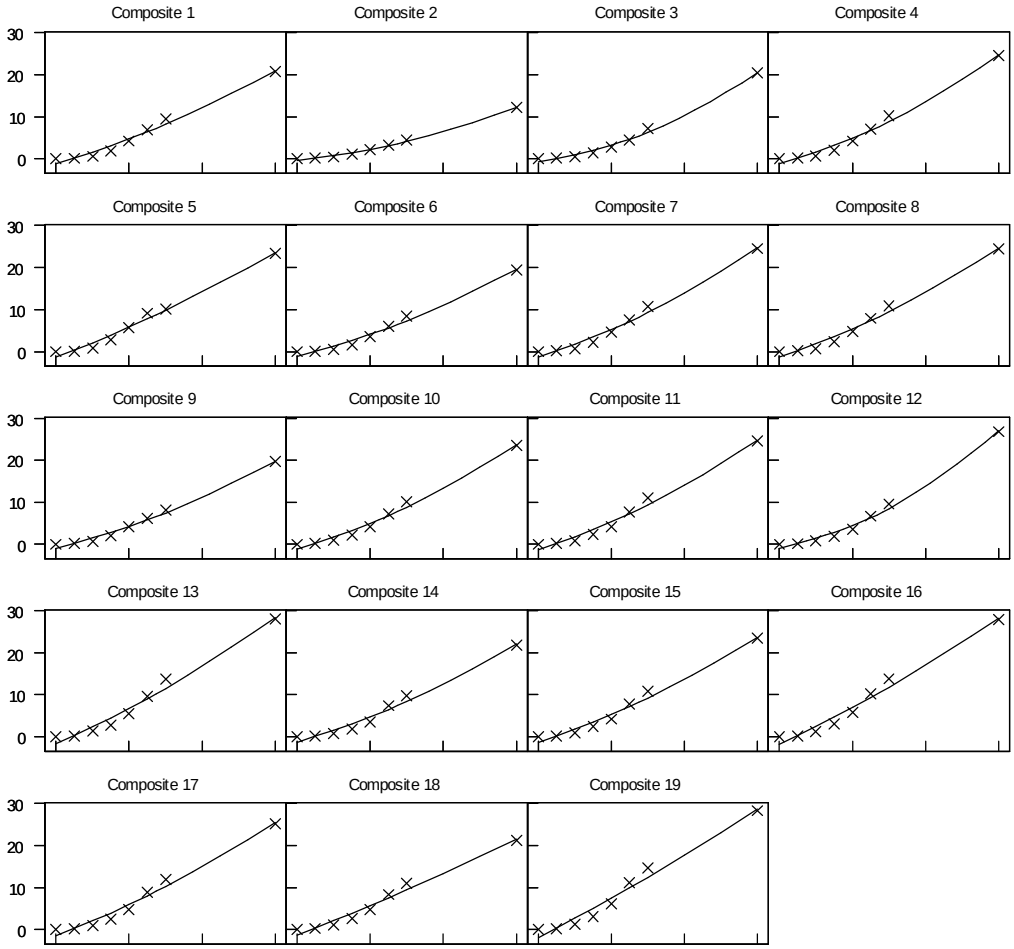


Figure 5.6 Genstat of exponential curves of composite plant gas production (mL), (y axis) over 24h (x axis).

The cumulative gas production of the composites at 0 - 24 h is shown in Figure 5.7. An average of 2.2±0.5 mL of gas was produced between 0 - 6 h of the incubation. Therefore, samples 2 (1.1 mL), 3 (1.4 mL) and 6 (1.6 mL) produced below-average gas, whilst samples 5 (2.8 mL), 13 (2.8 mL), 16 (3.0 mL) and 19 (3.0 mL) produced above-average gas volumes.

An average of 8.1±1.9 mL of gas was produced by the composite samples between 6 - 12 h of incubation. Samples 2 (3.3 mL), 3 (5.9 mL) and 9 (6.2 mL) had below-average gas production, while samples 13 (11 mL), 16 (10.8 mL) and 19 (11.7 mL) had above-average gas production.

At 12 - 24 h, an average of 12.8±2.0 mL of gas was produced by the composite samples. Therefore, samples 2 (7.8 mL) and 18 (10.2 mL) produced below-average volume, and sample 12 (17.2 mL) had above-average production of gas.

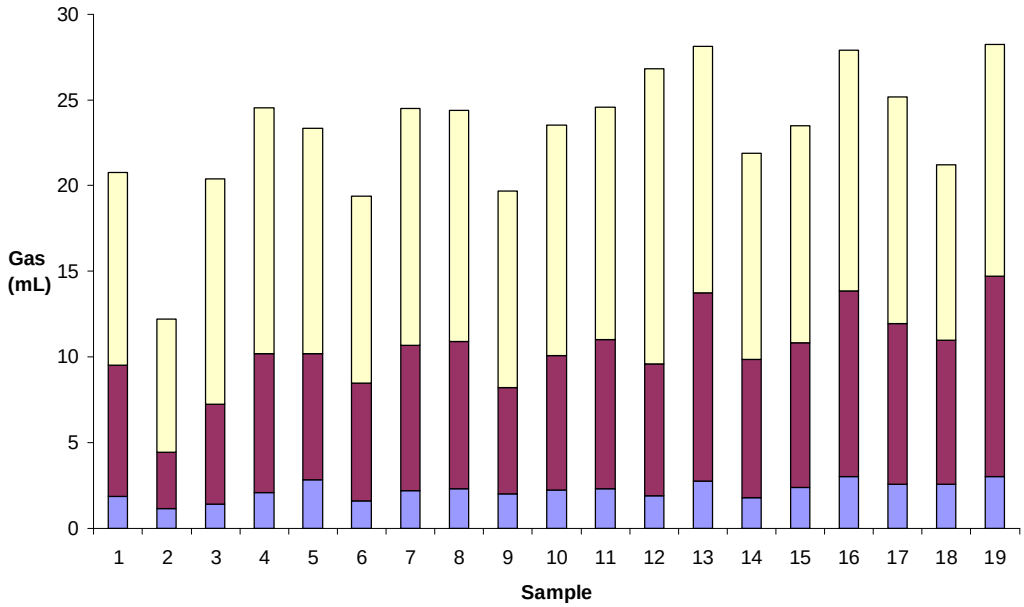


Figure 5.7 Gas produced by composite plant samples at 0 - 6 h (blue), 6 - 12 h (red) and 12 - 14 h (yellow) of incubation.

5.3.2.2 Nutritional profiles

The nutritional profiles for the composite samples (A) are presented in Table 5.19. Also shown in the Table are the calculated averages (B) for the same mixtures of plants. The difference between A and B for OMD, ME, CP and ash results were generally small, apart from composite 13 where there was a difference of 6% in the measured and calculated OMD and a difference of 10 MJ/kg in the measured and calculated ME contents.

According to both sets of values, plant mixes 16 and 19 had the highest ME content (6.8 - 7.2 MJ/kg) while sample 2 had the lowest (4.4 - 4.6 MJ/kg). Plant mix 16 also had the highest OMD (47.9 - 50.0%), while sample 2 had the lowest OMD (31.8%). Samples 6 and 14 had the highest CP content (23.1 - 25.5%), while sample 12 had

the lowest (9.0 - 9.3%). Samples 10 and 11 had the highest ash content (23.0 - 25.3%), while samples 2, 12 and 18 had the lowest (6.2 - 9.2%).

Table 5.19 Nutritional results of plant composites. A: mixes, B: average of individuals.

Composite	OMD (%)		ME (MJ/kg)		CP (%)		Ash (%)	
	A	B	A	B	A	B	A	B
1	39.1	38.6	5.8	5.5	13.0	12.7	15.0	16.8
2	30.6	30.4	4.4	4.4	11.7	10.9	6.0	7.4
3	40.6	41.1	5.8	5.9	18.1	16.8	12.1	15.9
4	43.9	42.9	6.3	6.1	17.1	17.9	13.1	16.3
5	42.1	41.0	6.1	5.9	15.7	15.9	11.9	14.3
6	40.5	42.6	5.8	6.1	20.6	21.6	9.8	13.1
7	44.2	42.4	6.3	6.0	17.0	17.3	18.1	21.2
8	43.0	43.7	6.2	6.1	13.7	13.8	18.9	22.4
9	38.3	40.6	5.5	5.8	13.5	13.3	13.1	14.3
10	41.9	42.1	6.0	6.0	12.3	12.1	21.8	25.3
11	42.2	41.7	6.1	5.9	10.5	10.8	21.3	24.9
12	42.5	41.5	6.3	6.1	8.4	8.3	8.4	9.2
13	46.0	39.5	6.6	5.6	12.6	13.1	19.5	22.2
14	42.8	41.6	6.1	5.8	18.6	19.5	20.4	24.0
15	43.4	43.1	6.3	6.2	18.6	20.7	8.9	12.5
16	47.1	46.1	6.8	6.6	16.7	15.3	16.7	20.2
17	43.6	43.2	6.3	6.2	13.0	13.9	20.1	23.3
18	38.4	39.5	5.6	5.8	10.8	10.6	5.8	6.3
19	45.7	47.8	6.6	6.9	10.9	13.5	19.6	20.9

5.4 Discussion

5.4.1 Cumulative gas production of plant species and composite samples

In terms of cumulative gas production over 24 h, there was variability both within and between samples, as shown in Figures 5.1, 5.2, 5.4 and 5.5.

In general, the logistic model fitted the cumulative gas production data better than the exponential model. The logistic model was developed for the automated gas fermentation technique where continuous measurements are taken and more detailed information is accumulated (Cone *et al.* 1996; Groot *et al.* 1996; Blummel *et al.* 2005), although in this study, continuous measurements up to 120 h were not made; however. Schofield *et al.* (1994) also found the logistic or gompertz models fit more complex plant samples better than exponential models. Williams (2000) showed gas production from wheat straw had a sigmoidal curve whilst that from rye grass had an exponential curve. The exponential model is widely used for agricultural plant pastures (Kamalak *et al.* 2005a; Kamalak *et al.* 2005b) and often for results determined by the nylon bag technique (Orskov 2000; Sallam 2005).

Care should be given to the estimation of parameters and application of predictive equations for the nutritive value of feeds (Sumsel & Filacorda 1996). The precision and variability of results depend on the composition and activity of the ruminal liquor, therefore initial conditions including basal diets, quantity of samples and particle size are very important (Williams 2000). These conditions were controlled in this study by using three rumen-fistulated sheep fed fixed basal diets. All plant samples were ground through a 2 mm screen and known sample quantities of approximately 200 mg were incubated in triplicates. Additionally, the Hohenheim hay standard with a known gas production was included in all incubations. Sample results were corrected for dry weight, duplicated blanks (ruminal fluid and buffer mixture only) and Hohenheim hay standard gas production.

The potential gas productions, as indicated by parameter A from the logistic model, were much higher than the observed gas production (G). Additionally, B values (time at which half of the asymptotic gas has been formed) were more than 12 h for all samples. Therefore the A and B estimates of the logistic model indicate that the 24 h incubation time did not allow for total fermentation of the samples by the rumen bacteria. Many studies measure the gas production of fermenting samples for periods between 48 - 120 h (Blummel *et al.* 2005; Gasmi-Boubaker *et al.* 2005; Kamalak *et al.* 2005a; Kamalak *et al.* 2005b; Monforte-Briceno *et al.* 2005; Sallam

2005; Hummel *et al.* 2006; Sallam *et al.* 2007). It is critical that the fermentation period is long enough to identify the asymptote; therefore the difference between the last two measurements must be less than 10% (Orskov 2000). The shortened incubation time may have resulted in poor model fittings and distorted coefficient estimates. However, 24 h is adequate for estimations of ME and OMD (Sallam *et al.* 2007). Blummel *et al.* (2005) found that *in vitro* DM degradability and the extent of cell wall degradability can be estimated from 24 h of gas fermentation.

Despite the limitations of the shortened incubation time, differences in plant degradability over time can be seen, where the individual and composite sample results indicate that some plants released nutrients slower than others. Composite sample 3 had very low gas production from 0 - 12 h of incubation, although it had average (13.1) production from 12 - 24 h, indicating that it released its nutrients slowly. This sample consisted of a mix of plants collected from RGS. The mix included *Atriplex amnicola, Maireana planifolia, Monachather paradoxus, Ptilotus obovatus* and *Rhagodia eremaea*, which are all relatively palatable species. The gas production of composite samples is a reflection of the gas production of individual species within the composite sample. *Maireana planifolia* had below-average gas production at 0 - 12 h. At 6 - 12 h, *Atriplex amnicola* had above-average production. At 12 - 24 h, *Solanum lasiophyllum* had below-average production, while *Monachather paradoxus* had above-average production. The gas production of the composite sample was possibly influenced by *Maireana planifolia's* low gas production during 0 - 12 h. Similarly, composite sample 12 was the only sample to produce above-average gas production at 12 - 24 h. This sample was a mix of wheat stubble heads and stems. At 0 - 6 h fermentation wheat stubble stems had below-average gas production, while wheat stubble heads had above-average gas production during the entire incubation. Therefore, as a combination, the fibrous stems slowed gas production initially but the digestible heads, which contained some wheat seeds, were harnessed by the rumen bacteria by the last 12 h of the fermentation. Studies have found that rumen degradability varies between plants, and can be changed by the addition of other plant species or supplements (Orskov 1988; Kamalak *et al.* 2005a; El-Waziry 2007).

Cumulative gas production curves can provide valuable information about the degradability of plants by rumen microbes and the effects of feeds on microbes (Montforte-Briceno *et al.* 2005; Gasmi-Boubaker *et al.* 2005), which can be related to feed intake by animals (Orskov *et al.* 1988; Khazaal *et al.* 1993; Shem *et al.* 1995; Kamalak *et al.* 2005b). This information can also be used to improve animal diets by adding appropriate supplements to diets to improve digestibility and subsequent feed intake and animal performance (Orskov 2000).

5.4.2 Nutritional profiles and mineral content of plant species

5.4.2.1 Nutritional content

All of the shrubs and annuals met sheep maintenance requirements for CP (>8%) (Meissner *et al.* 1999; McDonald *et al.* 2002) whereas *Monachather paradoxus* and *Stipa scabra* were the only grasses able to meet requirements. Species that were high in CP (*Enchylaena tomentosa, Maireana convexa, Maireana planifolia, Maireana pyramidata, Maireana thesioides, Maireana triptera, Maireana villosa, Rhagodia eremaea* and *Ptilotus macrocephalus*) were mostly chenopod shrubs and had similar or greater levels to that of lucerne or early flowering white clover (22 - 24% CP) (McDonald *et al.* 2002). Species low in CP (*Acacia* spp*., Scaevola spinescens, Melaleuca* spp*., Aristida contorta, Cymbopogon ambiguus, Enneapogon* spp*., Eragrostis* spp*., Stipa scabra, Schoenia filifolia* and wheat stubble stems) had levels comparative to that of straws (4 - 11%) (McDonald *et al.* 2002). These results are similar to those of Franklin-McEvoy & Jolly (2006a) who report that rangeland grasses have poor energy and protein content in summer and autumn, and animals are likely to have diets deficient in energy throughout the year.

In general, the grasses contained 30% more NDF compared to the shrubs, but had similar ADF and lower ADL contents. This suggests the grasses contain more hemicellulose than the shrubs (hemicellose = NDF - ADF). Therefore the grasses were more fibrous than the shrubs, but this may not necessarily affect their digestibility adversely, as hemicellulose is broken down to the energy source of volatile fatty acids by rumen microbes, and it is the ADL that lowers the digestibility

of plants (Jung & Allen 1995; McDonald *et al.* 2002). Grasses analysed by Hummel *et al.* (2006) were also found to have higher NDF and lower ADL compared to browse leaves due to higher hemicellulose content. The annual species had lower ADL content compared to the shrubs in this study, and also in Hummel *et al.* (2006).

No rangeland species alone, were able to meet the maintenance requirements of sheep in terms of OMD (>50%) and ME (>8 MJ/kg) (Meissner *et al.* 1999; McDonald *et al.* 2002). NDVI and rainfall results (Chapter 4) show that the Yalgoo shire was experiencing drought for the majority of the study period. Therefore, most of the plant material was mature and drying off, making it difficult to collect young leaf material, during field harvest. This has most likely contributed to the low OMD and ME results of many of the plant species. However, there is likely to be periods, especially following rain, when annual herbs and/or grasses will provide more nutritious green feed (Harrington *et al.* 1984b; Burnside *et al.* 1995). The grass *Monachather paradoxus* and the annual forb *Ptilotus macrocephalus*, which were collected while green but beginning to dry, had relatively higher values for both OMD (45% and 49.2%, respectively) and ME (6.6 MJ/kg and 7.3 MJ/kg, respectively) compared to other species. As plants age, the proportion of cell contents decrease while cell wall content increases (Huston & Pinchak 1991), including the amount of lignin (Cordova *et al.* 1978). Additionally, the formation of sugars, starches, protein and new material decreases (Chapman 1996). Therefore, the nutritional value decreases as plants mature.

Since it is known that the study area can support reproducing livestock, it is likely that the nutritional profiles of the individual plant species do not represent the nutritive value of the diet the sheep in the study area actually consumed. Numerous studies have found that analyses of specific plants rarely indicate the quality of diets consumed by animals (Papachristou 1993; Avondo *et al.* 2004). Wilson (1977) studied sheep and goat intake of a number of perennial shrubs and trees in western NSW and found no correspondence between digestibility and organic matter intake. The species of higher digestibility (*Atriplex nummularia* (69%)*, Maireana pyramidata* (58%)*, and Geijera parviflora* (59%)) were only eaten sparingly.

In addition, it is possible that livestock quickly ate the more nutritious material before field sampling occurred. For example, it was observed that the *Ptilotus macrocephalus* had been heavily grazed before sampling; therefore the material that was collected during this study is most likely the material that was residual or passed over by livestock. Some plants like *Scaevola spinescens* and *Cratystylis subspinescens* were difficult to sample due to their small leaves, very woody and numerous stems. New leaf material was collected from the ends of branches of various plants within paddocks; however, if new leaf material was not present older material was collected. Stems, flowers and fruit were avoided. Many volunteers assisted in plant collections; therefore, there may have been differences in what was collected by different people, where some people were more meticulous or consistent than others. Additionally, material for each species was collected from a number of plants within paddocks, therefore individual plant variability may have affected the quality of multi-plant samples, although it was assumed that by collecting from a number of plants, individual variability would be reduced. The sampled material may not have been representative of that consumed by grazing livestock as they would be more selective than was practicable using the hand-plucking technique. Edlefsen *et al.* (1960) found the use of hand plucking to estimate sheep diets resulted in higher lignin and cellulose content, and lower protein and ash content compared to results from oesophageal fistulated animals.

There is a lack of published information on the vast majority of plants analysed in this study, and most Western Australian researchers and pastoralists rely on one publication (Mitchell & Wilcox 1994) for guidance on WA rangeland species identification and nutritional value. The plants in this study generally had higher CP contents and lower digestibility than Mitchell & Wilcox (1994) reported. For example, they report that *Rhagodia eremaea* has up to 67% digestibility and contain 6 - 12% CP; however, in this study *R. eremaea* contained 11 - 23% CP, with an OMD of only 35 - 50%. Similarly, they estimate *Maireana pyramidata* has 60% digestibility and contains 22% CP, whereas in this study *M. pyramidata* had 12 - 27% CP and 22 - 40% OMD. Unfortunately, Mitchell & Wilcox (1994) do not state how their values were calculated and they more likely represent DM digestibility rather than OMD. It is also likely that they calculated digestibility's from fibre analysis data. This

technique is unreliable on rangeland shrubs, as it does not account for the negative effects of tannins and other volatile oils on digestibility, and can therefore overestimate (Makkar *et al.* 1997). Additionally, Franklin-McEvoy & Jolly 2006b highlighted that wet chemistry *in vitro* techniques for determining plant nutritive values are inconsistent and generally over estimate energy content and digestibility of highly salty plants. In contrast, the *in vitro* gas fermentation technique used for this study reveals the direct interaction between plants and rumen bacteria and therefore accounts for tannins and other secondary metabolites (Ammar *et al.* 2005).

However, the gas fermentation technique also has its limitations as it estimates the digestion of feed in the rumen and does not account for further digestion in the abomasum and intestines (Williams 2000). It is likely that the rumen ecology of the penned sheep, which were donors of the ruminal fluid used in fermentation for this study, is different from the rumen ecology of rangeland sheep due to their vastly different diets, which may have affected the OMD and ME results. The populations of rumen microbial species are affected by animal diets as different species are adapted to different resource conditions and digest different material (Russell & Rychlik 2001). Gradual introductions of new foods allow rumen microbial populations to adapt to changes, including diets containing secondary metabolites like oxalates (Duncan *et al.* 2000), tannins (Smith *et al.* 2005) and plant toxins (Smith 1992), enabling increased digestion efficiency and consequent higher feed intake. The rumen fluid of rangeland sheep is likely to be more efficient at digesting native plants that make up rangeland sheep diets, compared to rumen fluid from penned sheep fed on roughage diets. The donor sheep in this study were maintained on roughage basal diets as recommended by Menke *et al.* (1979) and Makkar (2004). Therefore, the results are comparable to other studies using similar methods.

These results indicate that nutritional analysis of plant species is an inaccurate way of ascertaining the nutritive value of diets actually consumed by animals. The use of advanced DNA and NIRS technology to more accurately determine the nutritive value of diets that rangelands sheep consume is reported in Chapter 7.

5.4.2.2 Seasonal, spatial and species variability

The nutritional profiles of each species varied widely over the study period. This variation may have been caused by many factors including seasons, rainfall, soil type, land systems, plant individuality and sampling accuracy. It is likely that all of these factors have influenced the results, which makes it difficult to distinguish which factors are more dominant.

Comparisons of two plant species collected from RGS on the same day (in June 2006), from adjacent paddocks with differing land systems and soils, showed spatial variation in general nutritional attributes (Table 5.20). Plants in the paddock with alluvial soils were more digestible, with higher ME, but less protein, than plants growing on stony hills (Norton *et al.* 2008). The nutritive value and mineral content of *Ptilotus macrocephalus* (Table 5.21) varied considerably between the two locations, particularly for NDF, Na, Ca, Mg, B, Fe, Mn and Zn.

Table 5.20 Nutritional values of foliage of two shrub species (*Ptilotus obovatus* and *Atriplex bunburyana*) collected in June 2006 from two different paddocks, one with sandy-loam soil (alluvial) and the other dominated by shallow stony soils (stony) on RGS in June 2006.

Nutritional attribute	*Ptilotus obovatus*		*Atriplex bunburyana*	
	Alluvial	Stony	Alluvial	Stony
CP (%)	13.1	19.4	12.1	13.4
ME (MJ/kg DM)	7.1	5.9	7.1	6.4
In vitro OMD (%)	49.0	41.6	49.5	45.6
Ash (%)	13.0	12.8	25.7	29.6

Norton *et al.* (2008)

Table 5.21 Differences in *Ptilotus macrocephalus* nutritional (%) macro mineral (%) and trace element (mg/kg) content collected from two paddocks, one with sandy-loam soil (alluvial) and the other dominated by shallow stony soils (stony), on RGS in June 2006.

Nutritional attribute	Alluvial	Stony
In vitro OMD	48.9	49.4
ME	7.0	7.0
CP	18.1	16.6
Ash	21.8	22.9
NDF	19.8	28.3
ADF	11.2	14.4
ADL	1.3	2.2
P	0.12	0.09
K	5.95	7.29
Na	0.73	0.18
Ca	1.97	2.26
Mg	1.43	1.18
S	0.25	0.29
B	51.2	30.9
Cu	5.4	7.2
Fe	210.4	163.4
Mn	83.2	90.8
Zn	20.1	49.9

Norton *et al.* (2008)

The climate of the study sites is characterised by a summer rainfall season with precipitation often in the form of storm events, and a winter rainfall season derived from frontal systems. During this research study there was high summer rainfall and very low winter rainfall, which seems to have affected the nutritional content of plants.

A comparison of nutritional content of *Atriplex bunburyana* and *Rhagodia eremaea* in Figures 5.8 and 5.9 indicate that there are rainfall, seasonal and species

differences between the plants. Protein content was low in August 2006 following the poor winter season, and by early summer (December) was only half the level from April - May. The increase in October 2006 seems to be a response to the higher rainfall in September (Figure 5.8). Additionally, the August 2007 protein values far exceeded those from August 2006 (Norton *et al.* 2008). *Rhagodia eremaea* consistently had higher protein content than *Atriplex bunburyana*. The OMD of *Atriplex bunburyana* and *Rhagodia drummondii* decreased considerably at the end of 2007 compared to 2006 (Figure 5.9). Similarly, Yayneshet *et al.* (2008) reported significant seasonal and species variation in the chemical composition of semi-arid browse and grass species. They found that CP, ME and in vitro DM digestibility decreased during the dry season and increased during the wet season.

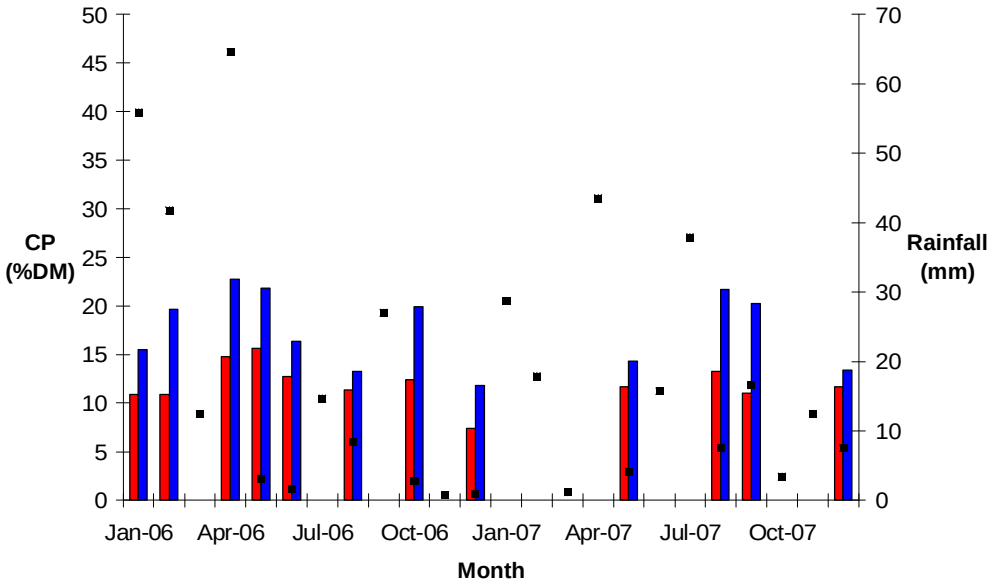


Figure 5.8 Rainfall for the study areas (points) and crude protein content for *Atriplex bunburyana* (red) and *Rhagodia eremaea* (blue) from January 06 to December 07.

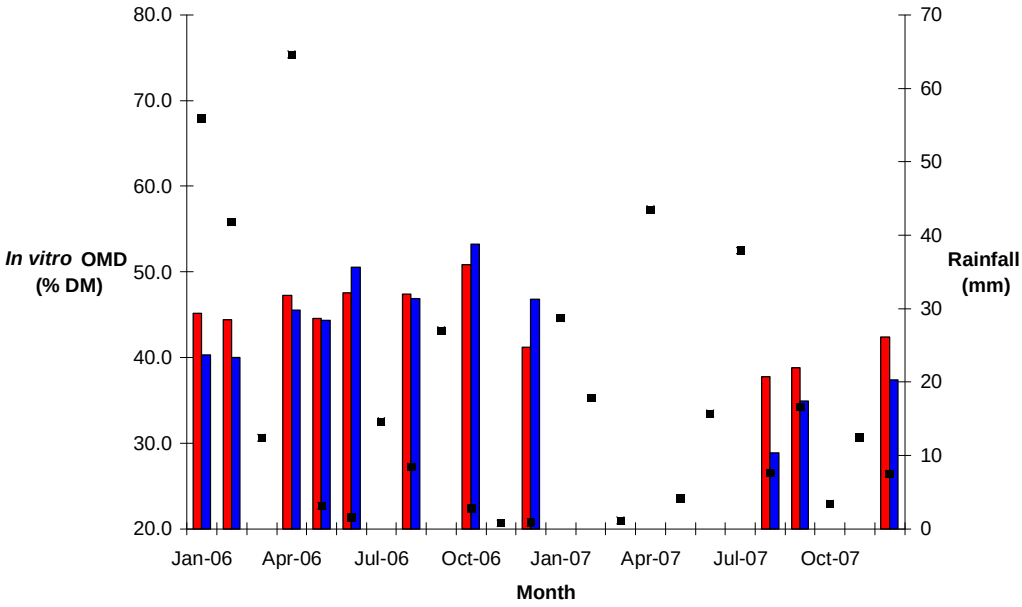


Figure 5.9 Rainfall for the study areas (points), and in vitro organic matter digestibility for *Atriplex bunburyana* (red) and *Rhagodia eremaea* (blue) from January 06 to December 07.

5.4.2.3 Mineral content

Mineral content in the plants was variable but in general they met most of the mineral requirements for sheep, apart from P.

Macro mineral content of the plants was variable. Many Australian rangelands soils have poor fertility (Handreck 1997). P is particularly low in Australian soils due to either the lack of P in soil parent material or to the highly weathered nature of soils (Beadle 1966). Australian plants are well adapted to coping with the low P availability (Handreck 1997); however, this mineral is considered the most limiting nutrient to animals after N (Cole *et al.* 1977).

Comparisons to previous studies suggest there may be regional difference in the nutritional content of species. *Ptilotus macrocephalus* had higher N, K, Ca and Mg, and lower P content than that reported by Islam *et al.* (1999) for the Pilbara region of Western Australia. *Maireana tomentosa* had generally higher N and Mg, similar P

and Ca, and lower K than reported by Islam *et al.* (1999). *Maireana pyramidata* had lower P, Ca and Mg, and higher K, Na and S content compared to those reported by Franklin-McEvoy (2005b).

Trace element content of the plants was very high and variable. This is influenced by the high trace element content in the soils, especially Fe which is known to be high in the rangelands, causing the red soil colour (Burnside *et al.* 1995). Trace element content of the plants may also have been influenced by dust contamination on the collected material, although attempts were made to keep this minimal. *Maireana pyramidata* had lower B, Cu, Fe and Mn, and similar Zn reported by Franklin-McEvoy (2005b).

5.4.3 Nutritional value of composite samples

The composite samples were created to mimic the possible combinations of plants that sheep may eat and potential chemical interactions. Individual species collected at the same time in the same location were mixed in equal proportions to create the composite samples. The species chosen ranged in palatability and were commonly found in the paddocks at the time of collections. It was assumed that due to their common occurrence, these species were likely to be consumed by sheep grazing the paddocks. On occasion, it was clearly observed that plants like *Ptilotus macrocephalus* had been grazed heavily at the time of collections, hence their inclusion in the study.

There was little difference between composite results and averages of the combined samples for OMD, ME, CP and ash, apart from sample 13. This indicates that combining samples had little effect on microbial rumen function. The OMD result for composite sample 13 was 6.5% more than that calculated from the average of the individual species, and the ME for sample 13 was 1 MJ/kg more than the average of contributing species. This indicates that the nutrients available to microbes were improved by combining the plant species in sample 13, enhancing microbial growth and efficiency. Supplements can achieve the same outcome; for example, the addition of urea to low-quality roughage diets increases microbial growth (Mlay *et al.*

2005; Currier *et al.* 2004). Sample 13 consisted of *Atriplex* spp*., Enchylaena tomentosa, Eremophila forrestii* and *Maireana pyramidata* collected from CGS-G in May 2007. It is difficult to determine what factor(s) resulted in the increased microbial activity fermenting the composite sample, which could have been affected by salt content found in the halophytes (*Atriplex* spp*., Enchylaena tomentosa*, and *Maireana pyramidata*), secondary metabolites likely to occur in the fragrant *Eremophila forrestii*, and fibre content. Fragrance in plants is associated with the presence of essential oils (Cowan 1999). Salt (Chiy *et al.* 2006), secondary metabolites, including phenolics, (Hagerman *et al.* 1992; Kaitho *et al.* 1998; Newbold *et al.* 1997) and lignin (Hummel *et al.* 2006) can have variable effects on microbial activity depending on their presence, concentrations, interactions and molecular forms. Unfortunately, the presence of secondary metabolites was not measured in the studied plants.

The same species combination of sample 13 occurred in sample 17, which was also collected from CGS-G, but in September 2007 rather than May. For sample 17 there was little difference in the measured and calculated OMD, ME, CP and ash contents. This indicates that season, rainfall or other unidentified factors have somehow impacted on the nutritive value of the species included in samples 13 and 17. Average rainfall for April 2007 (immediately preceding the collection of Sample 13) in Yalgoo town was 29.6 mL, while for September (collection of Sample 17) it was 16.2 mL. This suggests that Sample 13 had improved results due to higher rainfall. Due to the drought conditions in 2007, it is difficult to distinguish if seasons had an effect on plant quality, or the strength of seasonal influences on results, as has been previously reported (Salem 2005; Yayneshet *et al.* 2008). However, the average Na content of sample 13 (5.4±3.1%) was lower than sample 17 (6.6±3.8%), indicating that salt concentrations were higher in sample 17 plants, which may have been caused by a drier climate that increased salt concentrations in the soils and plants (Sharma *et al.* 1972).

The combinations of species within composite samples seemed to increase the nutritional value of poorer plants and decrease the value of the more nutritious species, which resulted in less variation between samples compared to individual

plant results. El-Waziry (2007) also found this for composites of *Acacia* and *Atriplex.* Samples 16 and 19 had the highest OMD and ME results as well as more adequate CP content compared to the other samples, therefore this plant combination had the highest nutritive value. Additionally, these samples had the highest gas production for the first 12 h of incubation. Samples 16 and 19 were from RGS and contained highly palatable plants including *Atriplex* spp*., Rhagodia eremaea, Sida calyxhymenia, Maireana convexa* and *Schoenia filifolia*. Sample 2 had the lowest OMD and ME content, but adequate CP and low ash content. This sample also had the lowest gas production over the 24 h of incubation. Sample 2 was from CGS-P and was dominated by the low value *Acacia* species.

5.5 Conclusions

The nutritive value of plants in this study was variable, influenced by seasons, land systems, soils, and species differences. In general the plants had low digestibility and were low in energy and macro mineral content, but high in protein and trace element content. Therefore, livestock grazing in these paddocks would need to search for sources of energy and easily digested feeds. However, the study was conducted over two very dry years and nutritional profiles of these plants may differ in times of average to above-average rainfall.

Interpretation of cumulative gas results is limited by the short incubation time of 24 hours. However, in general, plants of low palatability (Russell & Fletcher 2003) like *Maireana pyramidata, Scaevola spinescens* and wheat stubble stems consistently had low gas production, indicating high rumen retention time and low digestibility. Plants of high palatability like the annual species, wheat stubble heads and *Sida calyxhymenia* had high gas production indicating that they can be rapidly digested in the rumen. However, *Maireana triptera* is one of the least palatable species, yet the nutritional values give no indication of this.

The combination of plants in composite samples generally did not affect the efficiency of microbial fermentation, apart from sample 13, where microbial

fermentation seemed to be improved by the plant combination. However, it was not possible to determine what was influencing this sample.

It is questionable whether all the species sampled were consumed by sheep grazing these paddocks. However, the faecal DNA results in chapter 6 indicate that many of the plants analysed in this study were in fact consumed by the sheep. The analysis of rangeland plant chemical compositions provides valuable insight into the nutrition of plants available to livestock, and factors that influence plant nutrition. However, results from NIRS analysis in chapter 6 show that analysis of native plant nutrition does not necessarily provide accurate indications of grazing animal dietary intake.

6 Sheep production

6.1 Introduction

The quality and quantity of the feed available to sheep dictates the success of production parameters such as live weight and wool production. For example, a low quality diet will reduce wool growth, result in higher variability in wool strength along the staple, and reduce live weight gain (Holm *et al*. 2005). Therefore, measuring sheep production parameters provides an indication of the quantity and quality of animal diets. In this chapter live weight, BCS and wool production and quality during the study are examined.

6.2 Materials and methods

6.2.1 Feed management

Sheep on the rotationally managed station were moved from paddock to paddock every 4 - 6 weeks in 2006 (Table 3.3). During lambing (May - August) the sheep were left in Cattle paddock undisturbed, and in August given access to surrounding paddocks for free grazing. For approximately 2 months prior to shearing (October), the sheep were supplementary fed with about 1.5 kg wheat/head/week. In January 2007, due to inadequate feed on the station the sheep were moved and agisted on a wheatbelt property in the Morawa Shire (29º20'S 116º02'E), where they grazed on failed wheat crops until May. They were then moved back to the station where they were able to continuously graze Yuin, Buddadoo and Edamurta paddocks. They were also fed 1.5 kg wheat/head/week.

Sheep on the continuous-grazing managed station were free to graze the paddocks during the study period. One large bale of cereal hay was provided for the sheep on CGS-G in October 2007. This amount of supplementary feeding was considered insignificant by the station owners.

Refer to Chapter 3, Section 3.2.1 for further information on grazing management.

6.2.2 Live weights and body condition scores

Live weights and BCS were recorded every 1 - 3 months as outlined in Table 6.1. Measurements occurred when permitted by station owners. Refer to Chapter 3, Sections 3.5.2 to 3.5.4 for description of the relevant materials and methods. Data was analysed by ANOVA in a nested design as described in Chapter 3, Section 3.10.

Table 6.1 Calendar of animal-related activities for the two stations: live weight (LW), body condition scoring (BCS) and wool dye-banding (DB).

RGS		CGS	
Date	Event	Date	Event
28 Nov 2005	Shearing 1, LW, BCS	14 Dec 2005	Shearing 1, LW, BCS
24 Jan 2006	LW, BCS, DB	20 Apr 2006	LW, BCS, DB
26 Feb 2006	LW, BCS	21 Aug 2006	LW, BCS, DB
6 Apr 2006	LW, BCS, DB		
10 May 2006	LW, BCS		
19 Oct 2006	Shearing 2, LW, BCS	5 Dec 2006	Shearing 2, LW, BCS
30 May 2007	LW, BCS, DB	12 Apr 2007	LW, BSC, DB
6 Dec 2007	Shearing 3, LW, BCS	31 Oct 2007	Shearing 3, LW, BCS

6.2.3 Wool

Dye-bands (to determine wool growth) were applied at skin level on the sheep every 4 - 6 months, as outlined in Table 6.1. Dye-banding methods and analysis are described in Chapters 3.5.1 - 3.5.3, 3.5.5, 3.5.6 and 3.8.1. The results were statistically analysed using Genstat in a nested design where the original source of sheep were within management groups and within year.

6.2.4 Survival Rates

Survival rates of the test sheep were not monitored as definitive knowledge of whether an absent was sheep dead or alive was unattainable. On most of the data collection occasions, the sheep were trapped at watering points when traps were shut the night before. Therefore only the sheep that went to watering points while traps were shut were analysed. Joint trapping and mustering only occurred at shearing times (Table 6.1) however, sheep can still evade capture at these times. A number (11 from RGS and 4 from CGS-P were only assessed once at the start of the study (Dec 05).

6.3 Results

6.3.1 Live weights and body condition scores

6.3.1.1 Live weights

Changes in live weights of the sheep over the study period for the different management systems are shown in Figure 6.1. At the commencement of the study (at shearing in 2005) the average live weight of the sheep (off-shears) was 43.7±6.1 kg, with no significant differences ($P>0.05$) between the treatment groups (by design). There were also no significant differences ($P>0.05$) in live weight between the management systems when the sheep were weighed in April 2006 (RGS = 43.9 kg, CGS-G = 42.6 kg, CGS-P = 43.5 kg). However, there were significant ($P<0.05$) differences in live weight of the sheep between management systems from measurements made in August 2006 to shearing in 2007.

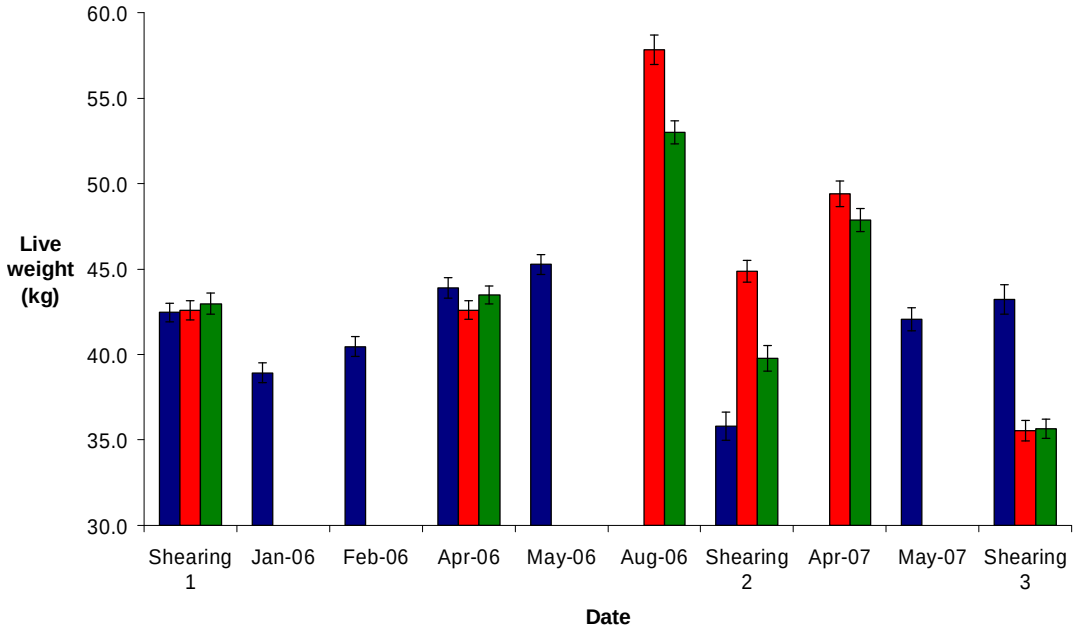


Figure 6.1 Average live weights of sheep managed under RGS (blue), CGS-G (red) and CGS-P (green) grazing systems from Nov/Dec 2005 (Shearing 1) to Oct/Dec 2007 (Shearing 3).

In August 2006, the sheep in CGS-G (57.8 kg) had significantly (P<0.001) greater live weights than those in CGS-P (53.0 kg). By the second shearing in October/December the managements systems differed significantly (P<0.001) where sheep in CGS-G had the highest live weights (44.9 kg) followed by CGS-P (39.8 kg), and RGS (35.8 kg) had the lowest live weights. At the final shearing in 2007, sheep in RGS had significantly (P<0.001) higher live weights (43.2 kg) compared to those in CGS (CGS-G = 35.5 kg, CGS-P = 35.7 kg).

The station of origin of the sheep had a significant (P<0.001) effect on live weight, regardless of which subsequent management system. Sheep sourced from Station 2, but managed on RGS (Station 1), had significantly (P<0.05) greater weights than the sheep originating from Station 1, except in May 2007. Sheep sourced from Station 2 and managed on CGS-G, always had significantly (P<0.05) greater live weights than sheep sourced from Station 1, except at the first shearing in 2005 (by

design). Sheep sourced from Station 2 and managed CGS-P, also had significantly ($P<0.05$) greater live weights than sheep sourced from Station 1.

Within each of the management systems there were significant ($P<0.05$) changes in live weights at different times throughout the study period. From the commencement of the trial (November 2005) until January 2006, the average live weight of the sheep in RGS decreased by 3.6 kg but then gradually increased to 45.3 kg by May 2006. However, by October shearing in 2006, the average (off-shears) live weight of these sheep was 35.6 kg, a decrease of 7 kg from the initial (off-shears) 2005 average weight (42.5 kg). By the time of shearing in December 2007, the average (off-shears) live weight of the sheep had increased to 43.3 kg, an increase of 7.7 kg from shearing in 2006 but only slightly higher than the average live weight at the commencement of the trial at shearing in 2005.

In 2006, sheep managed on CGS-G increased from an average live weight of 42.6 kg (December 2005) to 57.9 kg by August. However, like the sheep in RGS, the live weights had decreased by 2006 shearing (to 44.9 kg). In 2007, weights initially increased (from shearing December 2006) up until April; however, weights had again decreased by shearing (October) in 2007 (35.5 kg). By the time of shearing at the end of the study the average live weight (off-shears) had decreased by 9.3 kg from shearing in 2006 and by 7.1 kg from their initial weights in 2005.

Sheep live weights increased on CGS-P from an average of 43.0 kg at the commencement of the trial (December 2005) to 53.0 kg by August 2006. However, like the sheep on RGS and CGS-G, their weights had decreased by 2006 shearing (to 39.8 kg). In 2007, weights initially increased to 47.9 kg (April 2007); however, their weights decreased by shearing (October) in 2007 (35.7 kg). By the time of shearing at the end of the study the average live weight off-shears had decreased by 4.1 kg from the 2006 shearing and by 7.2 kg from the average live weight at the commencement of the study.

6.3.1.2 Body condition scores

The average body condition scores (BCS) of sheep over the study period are shown in Figure 6.2. These results generally reflect the data for live weights. At the commencement of the study (at shearing in 2005) the average BCS was 2.3±0.5. There were no differences in BCS between the management systems at start of trial (by design), but by the end of the trial BCS of sheep under the RGS (BCS = 1.8) were significantly greater (P<0.05) than those managed under CGS (BCS = 1.6). There were significant (P>0.05) differences between management systems over the study period, apart from shearing 1 and shearing 3, when at the latter sampling there were no differences in BCS for the sheep within CGS.

In 2006, the BCS of the sheep managed within RGS initially decreased (November 2005 to January 2006) by half a condition score (P<0.05) but then steadily increased (P<0.05) to a BCS of 2.5 by May. However, by October shearing in 2006, the BCS of these sheep had decreased to 1.9, a difference of 0.3 from the initial average BSC (P<0.05) measured at the previous shearing. Throughout 2007, the BCS of the RGS sheep did not change (P>0.05), and thus by the end of the trial the sheep had significantly (P<0.05) dropped in condition compared to their initial BCS.

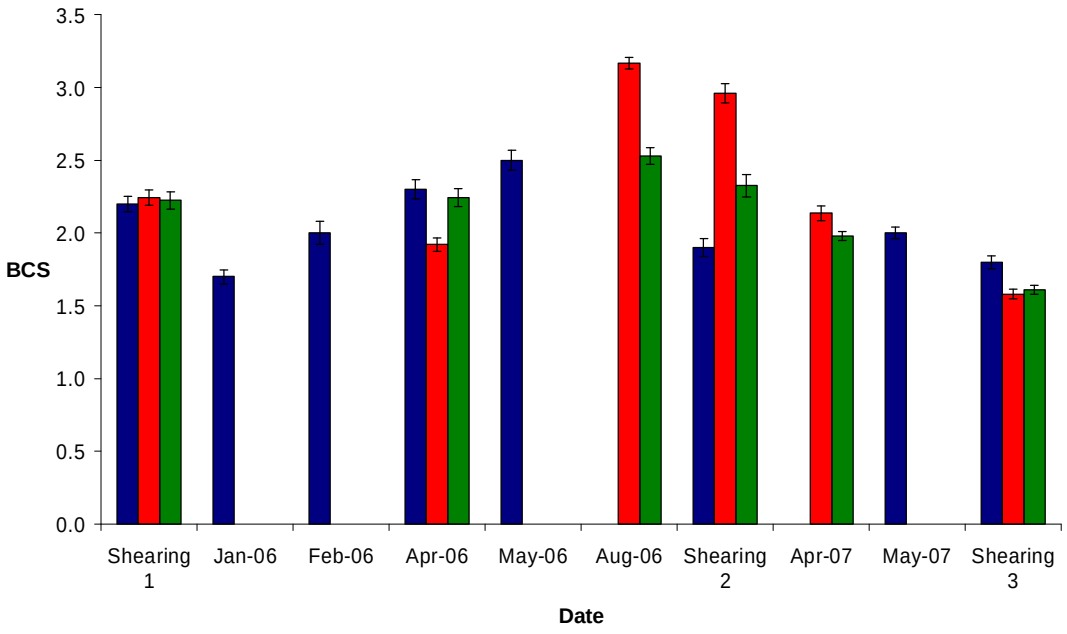


Figure 6.2 Average body condition scores (BCS) of sheep managed under RGS (blue), CGS-G (red) and CGS-P (green) grazing systems from Nov/Dec 2005 (Shearing 1) to Oct/Dec 2007 (Shearing 3).

The sheep managed on CGS-G decreased ($P<0.05$) in condition from 2.2 in December 2005 to 1.9 in April 2006, whilst over the same period the sheep managed on CGS-P had no change in BCS (BCS = 2.2). By August 2006, the sheep within both of the CGS had increased in condition ($P<0.05$) to 3.2 and 2.5 for CGS-G and CGS-P, respectively. However, by shearing in December 2006, the BCS of the sheep managed on both CGS had again decreased (BCS = 3.0 and 2.3). Over 2007, the BCS of the sheep within CGS (-G and -P) continued to decline, with the average BCS being 1.6 at the shearing in October 2007. Therefore, by the end of the study period the sheep in both of the CGS had significantly ($P<0.05$) dropped in condition compared to their initial BCS two years before.

The station of origin of the sheep had a significant ($P<0.001$) effect on BSC for sheep managed on CGS. Sheep sourced from Station 2 and managed on CGS-G, always had significantly ($P<0.05$) greater BCS than sheep sourced from Station 1, except at the first shearing in 2005. Sheep sourced from Station 2 and managed on CGS-P, also had significantly ($P<0.05$) greater BCS than sheep sourced from Station 1. Source (station of origin) had no effect on BSC of sheep management under RGS.

At the end of 2007 the study was terminated on welfare grounds as average BCS condition scores were below 2 for all of the study groups of sheep.

6.3.2 Reproductive status

Sheep on RGS lambed every year between May and August (Table 6.2). Sheep on CGS were mostly dry during 2006, apart from some ewes that joined with several wild rams. Sheep on CGS were joined in 2007; however, lambs were weaned before Shearing 3, therefore the impact of lambing on CGS animal production results cannot be determined.

Table 6.2 Proportion (%) of sheep that were lactating during weighing events on management systems.

Date	RGS	CGS-G	CGS-P
Shearing 1	0	0	0
April 2006	2.5	5.7	7.7
Shearing 2	61.4	13.2	13.6
Shearing 3	44.8		

6.3.3 Wool growth and production

Overall, wool production was superior (P<0.05) in 2006 compared to 2007, with the exception of wool length and yields, which did not vary significantly between years. There was no single management system that consistently did better than the others. The origin of the sheep had a significant effect (P<0.05) on wool length and position of break.

6.3.3.1 Wool production

Average greasy fleece weights (GFW) were significantly (P<0.001) higher in 2006 (5.5 kg) compared to 2007 (4.1 kg). There were also significant (P<0.001) differences between management systems. As shown in Table 6.3, in 2006 sheep managed on CGS-G had significantly (P<0.001) higher GFW (6.3 kg) compared to CGS-P, and the CGS sheep had significantly (P<0.001) higher GFW compared to the RGS sheep. In 2007, the sheep on RGS had higher (P<0.05) GFW compared to CGS sheep.

There were also significant differences between sources of sheep and management systems. In 2006, the sheep sourced from Station 1 had significantly (P<0.002) lower GFW (6.0 kg average) compared to sheep sourced from Station 2 (6.6 kg) on CGS-G. At shearing in 2007, on both RGS and CGS-G, sheep sourced from Station 1 had significantly (P<0.05) lower GFW (4.9 kg and 3.5 kg, respectively) compared to sheep sourced from Station 2 (5.5 kg and 3.9 kg, respectively).

Average clean fleece weights (CFW) were significantly (P<0.001) higher in 2006 (3.6 kg) compared to 2007 (2.7 kg). There were also significant (P<0.001) differences in CFW between management systems in 2006 (Table 6.3). RGS sheep had lower CFW (2.6 kg) compared to the CGS sheep (CGS -G and -P - 4.0 kg) (P<0.001) in 2006. In 2007, however, management system had no effect on CFW. There was a significant difference in CFW between sources of sheep on CGS-G in 2006. The sheep sourced from Station 1 (3.8 kg) had significantly (P<0.002) lower CFW compared to sheep sourced from Station 2 (4.2 kg).

Table 6.3 Average (±SD) greasy (GFW) and clean fleece weight (CFW) (kg) of sheep managed under different grazing systems.

Grazing system	2006		2007	
	GFW	CFW	GFW	CFW
RGS	3.9±0.8[a]	2.6±0.6[a]	5.2±1.2[a]	2.8±0.9
CGS-G	6.3±1.0[b]	4.0±0.6[b]	3.7±0.7[b]	2.7±0.6
CGS-P	5.9±1.0[c]	4.0±0.8[b]	3.7±0.5[b]	2.6±0.5

Values within columns with varying superscripts are significantly (P<0.05) different

6.3.3.2 Wool yields

Average wool yields did not vary overall (P>0.05) between 2006 (66.1%) and 2007 (66.0%). However, as shown in Table 6.4, there were significant (P<0.001) differences in yields between management systems and years. In 2006, yields were highest (P<0.001) for RGS (68.0%), whilst in 2007 yields were higher (P<0.001) for CGS (71.3%). In 2006, average yield for CGS-G (63.8%) was lower (P<0.001) than that from CGS-P (66.9%) and RGS (68%). In 2007, wool yields for RGS sheep (55.6%) was significantly (P<0.001) lower than for CGS sheep (71.3%).

Table 6.4 Average (±SD) wool yields (%) for sheep managed under different grazing systems.

Year	Grazing system		
	RGS	CGS-G	CGS-P
2006	$68.0\pm5.8^{A\,a}$	$63.8\pm5.2^{A\,b}$	$66.9\pm5.2^{A\,a}$
2007	$55.6\pm6.9^{B\,a}$	$71.3\pm6.1^{B\,b}$	$71.3\pm5.8^{B\,b}$

Values within columns (caps) and rows with varying superscripts are significantly (P<0.05) different

The Station of origin of the sheep had no effect (P>0.05) on wool yield, regardless of which grazing system they were subsequently managed under.

6.3.3.3 Wool length

Average wool length did not vary significantly between 2006 (66.1 mm) and 2007 (66.7 mm). However, length varied greatly between individual sheep where the standard deviation of wool length in 2006 and 2007 was 12.1 and 12.5, respectively.

Table 6.5 Average (±SD) wool length (mm) for sheep managed under different grazing systems.

Year	Grazing system		
	RGS	CGS-G	CGS-P
2006	66.3 ± 10.5^{A}	65.7 ± 12.6^{A}	66.4 ± 13.0^{A}
2007	$73.6\pm15.2^{B\,a}$	$61.7\pm8.8^{B\,b}$	$64.6\pm9.7^{B\,b}$

Values within columns (caps) and rows with varying superscripts are significantly (P<0.05) different

As shown in Table 6.5, the sheep managed under RGS grew longer (P<0.001) wool in 2007 compared to 2006. In contrast, sheep managed under CGS grew longer wool (P<0.05) in 2006. Average wool length did not vary significantly between management systems in 2006. In 2007, wool length for sheep managed under RGS was higher (P<0.001) than the length of wool grown by sheep managed under CGS.

The station of origin of the sheep affected wool length, as highlighted in Table 6.6. In 2006, sheep originally sourced from Station 1 performed significantly (P<0.001) better than sheep from Station 2 on the RGS and the CGS-P. In contrast, in 2007 sheep originally sourced from Station 2 performed significantly (P<0.05) better than sheep from Station 1, on RGS and CGS-G.

Table 6.6 Average (±SD) wool length (mm) of sheep originally sourced from Stations 1 and 2 then managed by rotation grazing or continuously stocked on high and low condition paddocks.

Source (Station)	Grazing system					
	RGS		CGS-G		CGS-P	
	2006	2007	2006	2007	2006	2007
1	70.3±8.8^{b}	72.0±17.4^{a}	65.1±14.0	59.5±7.5^{a}	72.1±13.5^{b}	64.2±10.1
2	62.7±10.9^{a}	75.8±11.7^{b}	66.1±11.3	64.5±9.8^{b}	62.5±11.0^{a}	65.0±9.6

Values within columns with varying superscripts are significantly (P<0.05) different

6.3.3.4 Wool strength

Average wool strength was significantly greater (P<0.001) in 2006 (44.9 N/ktex) compared to 2007 (43.0 N/ktex).

As shown in Table 6.7, in 2006, sheep on CGS-P had greater wool strength (P<0.01) than sheep on RGS and CGS-G. The grazing management system had no effect on wool strength in 2007.

Table 6.7 Average (±SD) wool strength (N/ktex) for sheep managed under different grazing systems.

Year	Grazing system		
	RGS	CGS-G	CGS-P
2006	44.2±4.2^{b}	44.3±5.0^{b}	46.0±4.3$^{A\ a}$
2007	43.5±3.9	43.0±4.6	42.6±5.6^{B}

Values within columns (caps) and rows with varying superscripts are significantly (P<0.05) different

The station of origin of the sheep had no effect (P>0.05) effect on wool strength, regardless of which grazing system they were subsequently managed under.

6.3.3.5 Position of break

There was a significant difference (P<0.001) in the average position of break (POB) in wool along the staple between 2006 (at 47.6 mm) and 2007 (at 28.7 mm).
As shown in Table 6.8, there were no significant differences between the years or treatments due to the high standard deviations.

Table 6.8 Average (±SD) position of break along the staple (mm) for sheep managed under different grazing systems.

Year	Grazing system		
	RGS	CGS-G	CGS-P
2006	33.2±25.1	56.0±14.7	52.1±19.5
2007	31.6±21.3	29.3±15.2	25.5±13.5

Values within columns (caps) and rows with varying superscripts are significantly (P<0.05) different

The station of origin of the sheep had no effect (P>0.05) effect on the position of break in the wool, regardless of which grazing system they were subsequently managed under.

6.3.3.6 Average, maximum and minimum fibre diameter

Average fibre diameter was significantly greater (P<0.001) in 2006 (21.1 µm) compared to 2007 (18.0 µm). In 2006, the wool grown by sheep maintained under CGS had significantly (P<0.001) greater fibre diameter than that produced by sheep managed under RGS. In 2007, the opposite occurred with sheep managed under RGS having significantly greater (P<0.001) fibre diameter than sheep maintained under CGS (Table 6.9). The station of origin of the sheep had no effect (P>0.05) on the average fibre diameter among the different grazing management systems.

Table 6.9 Average (±SD) fibre diameter (µm) for sheep managed under different grazing systems.

Year	Grazing system		
	RGS	CGS-G	CGS-P
2006	$20.4\pm1.6^{A\,a}$	$21.6\pm1.7^{A\,b}$	$21.2\pm1.6^{A\,b}$
2007	$19.3\pm1.5^{B\,a}$	$17.6\pm1.4^{B\,b}$	$17.2\pm1.1^{B\,b}$

Values within columns (caps) and rows with varying superscripts are significantly (P<0.05) different

The maximum fibre diameter along the staple was significantly (P<0.001) greater in 2006 (22.6 µm) compared to 2007 (20.0 µm). In 2006, sheep managed on CGS-G had a significantly (P< 0.001) higher maximum fibre diameter along the staple than sheep on CGS-P and RGS. In 2007, sheep on RGS had a significantly (P<0.001) higher maximum fibre diameter along the staple than sheep on CGS (Table 6.10). There were no significant differences between original sources of sheep within the different grazing management systems.

Table 6.10 Average (±SD) maximum fibre diameter (µm) along the staple for sheep managed under different grazing systems.

Year	Grazing system		
	RGS	CGS-G	CGS-P
2006	22.1 ± 1.8^{a}	$23.2\pm2.0^{A\,b}$	$22.6\pm1.8^{A\,a}$
2007	21.0 ± 1.6^{a}	$19.7\pm1.8^{B\,b}$	$19.4\pm1.4^{B\,b}$

Values within columns (caps) and rows with varying superscripts are significantly (P<0.05) different

There was a significant (P<0.001) difference in the minimum fibre diameter along the staple in 2006 (18.9 µm) and 2007 (16.3 µm).

As shown in Table 6.11, in 2006 sheep on RGS had a significantly (P<0.001) lower minimum fibre diameter along the staple compared to sheep on CGS. In 2007, sheep on RGS had a significantly (P<0.001) higher minimum fibre diameter along

the staple compared sheep on CGS. Station of origin of the sheep had no effect on the minimum fibre diameter along the staple.

Table 6.11 Average (±SD) minimum fibre diameter (µm) for sheep managed under different grazing systems.

Year	Grazing system		
	RGS	CGS-G	CGS-P
2006	18.3±1.6[a]	19.1±1.8[b]	19.2±1.6[b]
2007	17.2±1.5[b]	16.0±1.4[a]	15.7±1.2[a]

Values within rows with varying superscripts are significantly (P<0.05) different

6.3.3.7 Variations in fibre diameter along the staple

Fibre diameter was measured every 5 mm along the staple from the most recent wool growth, when samples were collected, to the previous shearing event per year. Sample sizes for fibre diameter from 70 mm onwards were too small to statistically test accurately. At all measurement sites, fibre diameter was greater (P<0.001) in 2006 compared to 2007 (Table 6.12).

Table 6.12 Comparison of average (±SD) fibre diameter (µm) along the staple (mm) in 2006 and 2007.

Length along staple (mm)	2006	2007
5	21.6±2.3^{b}	19.0±2.0^{a}
10	21.6±2.3^{b}	18.5±2.1^{a}
15	21.6±2.2^{b}	17.9±2.1^{a}
20	21.6±2.2^{b}	17.5±1.9^{a}
25	21.7±2.1^{b}	17.3±1.9^{a}
30	21.7±2.0^{b}	17.4±1.8^{a}
35	21.6±1.9^{b}	17.7±1.8^{a}
40	21.5±1.9^{b}	17.9±1.9^{a}
45	21.2±1.9^{b}	18.1±2.0^{a}
50	20.8±1.9^{b}	18.2±2.0^{a}
55	20.6±1.9^{b}	18.4±1.9^{a}
60	20.3±1.9^{b}	18.6±1.9^{a}
65	20.1±1.8^{b}	18.4±1.7^{a}

Values within rows with varying superscripts are significantly ($P<0.05$) different

As shown in Figure 6.3, in 2006 at 5 – 15 mm along the staple, in the period shortly before shearing, fibre diameter varied significantly ($P<0.001$) between the grazing management systems. At 20 – 30 mm, representing the earlier period, approximately mid-winter to spring, sheep maintained under RGS had significantly ($P<0.001$) smaller fibre diameter compared to sheep maintained under CGS management. At 35 mm, during late autumn to early winter, sheep on RGS had significantly ($P<0.05$) finer fibre diameter than sheep maintained on CGS-G. From 35 – 65 mm along the staple, that is, during summer immediately after shearing and into autumn, there was no difference ($P>0.05$) in fibre diameter between the different grazing management systems.

In 2007, the sheep managed under RGS had significantly ($P<0.001$) thicker fibre diameter than sheep managed under CGS, generally. At 15 – 25 mm and again at 65 mm along the staple, sheep maintained on CGS-G had greater ($P<0.001$) fibre diameter than those maintained on CGS-P.

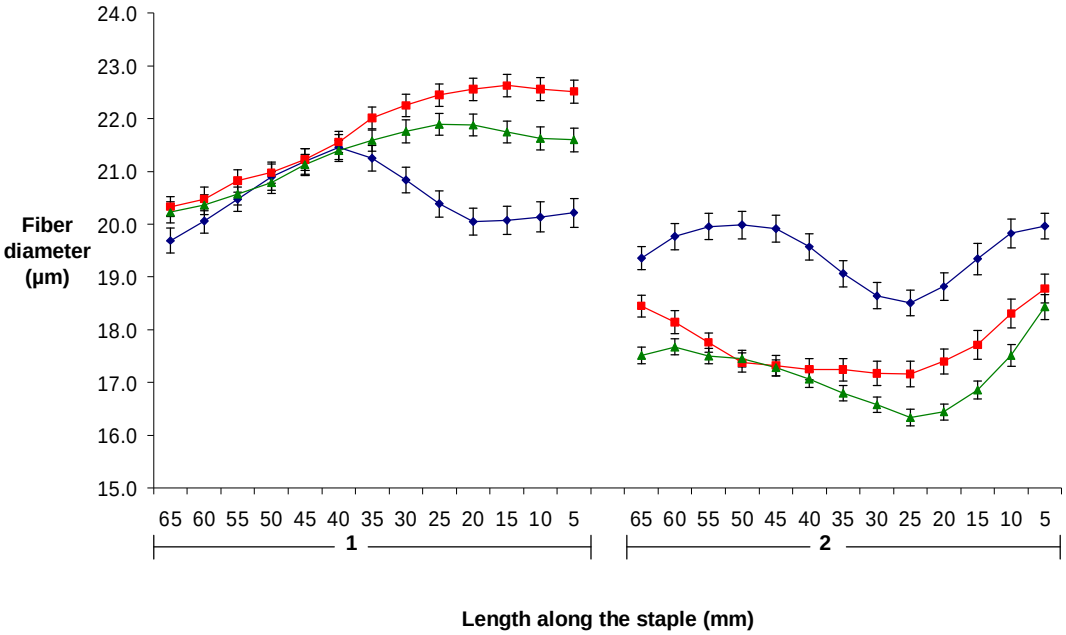


Figure 6.3 Comparison of average fibre diameter sheep managed under RGS (blue), CGS-G (red) and CGS-P (green) grazing systems. Section 1 is wool growth from shearing in 2005 (65 mm) to shearing in 2006 (5 mm). Section 2 is wool growth from shearing 2006 (65 mm) to shearing in 2007 (5 mm).

The station of origin of the sheep had no effect on fibre diameter, except at 60 mm (2006) along the staple for the sheep on RGS: the sheep sourced from Station 1 (19.3 µm) had finer wool ($P<0.05$) than sheep sourced from Station 2 (20.5 µm).

6.3.3.8 Fibre diameter variability along the staple

A comparison of wool results with above average (High) and below average (Low) variability in fibre diameter along the staple is presented in Table 6.13

In general, sheep on all grazing systems with low variability in fibre diameter along the staple had significantly ($P<0.05$) stronger wool and lower maximum fibre diameter. Additionally, sheep from CGS-G had higher ($P<0.05$) yields and lower ($P<0.001$) average fibre diameter.

Table 6.13 The effects of high and low variability along the fibre on average (mean±SD) wool parameters for grazing systems.

Wool Parameter	RGS		CGS-G		CGS-P	
	High	Low	High	Low	High	Low
Yield	60.6±8.7[a]	59.8±8.9[a]	64.1±7.1	69.6±7.2[b]	69.6±6.3[b]	68.5±5.4[b]
Length	71.3±15.3[b]	65.6±17.5[a]	63.8±10.7[a]	58.0±13.7[a]	63.8±9.0[a]	63.9±9.1[a]
Strength	38.9±2.3[a]	50.3±1.5[b]	37.2±2.9[a]	49.6±2.2[b]	36.8±3.4[a]	49.4±2.5[b]
Position of Break	26.6±21.6	29.7±21.7	49.0±16.9	34.4±19.4	39.0±16.3	37.0±20.9
Average FD	20.5±1.7	19.9±1.5	21.4±2.1[a]	18.7±2.3[b]	19.6±2.9	18.7±2.3[b]
Min FD	17.5±1.7	18.9±1.6	18.0±1.8	17.7±2.3	16.7±2.4	17.8±2.1
Max FD	22.7±1.8[a]	20.9±1.4[b]	23.8±2.0[a]	19.9±2.2[b]	22.4±2.5[a]	20.0±2.1

Values within rows with varying superscripts are significantly ($P<0.05$) different

When variability in fibre diameter along the staple was high, yield, average fibre diameter and POB were significantly ($P<0.001$) different between management systems. RGS had significantly greater length ($P<0.05$) than CGS-G and CGS-P. Strength was significantly ($P<0.05$) greater on RGS compared to CGS. Maximum fibre diameter was higher ($P<0.05$) on CGS-G compared to CGS-P and RGS.

In 2006, 14.7% of sheep on RGS had high variability in fibre diameter along the staple, and 12.0% sheep had low variability. There was 22.0% of sheep on CGS-G that had high variability, and 14.6% that had low variability. On CGS-P, there was 16.4% of sheep with high variability, and 23.3% with low variability. In 2007, 29.8% of sheep on RGS had high variability in fibre diameter along the staple, and 14.0% had low variability. On CGS-G, 12.3% of sheep had high variability, and 26.3% sheep had low variability. On CGS-P, 19.7% of sheep had high variability in fibre diameter along the staple, and 31.8% had low variability.

6.4 Discussion

6.4.1 Live weights and body condition scores

There was no grazing management system that consistently out-performed the others. However, sheep on CGS-G generally performed better than those on CGS-P suggesting that range condition influenced sheep performance. Similarly, Holm *et al.* (1991) found that sheep wool growth was adversely affected on a poor condition (low density of shrubs) site when herbage mass fell below 40kg/ha and on a good condition (high density of shrubs) site when it fell below 60kg/ha at Boolathana station, WA.

It seemed that both climate and management system affected live weights and BCS during the study. Climate seemed to be a dominating influence in 2006 with significant rainfall events, while management system was the dominant influence on animal production in 2007 when rainfall was low. Yan *et al.* (1996) found that seasonal conditions had a dominant effect on plant dynamics compared to management in years when rainfall was average to above average.

The increasing live weights and BCS of sheep for all grazing systems in 2006 were likely a response to high summer rainfall and consequent increase in plant photosynthetic activity (Fig 6.5 and 6.6). Vegetation growth, as reflected in NDVI, sustained sheep live weights and BCS by two to three months after rainfall dropped (May) and NDVI began to decline (June). Livestock responses to environmental changes are less sensitive than vegetation responses (Wilson *et al.* 1984b).

Management may also have affected live weights and BCS in 2006 (Fig 6.7). CGS did not join their sheep, which may have resulted in their higher average live weights and BCS by shearing time in December 2006, compared to RGS. Nutritional demands on ewes from the foetus and lamb are high during pregnancy and lactation. Net requirements for the growth of a foetus increases exponentially during gestation (McDonald *et al.* 2002). When a ewe faces periods of low feed nutrition and/or intake, her reserves will be used to meet the needs of the foetus (McDonald *et al.* 2002), although live weight may not change during pregnancy due to the increasing weight of the foetus. During lactation, energy demands increase further (Figure 6.4). Brand *et al.* (1999) found that sheep at high stocking rates eating wheat stubble required supplementary feed to meet energy and protein demands during pregnancy and lactation. Ewe live weights will decrease during lactation if there is insufficient supply of nutrients to meet lactation requirements as the animal exploits body reserves to compensate (National Academy Press 1985).

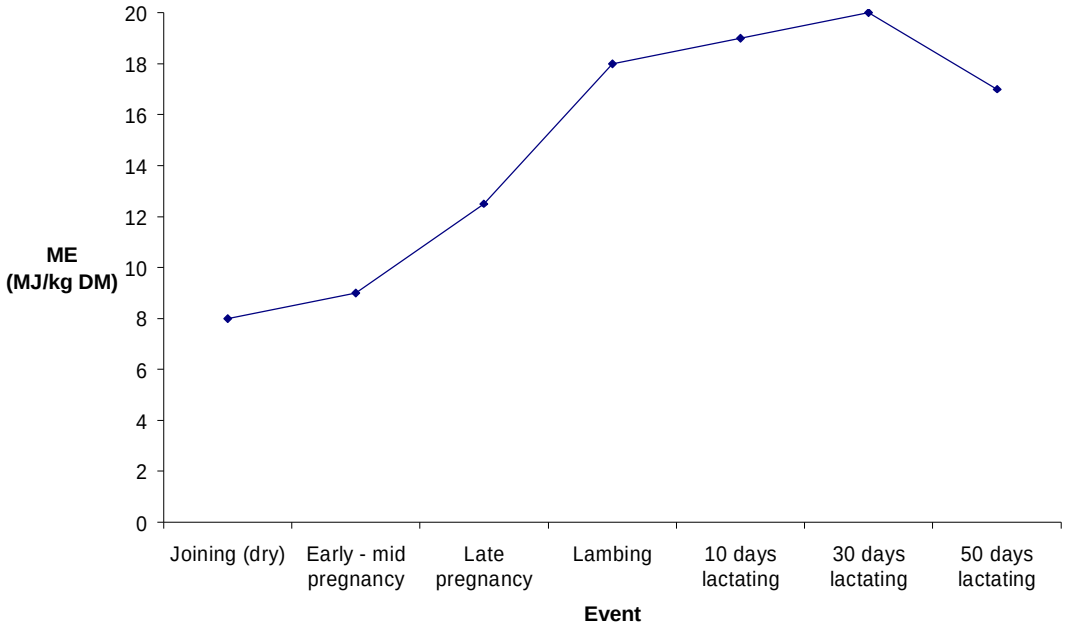


Figure 6.4 General energy requirements of 50kg ewes with single lambs during dry conditions (Curnow 2008).

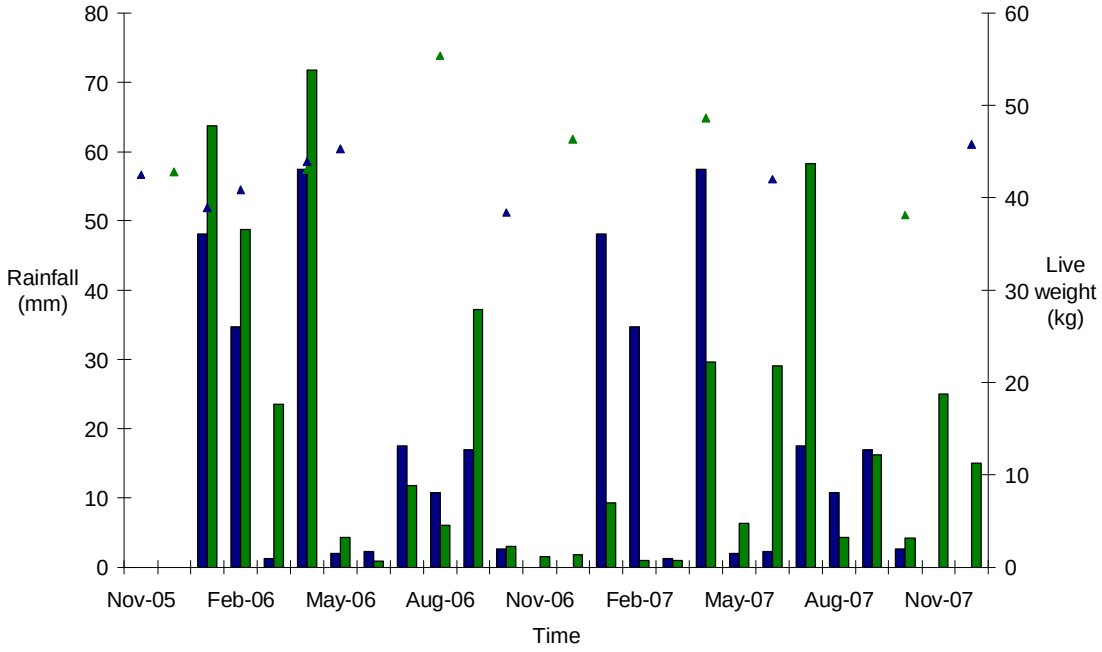


Figure 6.5 Rainfall (bars) and live weights (triangles) in 2006 and 2007 for RGS (blue) and CGS (green).

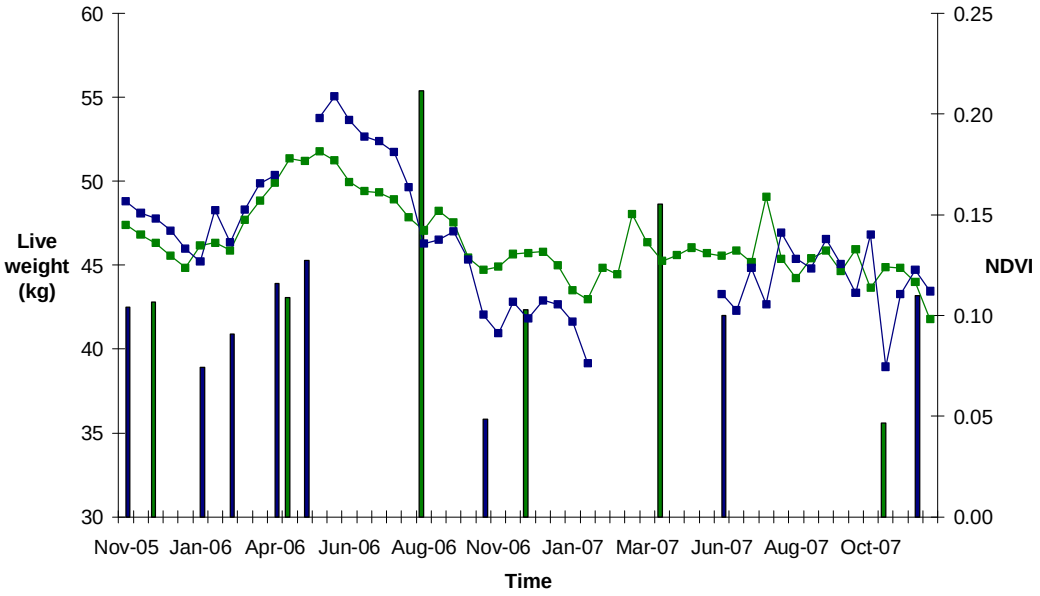


Figure 6.6 Live weights and NDVI (squares) in 2006 and 2007 for RGS (blue) and CGS (green).

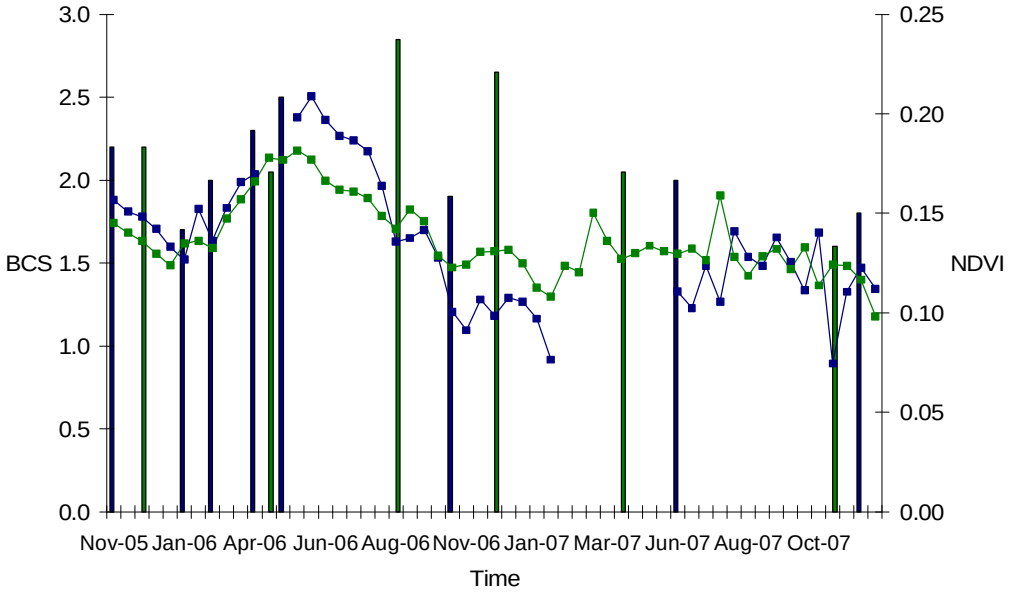


Figure 6.7 Body condition scores and NDVI (triangles) in 2006 and 2007 for RGS (blue) and CGS (green).

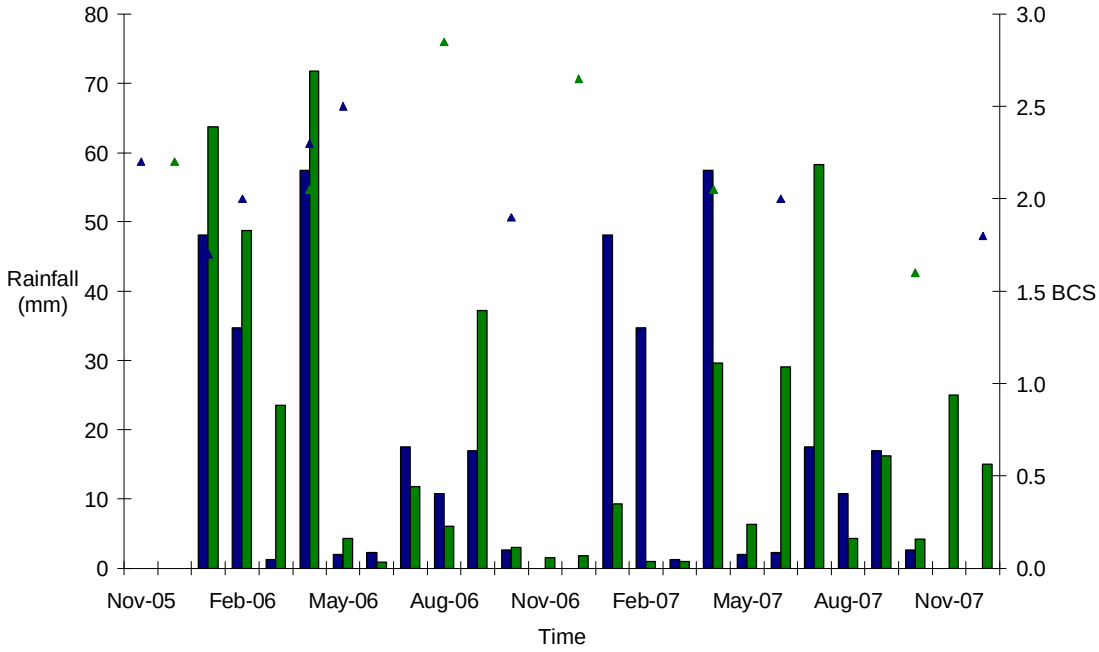


Figure 6.8 Rainfall (bars) and body condition scores (BCS) (triangles) in 2006 and 2007 for RGS (blue) and CGS (green).

Live weights and BCS of sheep on CGS declined steadily due to the drought (6.7 and 6.8). The effect of the drought on the performance of the sheep in RGS was confounded somewhat by the agistment of the sheep off-station, which resulted in an increase in their live weights due to improvements in agistment feed supply.

It is unclear if stocking rates affected results for RGS (Station 1), where the sheep were periodically moved into new paddocks of different sizes. The drought may have reduced the quality and/or quantity of feed in all paddocks whether they were stocked or un-stocked, therefore movement of sheep into un-grazed paddocks may not have had a beneficial effect. In a concurrent study looking at changes in perennial grasses on un-grazed paddocks, on Station 1 it was found that on one paddock the percentage of grasses increased, while they decreased on the other paddock between 2005 and 2007. The reduction in grasses was much greater in the grazed paddocks on Station 2 (M. Alchin, unpublished data, Curtin University of Technology).

Other grazing animals like kangaroos and goats were not accounted for in this study, but may have also affected feed availability in some paddocks. Kangaroos generally don't graze the same paddocks as sheep (Landsberg & Stol 1996), and prefer grass diets (Griffiths *et al.* 1974). Goats generally consume more of a browse diet than sheep (Papachristou *et al.* 2005; Rogosic *et al.* 2006). However, there is some overlap in grazing diets of sheep, goats and kangaroos, usually in summer when feed availability is lowest, which can result in increased total grazing pressure on the land (Fletcher 1991; Landsberg & Stol 1996). Goats were annually trapped and kangaroos were occasionally observed within each of the different grazing management systems, indicating that sheep, kangaroos and goats were grazing the paddocks concurrently. Goat and kangaroo populations were not monitored during this study therefore any differences in the extent of their grazing pressures on the grazing systems are unknown.

There appears to be a genetic difference between the sources of sheep, where sheep originally sourced from Station 2 had consistently greater live weights than sheep sourced from Station 1, on all paddocks. This suggests that Station 2's sheep were genetically superior in terms of live weight. Station 2 has been selecting sheep based on visual assessment of wool quality and animal body structure for many years, whereas Station 1 had in recent years purchased sheep from neighbouring wheatbelt producers, as part of their re-stocking program. Therefore genetic selection is more advanced on Station 2 compared to Station 1, which may have contributed to the differences in live weights.

Longer-term adaptation to the specific environment may have also contributed to the live weight differences between management systems. The sheep at CGS have been grazing rangelands for generations, whereas the sheep from RGS were brought in from a wheatbelt environment. Studies have found that sheep grazing preferences are learned at a young age from imitating adults grazing, and experiencing the taste and post-ingestive feedback of plants (Burritt & Provenza 1990; Provenza 1995b; Baraza *et al.* 2005; Papachristou *et al.* 2005). Sheep also learn about foods in the womb and during lactation as flavours are transferred from

the mother (Nolte & Provenza 1992; Nolte *et al.* 1992). As the sheep on CGS have been grazing the Yalgoo paddocks for generations, it is likely they are better adapted to the rangeland diet compared to the RGS sheep, which would have to learn by taste and post-ingestive feedback as to which plants are more nutritious and beneficial than others.

6.4.2 Wool production and growth

In general, wool characteristics were superior in 2006 compared to 2007. As was the case with live weights and BCS, results seemed to reflect both the deterioration in climate and management differences.

In 2006, average GFW production of sheep on CGS (CGS-G – 6.3 kg; CGS-P – 5.9 kg) was higher than GFW produced by the best station (5.1 kg) in benchmarks determined by O'Connor (2001) over 15 years (1985-2000). While average GFW production of sheep on RGS (3.9 kg) was lower than the worst station (4.5 kg) benchmark. In 2007, the opposite occurred with RGS producing a high average GFW (5.2 kg) while CGS produced low GFW's (Both CGS-G and CGS-P produced 3.7 kg). The benchmarks determined by O'Connor (2001) showed little difference between the average (4.6 kg), best (5.5 kg) and worst (4.5 kg) station GFW production over 15 years for stations throughout the arid shrublands including groups from the Murchison, Gascoyne, Paynes Find and Yalgoo. However, the results from this study show how variable wool production can be between years. Average clean fleece weights (3.6 kg in 2006; 2.7 kg in 2007) were similar to sheep studied at Boolathana Station, Western Australia, which produced 2.5 – 3.5 kg between 1989 to 1993 (Holm *et al.* 2005).

As shown in Figures 6.9 and 6.10, changes in average fibre diameter along the staple are related to NDVI and rainfall. For all of the study sites the NDVI increased from January - July 2006, and there was high rainfall during January, February and April 2006, although NDVI and rainfall for CGS were greater than for RGS. Wool growth seems to respond to the high rainfall and increasing NDVI as FD increased from January - April for RGS, and January - October for CGS. The longer response

for CGS may have been due to the higher rainfall and NDVI, although the drop in fibre diameter for sheep for RSG may have also been due to lambing; CGS did not join the ewes in 2006. Morrissey (1973) studied ewes grazing the mulga zone in WA also found that wool production was closely associated with rainfall during the wool growth period.

The relationship between wool fibre diameter, rainfall and NDVI reflect the feed quality and quantity available to the sheep. Studies have found that nutrition affects clean fleece weight, wool growth rates, staple strength, position of breaks, average and minimum fibre diameter and staple length (Hyder *et al.* 2002; Friend & Robards 2006).

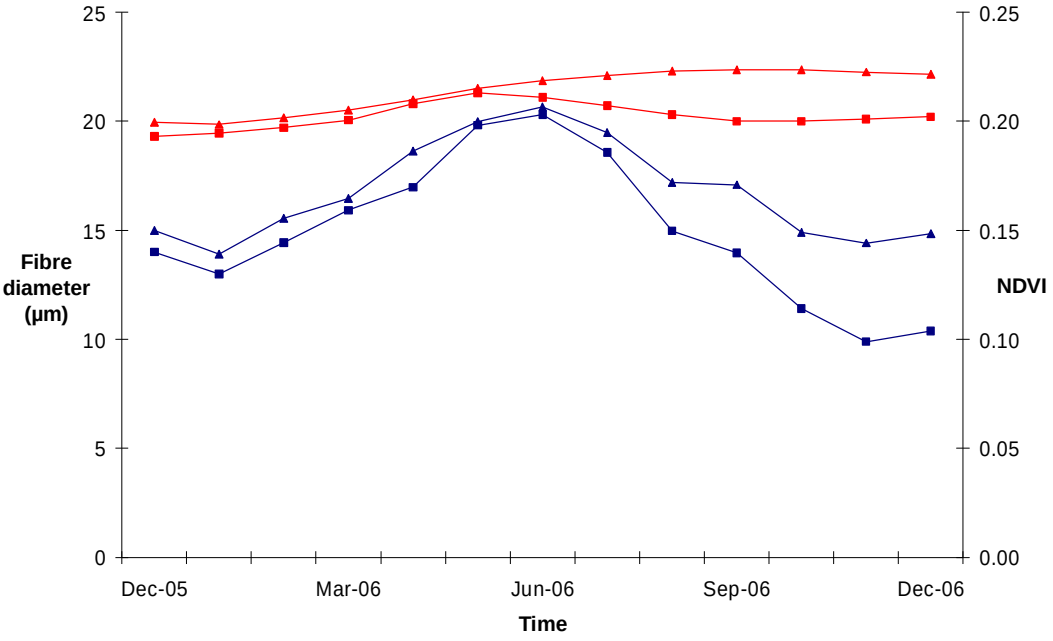


Figure 6.9 Average wool fibre diameter (red) and NDVI (blue) in 2006 for RGS (squares) and CGS (triangles).

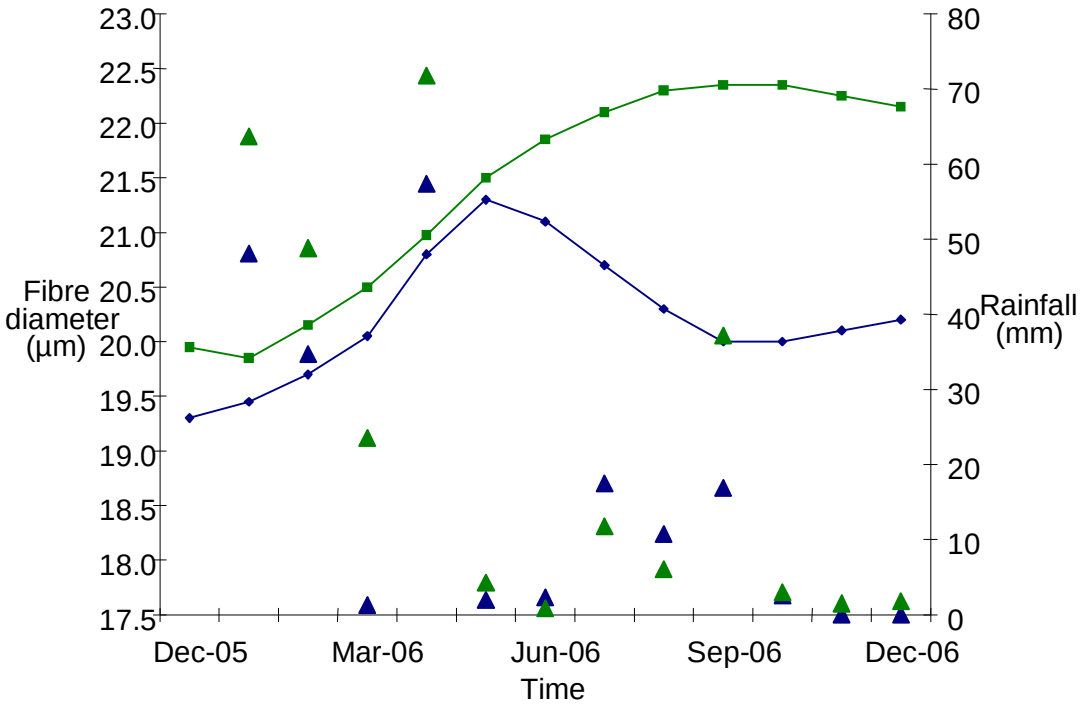


Figure 6.10 Average wool fibre diameter (line) growth and total monthly rainfall (triangles) in 2006 for RGS (blue) and CGS (green).

There was high variability in wool characteristics between individual sheep. This is probably due to independent behaviour of individual sheep selectively grazing the large choice of feed found in rangelands. Variability in fibre diameter along the staple affected wool yields, length, strength, average fibre diameter and maximum and minimum fibre diameter.

6.4.2.1 Wool yields

It seems sheep that had better nutrition produced wool with lower yields. In 2006 sheep on CGS-G had higher fibre diameter than CGS-P and RGS, indicating a higher plane of nutrition, yet CGS-G had the lowest yields. Similarly, during 2007, sheep on RGS had the highest fibre diameter, but the lowest yields compared to CGS.

The negative relationship between nutrition and wool yields seen in this study may have been caused by the wax and suint content. Wax and suint content in wool is affected by nutrition and in general, as nutrition increases, wax, suint and clean fleece fibres increase simultaneously resulting in no change in yield (Hynd & Masters (2002). However, the low yields in this study suggest that as nutrition increases, wax, suint and clean fleece fibres increased at different rates. Research by NSW Department of Primary Industries found that wool with high clean fleece weight (CFW) had more wax, less suint and less dust content compared to low CFW sheep, although the magnitude of the difference varied between years (Adams *et al.* 2006). It was also found that FD and live weight did not have a significant relationship to yield. A study by Graetz (1980) found that fleece yields were lower in sheep grazing saltbush pastures, compared to bluebush and grassland pastures in Australian rangelands. This suggests that the type of pasture also affect wool yields. However, the pastures grazed by sheep in this study were so varied within paddocks it is not possible to establish if this was an influence.

6.4.2.2 Wool length

Wool length varied highly between individuals with standard deviations (SD) ranging 10.6 - 13.0 mm in 2006 and 8.9 - 15.2 mm in 2007. High variation in wool length and growth between individual sheep has also been found in previous studies (Downes 1971; Reis 1992; Graetz 1980).

Wool length did not vary significantly between years or between management systems in 2006. However, there was a difference between grazing systems in 2007, where sheep from RGS grew longer wool compared to CGS. This difference in 2007 was most likely caused by the management differences resulting in significant differences in the quality of available feed. The sheep from RGS were agisted onto a failed wheat crop, which contained high energy wheat seeds (Table 5.9) and this higher quality diet would likely have resulted in greater wool growth.

6.4.2.3 Wool strength

Average wool strength for all sheep over the study period was very high. Strength of 35 N/ktex is acceptable for markets while 40N/ktex can fetch premium prices when combined with low fibre diameter (AWIb 2008). Sheep studied at Boolathana Station, Western Australia during 1989 – 1993 had average wool strengths of 20 – 35N/ktex (Holm *et al.* 2005).

The stronger wool produced in 2006 was likely due to the better seasonal conditions early in the year, which coincided with higher fibre diameter in 2006 compared to 2007 (Figure 6.10). The stronger wool of sheep from CGS-P in 2006 is likely to be due to the lesser variation in fibre diameter along the staple (compared to CGS-G and RGS). Sheep with low variability in fibre diameter along the staple had stronger wool (Table 6.14). Increased variability in fibre diameter along the staple typically reduces staple strength (Brown & Crook 2005; Friend & Robards 2006)

6.4.2.4 Position of break

Positions of break along staples are influenced by season and often occur at the break of season (Rowe *et al.* 1989; Doyle *et al.* 1995). The POB on CGS in 2006 occurred when fibre diameter was increasing, most likely in response to the high summer rainfall, which increased the level of nutrition. On RGS, the POB occurred when fibre diameter along the staple was decreasing, most likely in response to nutritional stresses of lambing. In 2007, the POB for all grazing systems occurred when fibre diameter was at its lowest point for the year (RGS 18.4 µm at 60 mm along the staple, CGS-G 17.1 µm at 55 mm along the staple, CGS-P 16.3 µm at 60 mm along the staple). This may have been a response to deteriorating nutrition.

Unfortunately, dye-banding during 2006 and 2007 was not 100% effective (see Chapter 6.4.2.7) and therefore it is difficult to determine the time of year that breaks in wool occurred and consequently the likely source of the breaks. The inefficient dye-bands may have caused high variability (SD 14.0 - 25.6 in 2006 and 15.1 - 21.3 in 2007) in POB among individual sheep.

Wool markets tend to prefer POB to be low, i.e. closer to the skin, as it results in long fibres with little loss during processing (AWI 2008c). Therefore, the wool from all management systems where breaks occur at mid length or towards the tips would not fetch premium prices in markets.

6.4.2.5 Fibre diameter

Fibre diameter parameters of average, maximum, minimum and change along the staple were likely to be influenced by climate and management. Fibre diameter was superior in 2006 (21.1 µm) compared to 2007 (18.0 µm), due to drier weather and thus reduced feed quantity and quality in 2007 compared to 2006 (see Chapter 4.3.1). Average fibre diameters were lower than those reported by Holm *et al.* (2005) (23 – 24 µm during 1989 – 1993).

In terms of fibre diameter along the staple, sheep from CGS had increasing fibre diameters, while sheep from RGS had decreasing fibre diameter along the staple from around April to shearing in 2006 (Fig 6.3). The differences are most likely caused by the factors that also affected live weights and BCS. These included response to summer rainfall, few ewe pregnancies on CGS, and possibly stocking rates.

In 2007, management appeared to have a strong effect on fibre diameter. It seems the sheep on RGS significantly benefited from agistment on the failed wheat crop resulting in higher average, maximum and minimum fibre diameter. The decrease in fibre diameter along the staple of these sheep between 35 mm and 25 mm (Fig 6.3) may be a reflection of the steady deterioration in the quantity and quality of the wheat stubble. The following increase between 25 mm and 10 mm (Fig 6.3) likely reflects the movement of the sheep back onto the station during cooler winter months with additional supplementary feeding provided. The decision to maintain stock within CGS all year seems to have contributed to the continuous decrease in fibre diameter. In terms of fibre diameter along the staple, the increase between 25 mm and 5 mm may be explained by cooler temperatures and some rainfall during winter. Unfortunately these observations cannot be supported with statistical results

as there were many influential factors that may have affected the results and as dye-banding was ineffective in 2007, changes in fibre diameter along the staple cannot be accurately correlated with time.

Average fibre diameter of ≤19.5 µm is considered fine and can fetch premium prices on wool markets (AWI 2008a). In 2007, RGS and CGS produced wool with average fibre diameters of 17.2 - 19.3 µm, and combined with the high strength (>40N/ktex) the wool would have fetched premium prices. All sheep in 2006 had average fibre diameters of >20 µm.

The drop in fibre diameter between end growth in 2006 and new growth after shearing (Fig 6.3) may have been a result of changes to skin follicles during the dry periods. Nutrition alters the size of follicle bulbs, the size and number of cells in the germinative region of bulbs, the rate of cell division in the bulbs, and the size of cortical cells (Lyne 1964; Hynd 1994; Hynd & Masters 2002). Schlink *et al.* (1996) found that wool follicle bulb diameter and dermal papilla length significantly decreased during summer and autumn, which reflected the seasonal nature of wool growth. In this study, the wool follicle bulb diameter and dermal papilla may have also decreased during the summer months. Shearing at RGS occurred in spring (October 2006), and as shown in Figure 6.3, the difference in fibre diameter between the end of section 1 and the beginning of section 2 was small. In contrast, the difference between the end of section 1 and the beginning of section 2 on CGS was large, possibly corresponding to the summer shearing (December 2006) and its effects on wool follicles.

6.4.2.6 Effectiveness of dye-banding

Dye-band application was straight-forward; however, there was difficulty in subsequently finding these dye-bands. In 2006, renewed dye-bands were required for 30 - 35% of the RGS sheep and 4.5 - 8% of the CGS sheep. Additionally, occasionally too much dye was applied to the sheep which burned the wool in the position of the dye. In 2007, all dye-bands failed and it is suspected this was due to the brand of hair dye used. Consequently, wool results could not be aligned with

time of year and therefore causes of wool changes could not be determined with any confidence.

The wool analysis complemented live weight and BSC monitoring. Despite the limitations associated with the poor dye-bands, wool analysis was an effective technique for measuring sheep responses to nutrition in the rangelands.

6.5 Conclusion

Sheep live weights, BCS and wool characteristics were influenced by climate and grazing management during this study, which inherently affected FOO. Therefore it should be possible to enhance the effects of good climatic conditions and minimise the effects of bad climatic conditions through appropriate management. The decisions on CGS (Station 2) to reduce stocking rates and avoid joining in 2006 resulted in higher live weights, BCS and superior wool characteristics. Supplementary feeding ewes toward the end of the 2006, August to December, on RGS (Station 1) assisted animals through lactation. In 2007, the decision to remove the sheep from RGS and agist them onto a failed wheat crop resulted in higher live weights, better wool and steady BCS. Overall, reducing stocking rates (Graetz 1980), delayed joining (Hawker & Kennedy 1978), supplementary feeding (O'Reagain & McMeniman 2002) and agistment are all management decisions that minimise the effects of drought on sheep.

Although there seemed to be some effects of the source of the sheep on production parameters, other researchers have found that genotypic differences in sheep do not affect the overall response of sheep to changing nutrition (Hyder *et al.* 2002; Friend & Robards 2006).

7 Assessment of sheep diets based on faecal analyses

7.1 Introduction

Faecal analyses are effective methods for compiling information about the diets of animals. Sample collections are easy and fast to carry out and unlimited in the number of samples collected, which is ideal for vast rangeland environments. This study used two of the newer technologies for faecal analysis of animal diets; DNA fingerprinting and Near Infrared Reflectance Spectroscopy (NIRS) to indicate diet composition and diet quality.

These technologies have increased the amount of information that can be estimated from faecal analyses, although reduced accuracy is still a weakness compared to more invasive methods (Mburuja *et al.* 1995; Morin *et al.* 2001; Wilson *et al.* 2003; Boval *et al.* 2004; Lundberg 2004).

7.2 Materials and methods

7.2.1 DNA fingerprinting

Unique primers were identified for 18 plant species (Table 3.1) that were provided from this study and a similar study in Kalgoorlie. Sheep faecal samples were then examined for the presence of the plant primers, indicating when and where these plants were consumed.

The procedures used in the plant and faecal DNA analysis are described in Chapter 3, Sections 3.6 and 3.6.2.

7.2.2 NIRS

The methodology associated with faecal NIRS analysis is described in Chapter 3, Sections 3.5.2, 3.5.7 and 3.5.8. Data from controlled studies involving grasses, salt-

containing and tannin-containing browse species (K. Mahipala, PhD student, Curtin University of Technology) was used to develop universal NIRS calibration equations to predict dietary intake of ME, CP, total tannins (TT), and total phenolics (TP) and OMD of diets. These equations were then applied to the faecal NIRS data obtained from this study to determine the quality of the diets, over time, of the sheep within the three grazing management systems: RGS, CGS-G, and CSG-P.

Differences between management systems and months were analysed in an unbalanced ANOVA, using Genstat.

7.3 Results

7.3.1 Plant DNA fingerprint detection in faecal samples

The plants that were detected in faecal samples during 2006 and 2007 are listed in Table 7.1. Of the 23 plants for which DNA primers had been developed, 13 were detected in the sheep faecal samples over the duration of the study.

Table 7.1 Plant species detected in sheep faecal samples.

Identification number	Species
0	No DNA detected (PCR negative)
1	*Acacia saligna*
2	*Aristida contorta*
3	*Atriplex* spp.
4	*Enchylaena tomentosa*
5	*Eremophila forrestii*
6	*Enneapogon caerulescens*
7	*Frankenia* sp.
8	*Maireana* spp.
9	*Ptilotus obovatus*
10	*Rhagodia eremaea*
11	*Scaevola spinescens*
12	*Solanum lasiophyllum*
13	*Austrostipa elegantissima*
14	Unmatched

In 2006, eight different plant species were detected; with *Rhagodia eremaea* the most commonly identified species. However, it was found throughout the year only in faeces from RGS (Table 7.2). There were two faecal samples that were PCR negative. Twenty eight of the amplified 'bands' (DNA fingerprints) from the faecal samples did not conclusively match any of the plant species in the reference base.

Table 7.2 Plant DNA detected in sheep faecal samples collected in 2006 from RGS, CGS-G and CGS-P.

Month	System	Frequency														
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jan	RGS											1				3
	CGS-G															
	CGS-P															
Feb	RGS				1							1				1
	CGS-G			1									1			3
	CGS-P				1											1
Apr	RGS											3				2
	CGS-G															1
	CGS-P			1												
May	RGS										1		1			3
	CGS-G															2
	CGS-P			1					1							
Jun	RGS	2			1	1			1			1	1			4
	CGS-G															
	CGS-P															
Aug	RGS															
	CGS-G															3
	CGS-P		1													1
Oct	RGS											1				
	CGS-G															
	CGS-P															
Dec	RGS															
	CGS-G															2
	CGS-P		1						1		1					2

Refer to Table 7.1 for species identity corresponding to grazing systems

In 2007, 11 plant species were detected throughout the year. *Frankenia* spp. was the most commonly identified followed by *Rhagodia eremaea* (Table 7.3). There were three faecal samples that were PCR negative. Fifty one of the amplified 'bands' (DNA fingerprints) from the faecal samples did not conclusively match any of the plant species in the reference base.

Table 7.3 Plant DNA detected in sheep faecal samples collected in 2007 from RGS, CGS-G and CGS-P.

Month	System	Frequency														
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	RGS															
May	CGS-G			1					1					1		3
	CGS-P								1							2
	RGS	1						1								3
Jun	CGS-G															
	CGS-P															
	RGS	1		1	3				3			1				5
Jul	CGS-G		1				2		2							3
	CGS-P															1
	RGS															
Aug	CGS-G				2				2							7
	CGS-P						1					1				1
	RGS		1	1	3				3							5
Sep	CGS-G								1			1				5
	CGS-P								1	1						1
	RGS								1			1			1	4
Oct	CGS-G	1			1		1	2	3		2	1				4
	CGS-P							2	2							7
	RGS		1		1				1			1				
Dec	CGS-G															
	CGS-P															

Refer to Table 7.1 for species identity corresponding to grazing systems

7.3.2 NIRS Dietary Analysis from Faecal Samples

The effect of season and grazing management on CP, ME and OMD is shown in Figures 7.1, 7.2 and 7.3, respectively. Differences between grazing systems within months were insignificant for OMD, ME and CP. There was a significant (P = 0.03) difference in average ME between grazing systems (RGS = 9.2%, CGS-G = 8.6%, CGS-P = 8.2%).

Dietary CP content generally increased over the study period for the grazing systems (Figure 7.1). In 2006, CP content initially declined from January to April to below maintenance requirements (6% for RGS and CGS-G; 4% for CGS-P), before increasing in June/August (RGS - 10%, CGS-G - 11%, CGS-P - 12.5%). Then there was a 1 - 2% decline in dietary CP at shearing time in October/December of 2006. Dietary CP intake increased (RGS - 4%, CGS-G - 2%, CGS-P - 1.5%) from shearing in 2006 to shearing in 2007.

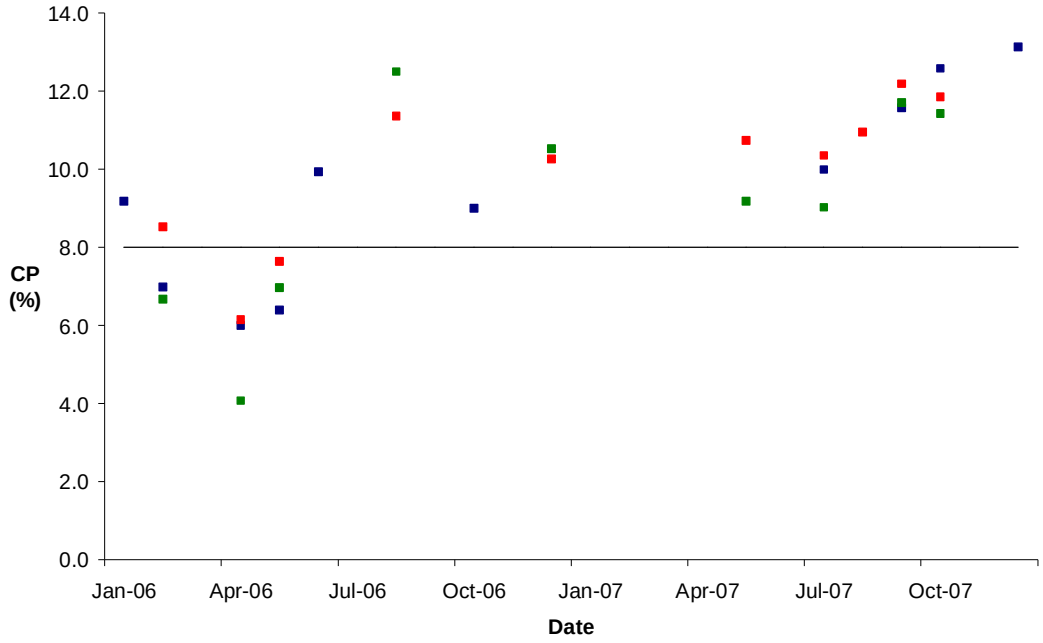


Figure 7.1 Dietary crude protein (CP) content (%) predicted using faecal NIRS for RGS (blue), CGS-G (red), and CGS-P (green). Line = standard requirements for maintenance (45 kg dry sheep).

Dietary ME content generally declined over the study period for the management systems (Figure 7.2). After an initial increase of 1.5 MJ/kg, ME intake of sheep within RGS steadily declined (from February to October) over 2006. Sheep within CGS-G, maintained ME intake at 9 - 9.5 MJ/kg in 2006, apart from a drop in May to 8%. Sheep within CGS-P, initially maintained ME intake at 9 MJ/kg from February to May in 2006, before a decline to around 8%. All grazing systems were able to satisfy ME requirements for sheep maintenance in 2006.

From January to May, 2007, the sheep within RGS were removed due to lack of available feed (and agisted off-station where grazing was available on cereal stubbles). During this period it was not possible to collect faecal samples to determine dietary parameters. In August 2007, the ME intake of these sheep was 10 MJ/kg, which declined to 7 MJ/kg by shearing in December. The ME intake of the sheep with CGS-G had declined by 1.3 MJ/kg from shearing in 2006 to May 2007. ME intake then increased to 9.5 MJ/kg in Aug 2007, before decreasing to 8 MJ/kg by shearing in October. The ME intake of sheep within CGS-P also declined, by 1.2 MJ/kg, from shearing 2006 to May 2007, followed by an increase to 8.4 MJ/kg by shearing in October. The ME intake of the sheep was below maintenance requirements for RGS in December, and for CGS-P in May and July of 2007.

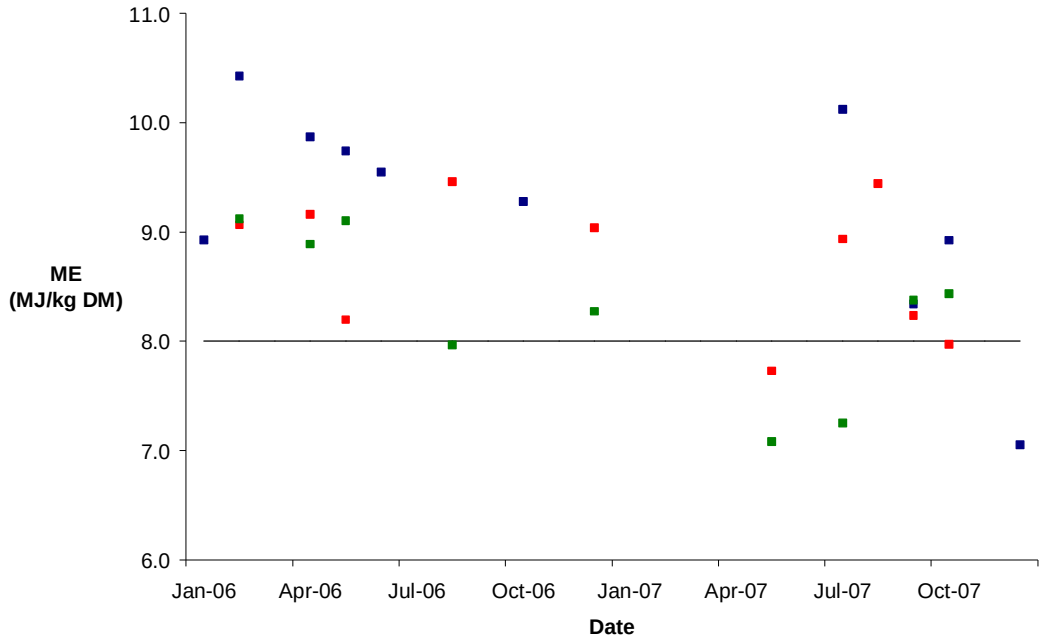


Figure 7.2 Dietary metabolisable energy (ME) content (MJ/kg DM) predicted using faecal NIRS for RGS (blue), CGS-G (red), and CGS-P (green). Line = standard requirements for maintenance (45kg dry sheep).

Dietary OMD initially increased between January (60%) and April (68%) for sheep within RGS, before decreasing by 11% to shearing in October 2006 (Figure 7.3). For the sheep within CGS-G, OMD fluctuated between 58% and 70% from February to August 2006 before declining to 54% by shearing in December. Within CGS-P dietary OMD followed a similar pattern to that for the sheep within RGS in 2006, with an initial increase of 7.5% from February to April, before declining to 48% by shearing in December.

In 2007, OMD of the diet was maintained at around 55% from July to shearing in December for sheep within RGS. OMD was also maintained at around 55%, apart from an increase in August to 62%, for sheep within CGS-G. Within CGS-P, OMD fluctuated throughout 2007, starting at 52% in May before decreasing to 49% in July, followed by an increasing to 67% in August and ending at 59% in October.

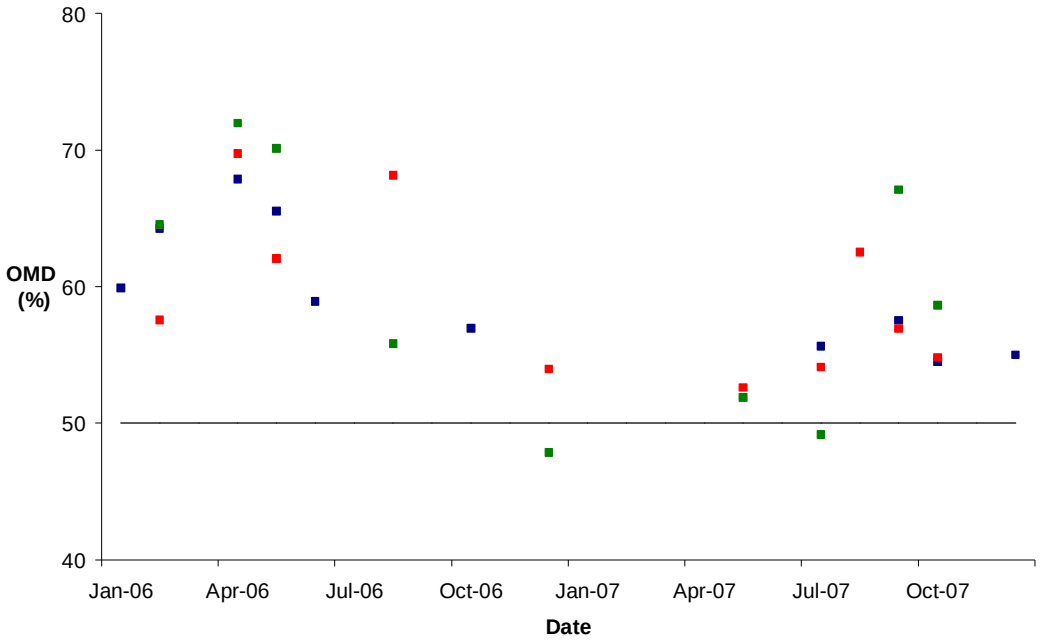


Figure 7.3 Organic matter digestibility (OMD) of the diet predicted using faecal NIRS for RGS (blue), CGS-G (red), and CGS-P (green). Line = standard requirement for maintenance (45kg dry sheep).

The TP and TT contents of the diet, calculated from faecal NIRS equations are presented in Tables 7.4 and 7.5.

Dietary TP content within RGS was extremely low (below detectable levels) for the majority of 2006, apart from small concentrations in April (1.4%) and June (1.3%). In 2007, dietary TP content rose to 2.1% in October, with a further increase to 2.6% in December. For CGS-G, TP content fluctuated, varying from non-detectable levels (Feb) to 2.4% (June) in 2006. In 2007, TP content decreased from 1.5% in January to 1.1% in May - August, before increasing to 2.2% by October. For CGS-P, TP content fluctuated, varying from below detectable levels (February and November) to 1.9% (June) in 2006. In 2007, TP content was generally higher than it was during 2006, ranging from 0.3% in May, 3.8% in September and 2.4% in October.

Dietary TT content within RGS increased from January (0.1%) to June (2.1%) in 2006. In October 2006, July 2007 and September 2007 TT content was very low

(below detectable levels), but increased to 2.3% by December 2007. Dietary TT content for CSG-G fluctuated between 1.5 and 2.9% in 2006, decreased from 1.3 to 0.7% from May to July 2007 before staying steady and 0.7% for the rest of the year. For CGS-P, dietary TT content fluctuated between 1.9 - 2.6% from February to May 2006. It was high (4.6%) in August, but very low (below detectable levels) by December 2006. During 2007, TT content fluctuated between 0.5 - 1.4%, apart from September when it rose to 4.3%.

Table 7.4 Predicted total phenolics (TP) and total tannins (TT) contents of the diet for RGS, CGS-G and CGS-P in 2006.

Date	System	TP	TT
Jan 06	RGS	<0.1	0.1
Feb 06	RGS	<0.1	<0.1
	CGS-G	<0.1	1.5
	CGS-P	0.5	2.1
Apr 06	RGS	1.4	1.3
	CGS-G	1.4	2.6
	CGS-P	<0.1	1.9
May 06	RGS	<0.1	1.4
	CGS-G	1.0	2.1
	CGS-P	0.6	2.6
Jun 06	RGS	1.3	2.1
Aug 06	CGS-G	2.4	2.9
	CGS-P	1.9	4.6
Oct 06	RGS	<0.1	<0.1
Dec 06	CGS-G	0.5	1.7
	CGS-P	<0.1	<0.1

Table 7.5 Predicted total phenolics (TP) and total tannins (TT) contents of the diet for RGS, CGS-G and CGS-P in 2007.

Date	System	TP	TT
May 07	CGS-G	1.5	1.3
	CGS-P	0.3	1.1
Jul 07	RGS	<0.1	<0.1
	CGS-G	1.1	0.7
	CGS-P	<0.1	0.5
Aug 07	CGS-G	1.1	0.7
	CGS-P	<0.1	<0.1
Sep 07	RGS	<0.1	<0.1
	CGS-G	2.1	0.7
	CGS-P	3.8	4.3
Oct 07	RGS	2.1	1.5
	CGS-G	2.2	0.7
	CGS-P	2.4	1.4
Dec 07	RGS	2.6	2.3

7.3.3 NDVI and animal diets

Figures 7.4 - 7.6 show the relationships of NDVI with dietary CP, ME and OMD, respectively.

In 2006, dietary CP intake seemed to have an inverse relationship with NDVI (Figure 7.4). As dietary CP initially declined from January to April, NDVI increased (January - June), whereas where dietary CP increased from May to October, NDVI declined (July - January).

In 2007, dietary CP generally increased, while NDVI fluctuated. There did not seem to be relationships between CP and NDVI of the different management systems. NDVI for CGS-G was always greater than the other two grazing systems, and

generally dietary CP was higher in CGS-G, but there was considerable variation among the grazing systems.

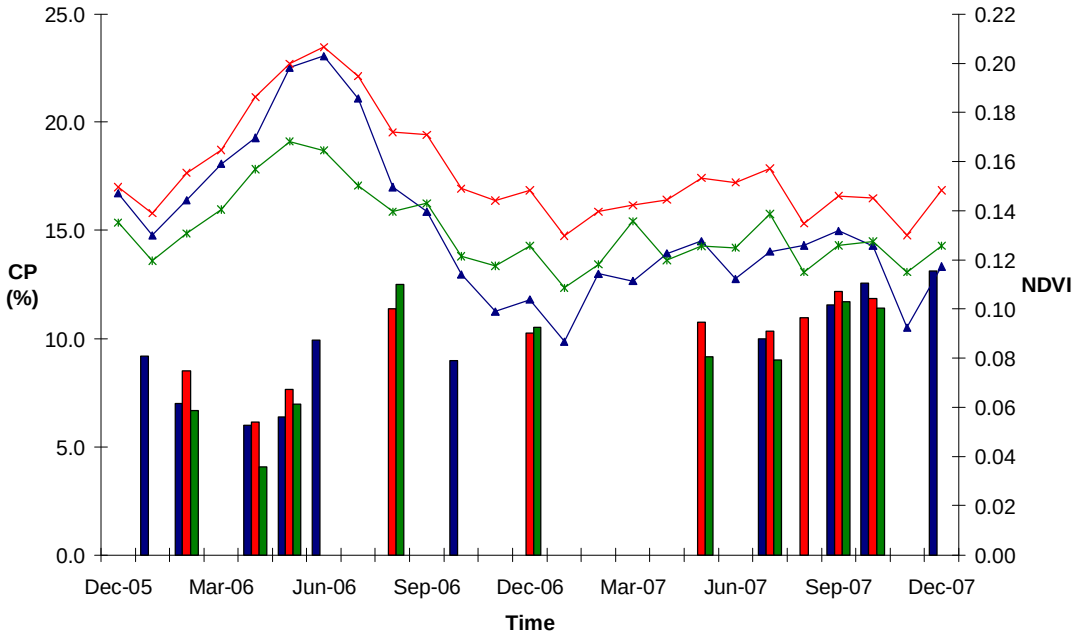


Figure 7.4 The relationship of CP (% DM) and NDVI (lines) during the study period for RGS (blue), CGS-G (red), and CGS-P (green).

Dietary ME intake did not seem to have a relationship with NDVI (Figure 7.5). Generally, ME fluctuated between 7 - 10 MJ/kg over the study period and there did not seem to be relationships between ME and NDVI of the different management systems. NDVI for CGS-G was always greater than the other two grazing systems, but ME content within the different grazing systems varied.

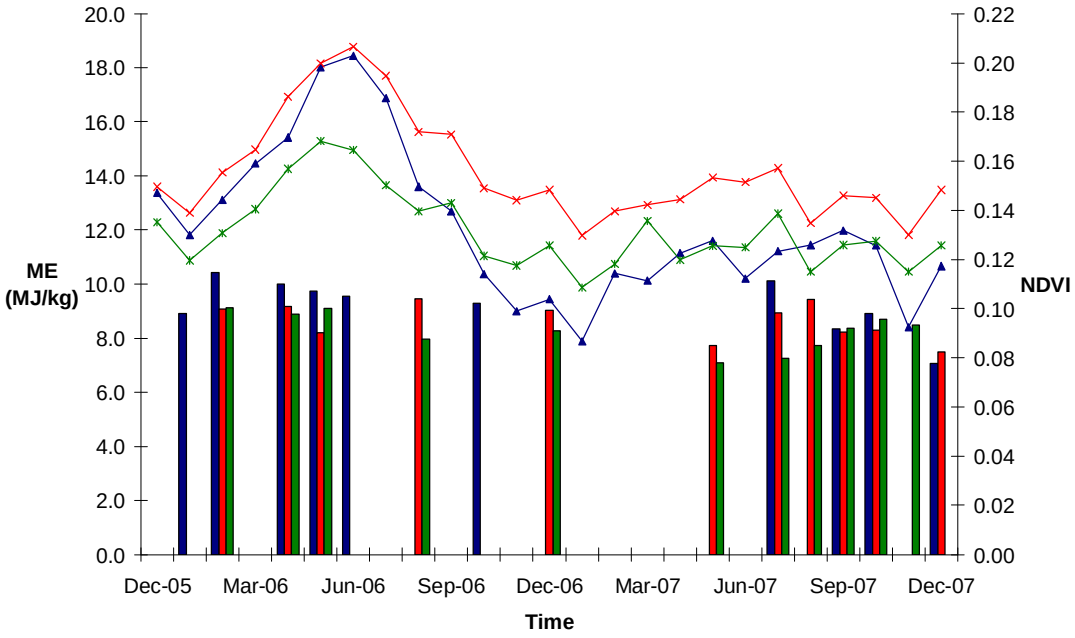


Figure 7.5 The relationship of ME (MJ/kg DM) and NDVI (lines) during the study period for RGS (blue), CGS-G (red), and CGS-P (green).

Dietary OMD seemed to have a positive relationship with NDVI in 2006 (Figure 7.6). OMD generally increased from January to April, while NDVI also increased from January to June. OMD then declined from May to December, apart from an increase for CGS-G in August. NDVI declined from July to January. Both dietary OMD and NDVI fluctuated in 2007. There did not seem to be relationships between OMD and NDVI of the different management systems. NDVI for CGS-G was always greater than the other two grazing systems, but OMD within the grazing systems varied.

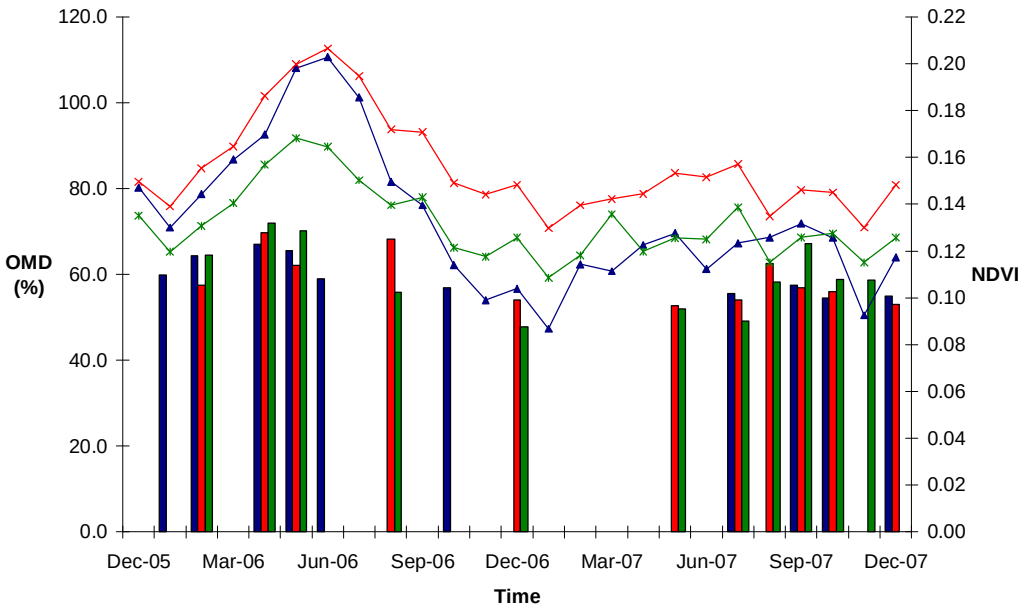


Figure 7.6 The relationship of OMD (% DM) and NDVI (lines) during the study period for RGS (blue), CGS-G (red), and CGS-P (green).

7.4 Discussion

7.4.1 Indications of grazing selectivity using plant DNA detected in faecal samples

The results in Tables 7.2 and 7.3 indicate there are probably both seasonal and rainfall effects influencing dietary selections of grazing sheep. In 2006, four of the target plant species were grazed by sheep within RGS in January (summer), which increased to nine by June (winter). Sheep grazing activity decreases in summer as they prefer to graze shorter distances in early morning and late evening, avoiding the heat of the day (Squires 1976b; Thomas *et al.* 2008) and decreased grazing activity may decrease opportunities to select a wider variety of plants. Additionally, by decreasing grazing area there is an increased grazing pressure within that area which can reduce the diversity of palatable species available for grazing.

In 2007, more species were identified in the dung (Table 7.3), indicating that the sheep were eating more of the target shrubs and grasses compared to 2006. These results may be due to grazing selectivity and the availability of plants. The

availability of green feed is influenced by rainfall and affects animal grazing (Freudenberger *et al.* 1999). Winter rainfall events trigger the growth of short-lived, highly palatable annual and biennial species and high summer rainfall events trigger grass growth (Harrington *et al.* 1984b; Burnside *et al.* 1995). This may explain why less of the target plants were detected in 2006 compared to 2007. The high summer rainfall in 2006 (Figure 4.1) and consequent increase in photosynthetic activity (Figure 4.2) indicate that availability of green feed increased. The live weights of sheep on CGS-P increased from 43.5 kg to 53 kg between April and July 06. The sheep most likely had a greater selection of palatable feed, including fresh short lived grasses, annuals and biennials, which were probably, grazed in preference to the perennial shrub and grass species targeted for analysis. As the environment dried and photosynthetic activity decreased at the end of 2006 and during 2007, the sheep resorted to eating less palatable (target) browse species. The tree (*Melaleuca* spp.) was sampled late in the study period in 2007, because a strong Teatree scent was detected in some faecal samples found on RGS paddocks and the CGS-G paddock close to where *Melaleuca* trees were located. The strong scented dung was collected between August and October 2007 and indicates that the sheep were running out of palatable feed, as it was previously unknown that the sheep ate this plant. This change in grazing according to forage availability and quality has been reported in a number of Australian rangeland studies on sheep and cattle (Wilson *et al.* 1969; Leigh *et al.* 1978; Squires 1980; Squires & Siebert 1983; McMeniman *et al.* 1986; Squires & Low 1987).

Wilson & Harrington (1984) grouped plants into four categories according to livestock preference from the most preferred actively growing grasses and forbs to species which are rarely or never eaten, due mostly to anti-nutritional factors. The majority of target species used in this study seem to fit into the second and third categories. The second category consists of palatable perennials eaten when category 1 plants decrease in availability and quality.

Of the species selected for inclusion in this study, *Rhagodia eremaea* was the most commonly detected species in both 2006 and 2007, which could be considered a category 2 species, according to Wilson & Harrington's (1984) categorisations. It is a

palatable species (Russell & Fletcher 2003) with a good nutritive value (refer to chapter 5 for nutritional information) and was relatively common in all of the grazed paddocks. Third category species consists of browse plants like mulga (*Acacia aneura*) and saltbush (*Atriplex* spp.), eaten when more palatable species decrease in availability (Wilson & Harrington 1984). *Frankenia* spp. was the most commonly detected species in 2007, but is not known to be particularly palatable (Mitchell & Wilcox 1994); therefore it is likely to be a category 3 or possibly category 4 plant. Its frequent detection in 2007 was most likely due to the dry conditions, when the deteriorating feed supply forced the sheep to resort to less palatable species, such as *Frankenia* sp.

There were some plants identified in the faecal samples that were not seen in the paddocks. *Acacia saligna* is not a common plant to the Yalgoo region (Gioia 2008), *Aristida contorta* and *Frankenia* spp. were not seen in CGS-P and *Enneapogon caerulescens* was never seen in any of the paddocks during the study period. This might have been caused by a misidentification of the DNA bands (or two or more species having the same number of base pairs) or the plants were in the paddocks but were not seen. Increased sampling of faeces over a wider area of the paddocks would have strengthened the data. Additionally, increasing the number of plant species in the DNA data bank would provide more information about sheep selectivity.

The use of faecal DNA is still only in its developmental stage in terms of determining the composition of the diet of grazing animals. The technology has previously been used to determine diet composition in monogastric sea lions (Deagle *et al.* 2005) and brown bears (Murphy *et al.* 2003). The diets of these animals are likely to be less complex than those of grazing ruminants and the voided faeces likely to contain less microbial DNA to 'contaminate' the sample. Due to microbial fermentation in the rumen, faeces voided from ruminants would presumably contain large amounts of microbial matter. The more sources of DNA in any sample the greater the difficulty in isolating individual sources of DNA (Jarman *et al.* 2004). Previous studies that have identified diet composition of plant remains (within faeces) were only able to establish the plant family or genus rather than the species (Hoss *et al.* 1992; Poinar

et al. 1998). In the current study one faecal sample could not be amplified, two samples were PCR negative and for almost every sample there were bands that could not be confidently identified. Despite the limitations of the new technology, DNA fingerprinting has been an effective tool to assess changes in diet choice/availability, and when further developed it has the potential to indirectly measure grazing pressures.

7.4.2 Indications of grazing nutrition and selectivity using NIRS

As highlighted in Chapter 5, the livestock had access to plants containing high protein but low energy contents and with generally low OMD. To meet their nutrient requirements (for maintenance at the very least) sheep would need to be highly selective to find digestible feed. However, the diet nutritive value results shown in Figures 7.1 - 7.3 indicate that the sheep were generally able to select a diet adequate in ME, OMD and CP during the study.

Dietary OMD intake increased from January to April before generally decreasing during 2006, and fluctuated in 2007 (Figure 7.3). Dietary ME intake generally decreased in 2006 and fluctuated in 2007 (Figure 7.2). Dietary CP intake initially decreased from January to April 2006, before generally increasing over the study period (Figure 7.1). The decrease in OMD and ME, and increase in CP during 2006, indicate that as the rainfall decreased (Figure 4.1), the sheep were eating more browse species, which are high in protein, but low in ME and OMD (Table 5.6). This reflects the DNA results discussed in Chapter 7.4.1. Coates & Dixon (2007) also found that dietary CP increased as cattle consumed more non-grass diets in dry periods. Dicko & Silenka (1991), and a number of other studies (Squires 1976b; Atiq-Ur-Rehma *et al.* 1999), have found that sheep increase browse intake in dry times. The fluctuating ME and OMD results in 2007 reflects the variable availability of energy and digestibility in diets, which is a result of low and intermittent rainfall and photosynthetic activity (Figures 7.5 and 7.6).

As shown in Table 7.5, the sheep consumed diets low (0 - 2%) to moderate (2 - 4%) in tannins (Aerts *et al.* 1999) during the study. Tannin intake generally increased as

rainfall decreased in August 2006, and September and October in 2007, but did not become high (>4%) (Aerts *et al.* 1999). This is a significant discovery as it is a common assumption that rangeland forbs and shrubs are high in tannins (Holechek *et al.* 1989; O'Reagain & McMeniman 2002; Papachristou *et al.* 2005). The low tannin and phenolic results in this study suggest that livestock are able to select diets low to moderate in tannins and phenolics, even in dry conditions, suggesting that there are ample supplies of plants that are low to moderate in tannin and phenolic content in the Yalgoo shire. A study by Kababya *et al.* (1998) found goats selected for stable, moderate tannin content throughout the year while eating browse diets.

Studies have shown that low tannin diets can be beneficial to sheep wool growth and live weights (Luque *et al.* 2000; Bhatta *et al.* 2005; Kamra 2005; Ramirez-Restrepo *et al.* 2005) as the tannin increases absorption in the abomasum and small intestine of essential amino acids that had been protected from degradation in the rumen (McNabb *et al.* 1993; Luque *et al.* 2000), and it improves energy to protein ratios (Leng *et al.* 1991). Therefore the combination of low tannins and high protein diets seen in this study can be beneficial to sheep wool and meat production. However, the benefits may be reduced if OMD and ME requirements are not met.

7.4.3 Relationships of NDVI and animal diets

Dietary CP and OMD seemed to be related to change in NDVI in 2006 (Figure 7.7 and 7.8). As NDVI increased, CP intake decreased and OMD intake increased. This indicates that as plant photosynthetic activity increases, animals selected for a more digestible diet, which consequently includes less browse species that are high in CP. As photosynthetic activity decreases, the sheep increase intake of browse species that are generally lower in digestibility, but high in CP (Wilson 1977; Franklin-McEvoy 2005a; Franklin-McEvoy 2005b). Due to the fluctuating dietary and NDVI results in 2007, it is difficult to distinguish if the same relationships of CP and OMD with NDVI occur. However, the NDVI results indicate that photosynthetic activity was low for the entire year and as a result, CP consumption was high compared to 2006, and sheep sought out feed adequate in OMD for maintenance

requirements. There was a greater reliance on browse species due to the overall decrease in feed availability.

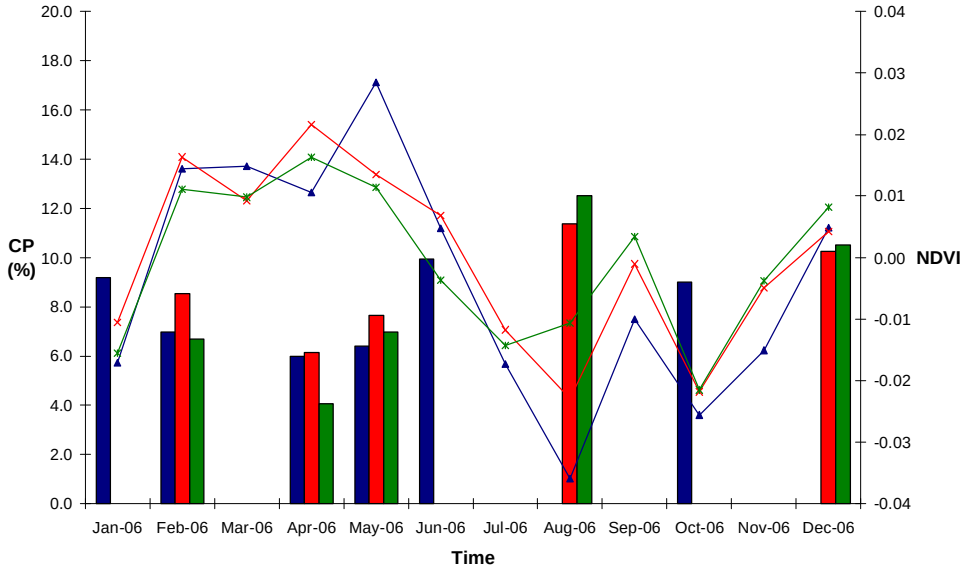


Figure 7.7 Dietary CP (% DM) related to change in NDVI for RGS (blue), CGS-G (red), and CGS-P (green) from January to December 2006.

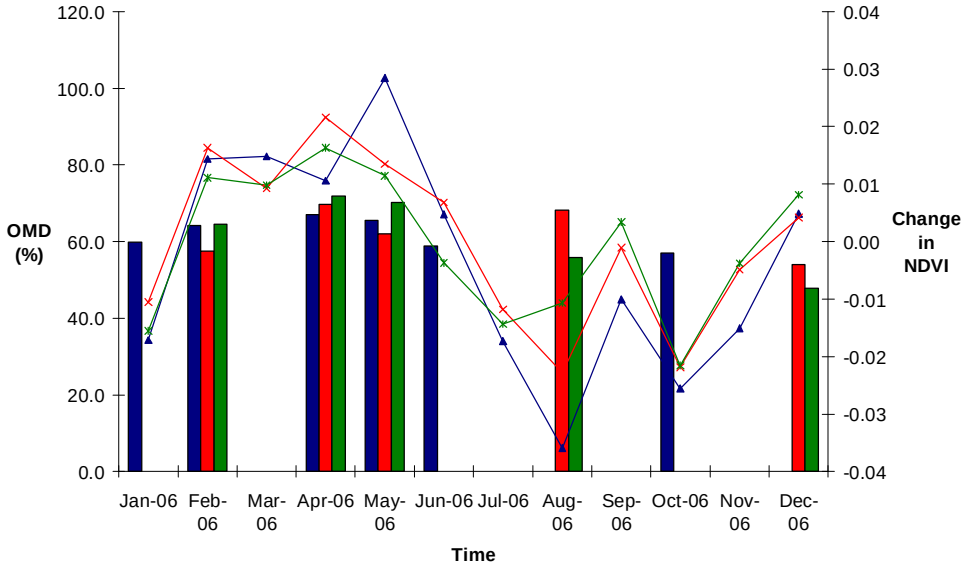


Figure 7.8 Dietary OMD content (% DM) related to change in NDVI for RGS (blue), CGS-G (red), and CGS-P (green) from January to December 2006.

Dietary ME did not relate well with NDVI (Figure 7.6), with ME seeming to stay at a fairly constant rate between 7 - 10 MJ/kg for grazing systems over the study period. Differences between grazing systems and months were insignificant. This indicates that although sheep were able to obtain more than enough ME for maintenance, availability of energy was limited and the sheep needed to be highly selective to obtain adequate energy intake, as evident in the low energy content in plants sampled (Chapter 5).

Sheep select feeds in order to maintain balanced energy-to-protein ratios (Leng *et al.* 1991; Villalba *et al.* 2002). In intensive agricultural regions of Australia, saltbush pastures are used to maintain sheep during times of low feed availability (Masters *et al.* 2005; Masters *et al.* 2007). Saltbush pastures are high in protein and salt, but low in energy (Thomas *et al.* 2007b), which is similar to rangeland environments (Franklin-McEvoy 2005a; Brennan *et al.* 2006). Norman *et al.* (2008) found that sheep performed better on oldman saltbush (*Atriplex nummularia*) pastures that had higher herbaceous under-storey biomass, than river saltbush (*Atriplex amnicola*) pastures. It is likely that the sheep selected more of the under-storey feed in the *A. nummularia* pastures, which contain higher energy content than the saltbushes. The study also showed that sheep performance improved when offered a high-energy grain supplementation. A study by Thomas *et al.* (2007b) found that energy rather than protein is important in sheep selectivity in saltbush pastures. This indicates the importance of energy in a high-protein, low-energy environment, and the preferences of sheep for energy-rich feed in energy-limited environments.

7.5 Conclusion

The faecal DNA and NIRS results indicate that the composition and quality of the sheep's diet were affected by the climatic conditions and the consequent changes in green feed availability.

CP intake increased and ME and OMD intake decreased as feed availability declined in dry periods. However, ME and OMD almost always met sheep maintenance requirements, indicating that sheep selectively grazed to meet their

needs. The sheep were also able to select low to moderate tannin and phenolic diets during the study, even in dry times, indicating that a large portion of plants in the Yalgoo Shire contain only low levels of tannins and phenolics. Rangeland environments offer a wide variety of plants for animal diets, which enable them to better meet their needs for nutrients and regulate toxin intake (Papachristou *et al.* 2005).

Of the selected plants in the study, none individually contained sufficient nutrients (Chapter 5) to satisfy sheep maintenance requirements. However, the dietary OMD and ME results show that the sheep were almost always able to meet maintenance requirements. Therefore, the analysis of the nutritive value of individual plants (even on the knowledge or assumption of their inclusion in the diet) does not necessarily reflect the nutritive value of the diet of the grazing animal.

The ability to analyse diet composition and quality of rangeland animals with faecal DNA and NIRS technology can significantly increase knowledge of rangeland environments, which can result in improvements to conservation and sustainable management.

8 General discussion

8.1 Introduction

In this study, technologies such as faecal DNA and NIRS analyses, and NDVI, coupled with the established methods of measuring sheep live weights, BCS, wool production and the nutritive value of plants, has expanded general knowledge of sheep nutrition in the Arid Shrublands of WA.

8.2 Revision of research questions

8.2.1 What plant species do the sheep on the two pastoral stations eat?

The analyses in Chapter 7 provide some indications of the types of plant the sheep were eating. Of the species that were DNA fingerprinted, in 2006 the sheep ate *Acacia saligna, Aristida contorta, Atriplex* spp*., Enchylaena tomentosa, Frankenia* sp*., Ptilotus obovatus, Rhagodia eremaea* and *Scaevola spinescens* in 2006 whilst in 2007, the sheep consumed *A. saligna, A. contorta, Atriplex* spp*., Eremophila forrestii, Enneapogon caerulescens, Frankenia* sp*., Maireana* spp*., P. obovatus, R. eremaea, Solanum lasiophyllum* and *Austrostipa elegantissima*. However, there were 28 amplified bands in 2006 and 51 in 2007 that did not conclusively match any of the reference plant species. This indicates that the sheep were consuming diets that contained more species than were analysed in this study.

At present, knowledge of plants that sheep eat in the Arid Shrublands of WA is mostly based on field observations by managers and researchers in various regions of the Australian rangelands (Russell & Fletcher 2003; Franklin-McEvoy & Jolly 2006b). Observations serve well to give a general idea of what plants are palatable and available to sheep in paddocks. However, the high number of unidentified bands found in this study suggests that additional tools are needed to strengthen the accuracy of observational assessments of paddock capacities to support a given number of animals.

Sheep grazing rangeland environments have access to a wide variety of plants and are therefore likely to have diverse diets that continuously change in response to changing availability, nutritive value of plants and dietary requirements (Provenza *et al.* 2009). Ruminants will select diets that provide necessary amounts of protein and energy, and balance supplies of macronutrients and toxins (Provenza & Villalba 2006; Rogosic *et al.* 2006). Selective grazing of diverse environments allows animals to maximise benefits to health and production. Thomas *et al.* (2007b) offered sheep a choice of feeds of high and low salt, energy and/or protein to simulate a changing saltland pasture and found that they selected diets that improved their live weight gain compared to sheep offered only high salt feeds. However, the benefits of a varied diet are limited by availability, which is influenced by seasons. Coppock *et al.* (1986) found that ruminant diets and habitats in free ranging environments were greatly influenced by season, where diet diversity decreased, and habitat variety increased, during prolonged dry periods.

The analyses of DNA plant "fingerprints" in animal faecal matter provide more accurate information of diet composition (Valentini *et al.* 2009). Expanding the plant DNA database would provide greater information on dietary components of rangeland sheep diets, which could be linked to more sustainable grazing management strategies. To know what sheep prefer to eat, and when, would allow managers the opportunity to manipulate grazing management strategies to provide sheep with the feed they are likely to eat at certain times of the year, and conserve preferred plants by limiting access. Currently, the proportions of plants in animal diets cannot be determined by DNA analysis. Knowing the proportions of plants consumed would give better insight into animal preferences for plants and how diets change spatially and temporally. Genetic analysis of faecal matter could potentially provide a quantitative estimate of diet composition rather than just qualitative information on the presence or absence, assuming that the amount of (faecal) DNA from each species is proportional to the mass (of the particular plant) in the diet. Recent testing did provide a rough estimate of the proportion of the fish present in the meals fed to sea lions (Deagle *et al.* 2005).

8.2.2 *How nutritious are the target plant species (refer to Appendix 1 for the list of plants tested)?*

There is little information on the nutritional value of WA rangeland plants (Wilson 1977; Mitchell & Wilcox 1994; Brennan *et al.* 2006). Franklin-McEvoy & Jolly (2006b) surveyed producers and found that they determined the nutritional value of plants by observing stock preferences and their performances on areas dominated by the preferred species. They found that few producers test the nutritional value of plants; they did not know which species should be more important. Nutritional content in plants is affected by soil mineral content, soil moisture content, soil biodiversity, plant age, plant reproductive status, plant moisture stress, ambient temperature, seasons, and the adaptive abilities of plant species to absorb nutrients (Mengel & Kirkby 2001). The nutritional content of individual plants and species can provide indicators of how nutritious that plant can be to sheep; however, the analysis of sheep faecal matter using NIRS technology can provide more accurate information on the quality of diets consumed.

The results presented in Chapter 5 indicate that the plants collected for this study were generally low in energy and digestibility, but high in crude protein, and variable in mineral content. The results in Chapter 5 also suggest that nutritive value of the plants varied due to season and rainfall. All the plants selected for analysis were individually inadequate in ME or OMD to satisfy maintenance requirements for sheep. However, the results presented in Chapter 7 indicate that the sheep were consuming diets low in tannins and other phenolics, and adequate in ME, OMD and CP for maintenance requirements during most of the study. This suggests that they were selecting the most nutritious plants and plant parts from those available, and avoiding secondary metabolites. Therefore results from Chapters 5 and 7 indicate that analyses of plant nutritional content (Chapter 5) did not give accurate indicators of the quality of the diet selected by the sheep.

Current techniques for analysing nutritional content of plants do not account for high levels of salt or secondary compounds commonly found in rangeland species, and tend to over-estimate true values (Franklin-McEvoy & Jolly 2006b). Additionally, the

analyses of individual plants do not account for accumulated effects of varied diets. Rogosic *et al.* (2006) found that goats were able to eat more when offered a mixed diet of tannin- and saponin-rich plants compared to diets rich in either tannin or saponin. The authors suggested that simultaneous consumption of tannin- and saponin-rich plants may result in chemical interactions within the intestinal tract that inhibit toxic effects of the phytotoxins.

It is difficult to ascertain in rangeland environments exactly what plants, and plant parts, animals eat and in what quantities, which would affect the overall quality of the animals' diet (Mayes & Dove 2000). In terms of the WA Arid Shrublands, and the study area, there are minimal sources of solid data on what plants sheep consume (Franklin-McEvoy & Jolly 2006b). Expanding the plant DNA data bank would enable determination, from faecal analysis, of what sheep actually do consume and then research could be directed to determining the feeding value of these identified plants, rather than selecting plants that are *thought* to be consumed (as is the current situation).

Undertaking laboratory analysis of individual plant chemical composition seems to be of limited value as it does not reflect the quality of the diet selected by grazing animals (Wilson 1977; Papachristou 1993; Avondo *et al.* 2004). However, more detailed studies on how the nutritive value of palatable WA rangeland plants changes over time, seasons, stage of maturity, water stress, heat stress and grazing pressures, may provide some insight on selections made by grazing animals and ecological and dietary patterns that may occur among plant species.

The NIRS results indicate that the quality of the diets changed during the study due to rainfall and seasonal effects (Chapters 7.3.2 & 7.3.3). As environmental conditions dried, CP consumption increased as sheep ate more browse species, and ME consumption and OMD decreased as availability of those components declined. This knowledge will allow managers the opportunity to provide digestible, high-energy supplements to their livestock in dry times, which may improve production and prolong survival.

The faecal NIRS results suggested that animals were able to consume diets low in tannins and phenolics. This result is contrary to the general assumption that sheep have high intake of secondary compounds that inhibit digestion because most rangeland plants have high tannin and phenolic content (Wilson & Harrington 1980). Recent research has found that two of the common shrubs, *Atriplex amnicola* and *Rhagodia eremaea* are low in total tannin content (Kumara Mahipala *et al.* 2009). Further testing of the phenolic content of plants in the Yalgoo area would be able to expand these results.

8.2.3 How variable are the individual test sheep's wool, live weight and BCS?

The variability in fibre diameter along the staple directly relates to sheep genetics (Safari *et al.* 2005) and nutrition (Sharkey *et al.* 1962; Nagorcka 1977). Sheep nutrition can be affected by numerous factors including climate (Coppock *et al.* 1986), quality and quantity of feed available (Adams *et al.* 2002), sheep health (Li *et al.* 2007) and reproductive status (pregnant, lactating, dry) (Teasdale 1998). Comparisons of individual fibre diameter results in Figure 6.4 suggest that there was high variability among individual sheep and in their ability to respond to these factors. Wool length also varied highly between individuals with standard deviations (SD) ranging between 10.6 - 13.0mm in 2006 and 8.9 - 15.2mm in 2007 (Chapter 6.3.2.3). Morrissey (1973) study of ewes grazing in the mulga zone of WA and also found high variability in wool production between individual sheep.

The high variability in individual wool performances of the studied rangeland sheep show that it would be very difficult for managers to obtain uniform wool production from their mobs. There is insufficient data in this study to determine what is causing the variability. Possible causes could include nutrition, health, physiological status and genetics. In expansive and variable rangeland conditions it can be challenging for manager's control these possible causes. Further research where more comprehensive data in obtained on diet quality, fibre diameter, live weight, BCS, blood lines, health and physiological status of identified sheep over a specific time period of known climate, may allow for detailed modelling analyses to show relationships between these parameters. If the causes of the variability can be

determined, managers and researchers can create ways to minimise the variability and improve market value of the wool clip.

8.2.4 Do blood-lines affect the test sheep's wool, live weights and BCS?

Studies have found that sheep live weights, wool quality and production, fertility, reproduction, health and stamina are affected by various genes passed through generations (Safari *et al.* 2005; Adams *et al.* 2007; Safari *et al.* 2007). The results presented in Chapter 6 indicate that blood-lines seemed to affect sheep live weights, BCS, wool length and POB in wool. The results in this study show a number of differences between sheep sourced from the two stations.

Sheep from Station 2 had significantly higher live weights during most of the study compared to sheep from Station 1 on each of the management treatments – RGS, CGS-G and CGS-P. Similarly, sheep from Station 2 had generally greater BCS that sheep from Station 1 managed on CGS-G and CGS-P. The stronger blood-line on Station 2 is most likely due to the many years of breed selection that has occurred on the station, whereas many of the sheep from Station 1 were bought within the last 5 - 10 years.

Blood-lines also seemed to affect wool length and position of break along wool staples, as shown in Tables 6.6 and 6.9. Sheep from Station 1 grew longer wool than sheep from Station 2 on RGS and CGS-P in 2006, whereas sheep from Station 2 grew longer wool than sheep from Station 1 on RGS and CGS-G in 2007. This may suggest that sheep from Station 1 perform better in-terms of wool length than sheep from Station 2 when climatic conditions are good, as were seen at the beginning of 2006, whereas sheep from Station 2 perform better during stressful, dry conditions that occurred during 2007.

The influence of blood-lines on position of breaks in wool staples is more variable between year and paddock management, compared to the influence on blood-lines on live weights, BCS and wool length. In 2006, sheep originally sourced from Station 2 had fibre breaks positioned further along the staple than sheep sourced from

Station 1 when managed under either RGS or CGS-G, in 2006, or CGS-G, in 2007. Since breaks in fibre are directly related to nutrition, these results may suggest that sheep from Station 2 were able to maintain a high plane of nutrition for longer during the year than sheep from Station 1 on CGS-G and RGS. However, the results may have been affected by ineffective dye-banding.

8.2.5 How does the diet affect the test sheep's wool, live weights and BCS?

Animal health and production is dependent on the nutrients consumed and processed in the body (Weston & Hogan 1973). Rangeland animals have a wide selection of plants available for consumption (Archer 1992), many of which are thought to contain secondary metabolites (Holechek *et al.* 1989; O'Reagain & McMeniman 2002; Papachristou *et al.* 2005) that can complicate the digestion and absorption of essential nutrients (Launchbaugh 1996; Bhatta *et al.* 2005; Kamra 2005). Therefore, animal nutrition research in the rangelands is difficult and precision is challenging (Holechek *et al.* 1982c). The precise diets of the sheep in this study are unknown and therefore the effects of diets on wool, live weights and BCS cannot be determined. However, the animal production results (Chapter 6) and the NIRS results (Chapter 7) have provided general indicators of the quality of the diets consumed and the subsequent effects on animal production.

The NIRS results (Chapter 7) indicate that the sheep were consuming diets adequate in CP, OMD and ME to meet maintenance requirements throughout the study period. However, extra nutrition is needed to meet daily maintenance plus additional functions such as walking, grazing, pregnancy, lactation, and body temperature control in hot and cold weather (McDonald *et al.* 2002). As the study progressed through the dry conditions at the end of 2006 and throughout 2007, the energy content and digestibility of the diets decreased while CP and tannin intakes increased (Chapter 7). Additionally, sheep live weights, BCS and wool production declined (Chapter 6), indicating that their diets were not providing sufficient nutrients to meet all of their needs.

The faecal DNA results (Chapter 7) show a decrease in the diversity of the diets selected by the sheep as the dry conditions progressed, which coincided with a decrease in animal production during summer (Chapter 6). This is likely due to reduced quality and quantity of feed in summer months. Rangeland plants have a number of physiological responses to dry times including leaf shedding (Vesk & Westoby 2003), increased secondary metabolites to protect against grazing (Bryant *et al.* 1992), dormancy and reduced growth (Holechek *et al.* 1989). These responses make most rangeland plants less palatable during dry times. Additionally, the plants are naturally drier (less moisture content) and less digestible. Therefore, availability of palatable plants would have decreased and, consequently, the sheep diets would be less diverse.

High selectivity and competition among grazing animals for nutritious material can result in land degradation if stocking rates are not managed correctly (Holm *et al.* 2005; Brennan *et al.* 2006). When availability of palatable plants is reduced either in dry times or due to resource degradation, animal diets become less diverse and grazing pressure on sought-after plants increases. With increased grazing pressure, desired plants and species can be grazed out, further reducing diversity (Landsberg *et al.* 2003; Hacker *et al.* 2006). Total grazing pressures of livestock, feral and native animals must be monitored and controlled in paddocks to reduce overgrazing. Livestock numbers within paddocks will depend on pasture quality and quantity and how these change over time. A paddock with a low proportion of high-quality feed may not be able to sustain as many sheep as a paddock with a higher proportion of high quality feed.

8.2.6 Are the test sheep's nutrition affected by different flock management strategies?

Pastoral managers must be flexible with stocking rates, grazing management systems and timing for mating, lambing and shearing to be able to respond effectively to the variable climate in the rangelands. The actions pastoral managers take in managing their animals can directly affect the quantity and quality of food

accessible within paddocks, which inherently affects the nutrition available to livestock.

Both stations stocked their paddocks above the recommended carrying capacity (RCC) outlined by Van Vreeswyk & Godden (1998) during the study (Table 3.1 and Chapter 3.2.1.2). The RCC estimates the total number of animals that can be safely carried (with minimal impact on ecosystems) during summer following a reasonable winter (Van vreeswyk & Godden 1998). Therefore it is a conservative, fixed estimate that has limited applicability to rangeland management. Carrying capacity should be a dynamic parameter expressing stocking rate in relation to available resources and can change monthly, seasonally and annually (Alchin *et al.* 2008).The primary factor affecting carrying capacities is rainfall, but it also depends on store of forage from the previous year, the nature of the animal production system and safe utilisation levels (Wilson *et al.* 1984a). When rainfall is above-average carrying capacity will generally increase as forage production within the ecosystem increases (Ludwig *et al.* 1997). The pastoral owners of Station 1 and 2 stocked their paddocks in the aim of minimising impact on the ecosystem while also utilising winter feed and maintaining economic viability. The original numbers of sheep at the beginning of the study were expected to result in a reasonable flow of nutrition to the animals; however, as conditions dried it is likely that the animals were overly constrained in what they could obtain from the environment. The station owners tried a number of management tactics to reduce animal impact during the drier years, however the increased presence of perennial shrubs in the diet towards the end of the study (as indicated in Chapters 7.3 and 7.4) suggests that food resources were declining and the risk of overgrazing was increasing. Grazing impacts on plant biomass and populations was not measured therefore it is unknown if overgrazing occurred during the study.

The original aim of this study was to compare the nutrition and production of sheep managed rotationally and continuously on commercially managed pastoral stations. However, due to the dry conditions the station owners had to change their management plans during the study period to, first, ensure the survival of their livestock and, second, maximise their production outputs. The changes in sheep live

weights, body condition scores and wool production shown in Chapter 6 indicate that the management decisions made for each of the three study treatments affected the quality and quality of the diets consumed and ultimately sheep production.

The management actions that occurred on CGS and RGS during the study were described in Chapter 4.2.1. The live weight and wool fibre diameter results (Figures 6.1 and 6.3) indicate that the decision not to mate most sheep on CGS may have resulted in better wool production in 2006. The decision to agist the RGS sheep during the summer of 2006-2007 seemed to result in better wool and live weight production. It is difficult to determine if the use of rotational grazing on RGS in 2006 affected sheep production. However, the decline in live weights from the first shearing to January 2006 may have been caused by overstocking in Yalgoora paddock (Table 3.3) due to the sheep staying in the paddock past the capacity of the paddock to provide food (R. Mitchell, RGS Manager, pers. comm..). It seems that the steady increase in live weights from January to shearing in October/December 2006 may have been due to better rotational management during the rest of the year. However, due to the lack of control of all influencing factors, it is difficult to determine what proportion of sheep production changes were caused by management or by environmental conditions.

The NDVI and wool fibre diameter results (Chapter 6.6.2) indicate that effects of management seemed to be secondary to the effects of climate on sheep production and nutrition. High rainfall at the beginning 2006 seemed to increase the photosynthetic plant activity which consequently resulted in increased wool fibre diameter along staples (Figure 6.10 & 6.11). The management decision to avoid sheep mating on Station 2 may have contributed to the higher fibre diameter towards the end of the year on CGS (Figure 6.3). In 2007 there were fewer rainfall events, resulting in generally lower NDVI. With the low photosynthetic activity of plants within paddocks, management decisions like agistment of sheep off RGS resulted in higher fibre diameters compared to CGS (Figure 6.3). Franklin-McEvoy & Jolly (2006b) found that most managers used destocking as a way to control land degradation in dry times.

8.2.7 Do faecal DNA and NIRS analyses provide and accurate way to predict the nutritional status of sheep grazing expansive paddocks and broad diets?

Currently there is no useful means of ascertaining the quality of the diet of sheep grazing on the very diverse 'pastures' of the rangelands. Researchers and managers can only hypothesise diet characteristics based on variations in animal production, general estimates of the quality and quantity of food on offer at particular times of the year, and general nutritional information of various plants observed to be palatable.

The results in Chapter 7 indicate that faecal DNA and NIRS analyses were effective tools for analysing sheep nutrition in the rangelands. They produced more detailed and accurate results compared to analysing individual plants (Chapter 4), were less invasive for the animals, and samples were easy to collect therefore more samples were taken over a larger area compared to other techniques used to determine animal diets (Refer to Chapter 2.4 for descriptions of alternative techniques).

The large number of plant species that sheep could possibly eat in the rangelands limits the effectiveness of using faecal DNA to analyse individual plant consumption, as the initial process of finding unique primers for individual plants is expensive and time-consuming. However, once the identification of unique primers has been established, faecal DNA analysis is a cheap, fast and accurate method for analysing animal diets. These qualities make faecal DNA ideally suited to expansive and variable rangeland environments.

Further studies using faecal DNA and NIRS in other rangeland environments can expand on the results found in this study. In fact, a similar study (S. van Wyngaarden, Curtin University of Technology, unpublished data) was carried out near Kalgoorlie at the same time as the research near Yalgoo. This study also found the use of faecal DNA and NIRS to be an effective, fast and easy way to study sheep nutrition over expansive and variable rangeland environments.

Additionally, the relationships of NDVI to average fibre diameter (Chapter 6) and to OMD (Chapter 7) indicate that NDVI can be used as a tool to indicate sheep nutrition and production in the rangelands. Hamel *et al.* (2009) found correlations between NDVI and faecal CP that supported the use of NDVI as a proxy for vegetation attributes in population ecology and animal management. NDVI information can be obtained quickly as satellite images are taken daily. Therefore managers can almost immediately decide on management options, and can manipulate stocking rates to optimise production (and minimise degradation) in reaction to NDVI changes. However, the relationships between NDVI and dietary OMD, and average fibre diameter along wool staples, were not statistically testable in this study. Therefore, further research specifically testing these relationships is needed.

8.3 Relationships between the nature of the forage on offer, sheep nutritive intake and sheep production

NDVI shows the photosynthetic activity of the vegetation within paddocks and gives an indication of the nature of the forage on offer (Pickup 1989; Specht & Specht 1999; Ramsey *et al.* 2003). The NDVI results in this study (Figure 4.3) indicate that the forage was increasing in photosynthetic activity from the end of January to May/June 2006 before decreasing for the rest of the year. As the photosynthetic activity of the forage increased, sheep dietary intake of CP decreased while intake of OMD increased (Figures 7.7 and 7.8), suggesting that more digestible forage was available to the sheep and the need to graze perennial shrubs (high in CP) was low. Additionally, it seems that sheep live weights, body condition scores and wool fibre diameter also responded positively to the increase in photosynthetic activity (Figures 6.6, 6.7 and 6.9). As conditions dried, the photosynthetic activity decreased, as did OMD intake, live weights, body condition scores and wool fibre diameter, while dietary intake of CP increased. This suggests that the sheep were eating the less digestible perennial shrubs (high in CP), but that the selected diet was not of sufficient quality to support the continued increase in sheep production parameters. In 2007, photosynthetic activity fluctuated and relationships with dietary intake and sheep production are unclear.

The nature of these results are not surprising as it is known that annual and biennial species are more digestible and palatable compared to perennial species (Leigh *et al.* 1979; Wilson & Harrington 1984; Norman *et al.* 2008). Perennial species are generally high in protein but low in digestibility and thus are more heavily relied on as a food source in dry times (Wilson & Harrington 1984; Burnside *et al.* 1995; Franklin-McEvoy 2005). Studies have found that sheep can survive on perennial species but not thrive (Leigh *et al.* 1968; Wilson & Leigh 1970; Arnold *et al.* 1994). The relationships found between NDVI and sheep fibre diameters, live weights, body condition scores and intake of CP and OMD have not been documented before. The relationships were not clear in 2007, therefore further more refined research over a longer period is required to confirm these findings.

8.4 Strengths and weaknesses of the study

There were a number of weaknesses to the project design including insufficient sample frequency, lack of replication of the grazing systems, and lack of monitoring of outside factors that may have been influenced the results. These weaknesses reduced the precision of the study; however, the use of faecal DNA and NIRS technologies, and relating NDVI to animal and plant changes, provided useful information about the nutrition of sheep in the Yalgoo area.

Sampling frequency during the study was irregular and was reduced as the dry conditions progressed. The sampling frequency was limited by distance, approval and assistance from station owners, help from volunteers and finances. The amount of information obtained and accuracy of results for the study could have been improved if sampling of sheep live weights, BCS, wool, faecal matter and plant material had occurred at least monthly and at all study sites simultaneously.

Replication of the grazing systems at property scale would have been very difficult as property land systems and vegetation vary spatially and temporally. However, due to the lack of replication, the grazing systems cannot be compared with valid statistics.

There were many possible factors that may have influenced the study results and not all the influences were monitored sufficiently, including soil variability, land systems, spatial variability in feed resources and additional grazing animals such as kangaroos and feral goats. As these factors were not monitored adequately they were not able to be included in the explanation of findings. However, the greatest influences - management and climate - were monitored.

In establishing the project design the prolonged below average rainfall could not have been predicted or planned for. Nevertheless, the study provided information on the effects of dry conditions on plant nutrition and sheep diets in the region, which will be invaluable to managers as the climate is predicted to become drier in the future due to global warming. This study used the technologies of faecal DNA and NIRS to analyse sheep diets, and related NDVI results to animal production and dietary results, which has not occurred in previous studies.

8.5 Conclusion

During 2006 both stations experienced one of the driest winters on record (BOM 2006) and below average rainfall and photosynthetic activity (Figure 4.5) for the majority of the study. Pastoral enterprises in the Gascoyne and Murchison were influenced by dry conditions and deteriorating stock returns (Van Vreeswyk & Thomas 2008) As a result, the owners of the study sites had to change their management plans for the sheep, to maintain their health and survival. These changes enabled the sheep to obtain a reasonable diet and maintain reasonable production indicating that management plays an important role in ensuring productivity in an uncertain climate with limited resources. The altered management plans inevitably affected the original design of the study and consequently reduced the statistical strength of the data collected. However, the use of advanced technology such as faecal DNA fingerprinting, NIRS and NDVI allowed for the exploration of relationships between sheep diets and nutrition with climatic and spatial influences.

The results from this study have provided some interesting insights in the nutrition of sheep diets in the Yalgoo area. However, the statistical strength of the findings are weak, therefore further research is required to expand on the results and to see if they are applicable to other areas of the Arid Shrublands, and generally to rangelands of Western Australia and Australia.

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Appendices

Appendix 1: List of plant species collected during the study

Species	Common Name	N*
Acacia grasbyi	Miniritchi	4
Acacia tetragonophylla	Curara	3
Aristida contorta	Wind grass	2
Atriplex amnicola	River saltbush	9
Atriplex bunburyana	Silver saltbush	17
Cratystylis subspinescens	Sage	2
Cymbopogon ambiguus	Lemon grass	1
Enchylaena tomentosa	Ruby saltbush	15
Enneapogon spp.		1
Eragrostis spp.		1
Eremophila forrestii	Wilcox bush	12
Maireana convexa	Mulga bluebush	6
Maireana planifolia	Flat-leaved bluebush	1
Maireana pyramidata	Sago bush	19
Maireana thesioides	Lax bluebush	3
Maireana tomentosa	Felty bluebush	3
Maireana triptera	Three-winged bluebush	4
Maireana villosa	Silky bluebush	4
Melaleuca sp.	Paper bark	1
Monachather paradoxus	Broad-leaved Wanderrie	2
Ptilotus macrocephalus	Pussy tail Mulla mulla	2
Ptilotus obovatus	Cotton bush	19
Rhagodia drummondii	Lake fringe rhagodia	8
Rhagodia eremaea	Tall saltbush	18
Rhodanthe chlorocephala	Everlasting daisy	1
Scaevola spinescens	Currant bush	1
Schoenia filifolia	Everlasting daisies	1

Sida calyxhymenia	Tall sida	3
Solanum lasiophyllum	Flannel bush	15
Stipa scabra		1

*Number of samples collected over the study period

Appendix 2: Description of land systems found on Plates 3.1 and 3.2.

	Land system	General description
Gab	Gabanintha	Ridges and rounded hills of basalt, dolerite, jaspilite and greenstone.
Chl	Challenge	Gently undulating plains with occasional hills, tors and low breakaways on granite.
Ner	Nerramyne	Plains and low rises on weathered granite above sandy drainage plains.
Vio	Violet	Undulating plains with stony and gravely mantles and low rises with limonite.
Kal	Kalli	Level to gently undulating plains of red sand over laterite.
Tin	Tindalarra	Very gently inclined wash plains with concentrated drainage zones.
Rai	Rainbow	Level to very gently inclined wash plains.
Ero	Ero	Tributary flood plains on hardpan.
Car	Carnegie	Salt lakes with fringing alluvial plains, kopi dunes and sandy banks.
Mil	Mileura	Calcrete platforms and alluvial plains with saline soils.
Jun	Jundee	Level to very gently inclined wash plains with mantles of fine ironstone gravels.
Euc	Euchre	Low breakaways with short saline foot slopes.
Tal	Tallering	Prominent ridges and hills of banded ironstone, dolerite and sedimentary rocks.
Wil	Wiluna	Low lateralised hills of amphibolite, schist and greenstone with extensive lower slopes and stony plains.
Wat	Watson	Hills, rises and gravely plains on sedimentary rocks.
Yew	Yewin	Broad saline flood plains with low kopi dunes, drainage foci and claypans.

Rac	Racecourse	Partly calcreated alluvial plains.
Mon	Monk	Very gently inclined wash plains with occasional wanderrie banks in lower areas.
Jos	Joseph	Undulating yellow sandplain with very dense mixed shrublands.
Lab	Lake bed	Lake bed unit of the Carnegie land system

(Payne et al. 1998)

Appendix 3: Description of dominant soils and vegetation types on the study site land systems.

Land system	Soils	Vegetation
Gabanintha	Stony soils and shallow stony red earths.	Very scattered to scattered tall shrublands of *Acacia quadrimarginea* or *Acacia. aneura; Ptilotus obovatus* a common undershrub.
Challenge	Shallow coarse red clayey sands on granite.	Scattered mixed shrublands with *A. anuera* or *A. quadrimarginea* tall shrubs.
Nerramyne	Shallow coarse red clayey sands on granite.	Scattered to moderately close tall shrublands of *A. quadrimarginea* and other acacias.
Violet	Shallow red earths on greenstone.	Very scattered to scattered *A. aneura* and *Acacia ramulosa* tall shrublands with sparse wanderrie grasses.
Kalli	Deep red clayey sands, occasionally overlying ferruginous gravels.	Moderately close to close tall shrublands of *A. ramulosa* and *Acacia coolgardeniensis* with wanderrie grasses.
Tindalarra	Deep red earths or shallow hardpan loams on hardpan.	Scattered to moderately close tall shrublands co-dominated by *A. ramulosa, A. aneura, Acacia grasbyi* and *Acacia acuminata* subsp. *burkittii* (fine leaf jam).
Rainbow	Shallow and deep red earths on hardpan or deep red clayey sands on gravel.	Scattered to moderately close acacia tall shrublands.

Ero	Shallow duplex on hardpan, shallow hardpan loams and deep duplex soils.	Very scattered to scattered low halophytic shrublands may be dominated by *Atriplex bunburyana* or *Maireana pyramidata*.
Carnegie	Shallow duplex on hardpan or occasionally calcrete.	Scattered halophytic low shrublands, may be dominated by *Atriplex vesicaria* or *A. bunburyana*.
Mileura	Variable depth duplex and clays, with shallow hardpan loams and shallow red clayey sands on calcrete or hardpan.	Scattered halophytic low shrublands, occasionally dominated by *A. bunburyana,* also scattered *Acacia eremaea* tall shrubland with halophytic undershrubs.
Jundee	Shallow hardpan loams or red clayey sands on hardpan, with deep red earths, occasionally on hardpan.	Scattered to moderately close *A. aneura* tall shrublands.
Euchre	Shallow red earths or shallow red clayey sands on hardpan or deep red earths.	Scattered to moderately close eucalypt woodland with acacia tall shrublands and *Amphipogon* spp. or *Monachather paradoxa* perennial grasses.
Tallering	Shallow red earths and stony red earths.	Scattered to moderately close tall shrublands of acacia.
Wiluna	Shallow stony red earths or stony soils.	Scattered mulga shrublands.
Watson	Very shallow red earths on parent rock or gravel.	Moderately close tall shrublands of *A. ramulosa*.

Yewin	Shallow (occasionally deep) duplex on hardpan.	Scattered to moderately close low shrublands or mixed height shrublands dominated by *M. pyramidata, Cratystylis subspinescens* or *Atriplex* spp. below *A. eremaea* and *Acacia masliniana*.
Racecourse	Deep clayey or duplex soils, shallow calcareous loams and red earths on calcrete and hardpan.	Moderately close *Acacia tetragonophylla* tall shrublands.
Monk	Red earths on hardpan at variable depth.	Generally scattered *A. aneura* tall shrublands, denser in groves.
Joseph	Deep yellow and red clayey sands.	Close to closed mixed shrublands commonly with acacia and melaleuca tall shrubs and low heath shrubs, or moderately close to close *A. ramulosa* tall shrublands.

(Payne *et al.* 1998)