Chapter 1 General introduction

Chilean needle grass (*Nassella neesiana* (Trin. & Rupr.) Barkworth, CNG) is a highly invasive perennial spear grass (Gardener 1996; Storrie and Gardener 1998). Concern about the invasion of pastures in southeastern Australia by CNG began to mount in the 1970s. Native to temperate South America, CNG can completely over-run pastures resulting in canopy cover of up to 60%. Such infestations lead to a substantial reduction of stock carrying capacity during the summer months when the weed produces large quantities of unpalatable flower stalks. By the 1990s many farmers in New South Wales and Victoria found that they had expanding cover of CNG in their paddocks. Furthermore, the weed has been invading conservation areas comprising of native grasslands, grassy woodlands and riparian vegetation in many areas.

Studies undertaken at the University of New England in the mid 1990s determined the basic biology and ecology of this weed and the mechanisms behind its reproductive success and invasive potential (Gardener 1998). A gap in the knowledge for achieving long-term control of this weed was appropriate grazing management strategies that both suppressed and better utilised the weed. CNG has become naturalised in Australian pastures and land managers have had little success in controlling it. A potential strategy is to manage it as a pasture species (Gardener 1998). Feed evaluation trials in northern New South Wales showed that if managed correctly, CNG may be able to provide feed of moderate value to livestock. This finding was in contrast to much of the information then available in Australia, which suggested that CNG had such low palatability that stock would graze it only as a last resort (Duncan 1993; Gardener 1998).

The key goal in successfully managing CNG in a pasture is the reduction in the number of flowering tillers. This has two main benefits – increasing the plant's feed value during the summer months and reducing seed production, and therefore, dispersal and further invasion of pastures and natural ecosystems.

Gardener (1998) observed that seed production appeared to be sensitive to an interaction between temperature and rainfall. It is likely then that variation in plant behaviour due to climate will strongly affect management options, making work undertaken in northern New South Wales less relevant to Victorian infestations. This means that management recommendations will not be easily generalised from one region to the next and management trials will need to occur in the different climatic regions. The hypothesis to be tested in this thesis is that CNG can be utilised through grazing for both animal production and to reduce its populations in agricultural situations.

Over a 3 year period, glasshouse trials, and field trials spanning the known naturalised range of CNG, were undertaken on grazing properties from Glen Innes and Goulburn in New South Wales to Toolleen and Greenvale in Victoria. The aim of these trials was to discover how to maximise the usefulness of this plant for animal production while at the same time keeping it in check, by establishing the:

1. feed value of CNG in a southern infestation over 2 seasons with clipping or modified soil fertility when compared with cocksfoot (*Dactylis glomerata*);
2. ability of CNG to grow in soils of different fertility and pH when compared with phalaris (*Phalaris aquatica*);
3. growth response of CNG to chemical control strategies and pasture competition when integrated with grazing management; and
4. species of grazer and grazing management system suitable for CNG infestations.

This thesis combines work undertaken in two projects as part of the CNG National Strategy (Weeds of National Significance) - the CNG Regional Best Practice Management and CNG Grazing Management for Long-term Utilisation and Control projects. Botanical nomenclature used within this thesis is according to the CSIRO Handbook of Economic Plants of Australia (Lazarides and Hince 1993).

Chapter 2 Literature review

In this thesis I aim to investigate grazing management for long term utilisation and control of Chilean needle grass (*Nassella neesiana* (Trin. & Rupr.) Barkworth, CNG). As background in this chapter I briefly review literature on the impacts of CNG, how to distinguish it from other similar species, its lifecycle, spread and seedbank. Specific literature relating to each experimental hypothesis will be reviewed in the relevant chapter.

2.1 Chilean needle grass background

CNG is able to tolerate drought and heavy grazing creating a huge potential to spread and overrun existing vegetation (Gardener 1996). CNG has been recognised as potentially the worst environmental weed of grasslands in southeastern Australia (McLaren *et al.* 1998). In Victoria, weed scientists have seen CNG choke out trial plots of serrated tussock (Hocking personal communication) and claim that it is poised to become one of the greatest threats to agriculture (Hunt 1996).

One of the main reasons for the success of CNG is its seed production. CNG is able to produce panicle seeds, stem seeds (cleistogenes) and underground seeds (basal cleistogenes) to extend its seeding period (Figure 2.1). In Hawke's Bay, New Zealand, reproductive stems have been observed at densities of 793 ± 128/m^2, each with an average of 38 seeds per panicle. This equates to an estimated seed yield of 30,148 ± 4877 seeds/m^2 (Slay 2001).

In its country of origin, Argentina, CNG is considered to be an important high value winter stock feed, whilst the plant is still in its vegetative state (Rosengurtt *et al.* 1970). However, during the warmer months in Australian conditions (spring and summer), the production of large amounts of unpalatable flower stalks and very little leaf causes a severe reduction in plant palatability and reduces stock carrying capacity by up to 75% (Duncan 1993; Gardener 1996; Storrie and Gardener 1998).

Figure 2.1 3 seed types of Chilean needle grass (top to bottom; stem cleistogenes, panicle seeds, basal cleistogene).

2.2 Chilean needle grass identification differentiation

There are several factors that aid in the identification of CNG in relation to other similar looking grasses. Tussocks of CNG are mushroom shaped in appearance and have leaves up to 20 cm long on average (Slay 2002b). The growth form of CNG is rather more like that of Ryegrass (*Lolium* spp.) or Cocksfoot (*Dactylis glomerata* L.) than the very pronounced tussock growth of plants such as serrated tussock (*Nassella trichotoma*) and the common native tussock grass (*Poa labillardieri* Steud.)(McLaren *et al.* 2004). Duncan (1993) found that CNG plants growing in New South Wales can be distinguished from other similar looking grasses as the leaves of CNG are hairy, unlike *Festuca arundinacea* and *Austrodanthonia* spp.

Gardener (1996) found that the corona (crown/ raised ring of barbs) at the junction of the seed and the awn (Figure 2.2) is the best feature for distinguishing CNG from native spear grasses (*Austrostipa spp.*) grasses. Wallaby grasses (*Austrodanthonia* spp.) are similar looking grasses to CNG yet they have a distinct tuft of hairs at the collar and the lower side of their leaves is sparsely hairy, unlike CNG which is hairy (Slay 2002b). Certain Brome grasses (*Bromus* spp.) have a similar nodding seed head to CNG, although Slay (2002b) found these seed heads to be a lighter violet colour with shorter finer awns extending from a tapered lemma.

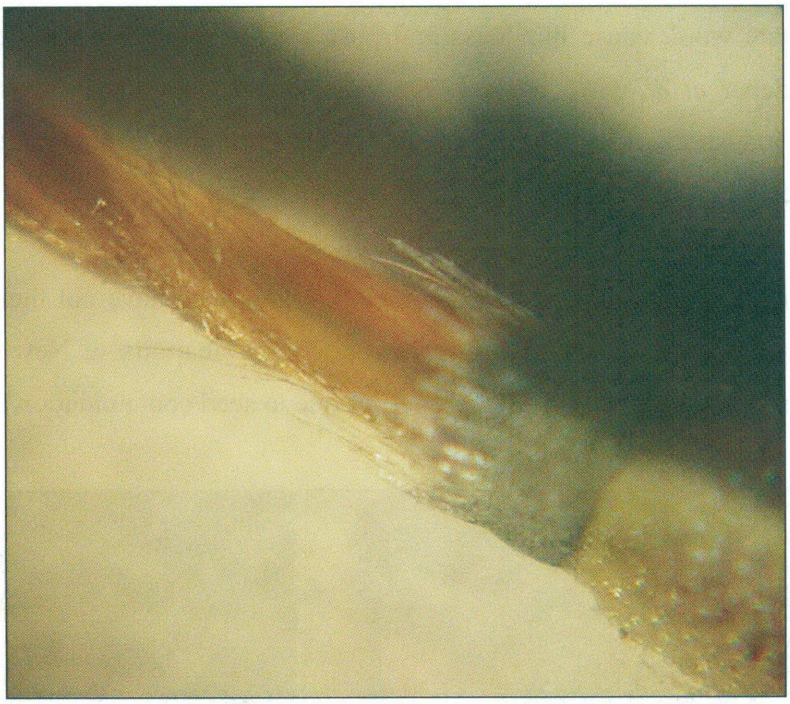

Figure 2.2 Corona at the junction of the panicle seed and the awn on CNG.

2.3 Impact of Chilean needle grass

2.3.1 Competition, productivity and competitiveness

As a weed, CNG is an environmental and agricultural concern as it can withstand moderate to severe water stress and can thrive in both high and low fertility, thus making it highly competitive against introduced and native pastures, and disruptive of summer grazing systems (Slay 2002b; c). CNG slowly establishes a dense grass mat, with a canopy that can occupy up to 60% of pasture and builds up seed reserves in the soil by means of highly efficient seed production (Gardener 2001; Slay 2002b; c). It has been observed that with no active management, CNG can spread at a rate of 120-140 m per year (Slay 2002b).

2.3.2 Stock and physical problems

The very sharp pointed seed of CNG means that infested pasture whilst in head should not be grazed, and is unlikely to be grazed by stock, especially by sheep (Slay 2002c). Grazing CNG paddocks whilst the weed is seeding is likely to damage sheep pelts, contaminate wool, cause blindness and pose a general welfare risk to livestock (Figure 2.3)(Gardener *et al.* 1996; Nair 1993; Slay 2002b). For these reasons Department of Primary Industries officers in north east of Victoria have recommended farmers exclude their stock when CNG begins seeding (Patterson 2001).

The panicle seeds also pose a risk to meat workers who have cut their hands on panicle seeds as they push the hides off carcasses. Some abattoirs in New South Wales have rejected stock from CNG infested properties due to seed contamination (Woods 2003).

Figure 2.3 Examples of CNG seed contamination in gum of horse and fleece on lamb.

2.4 Chilean needle grass lifecycle and seed production

2.4.1 Seed types

CNG has three types of seed - panicle seeds (physically exposed sexual parts; chasmogamous flowers), axillary/stem cleistogenes (less floral parts that originate from nodes under leaf sheath) and basal cleistogenes (subterranean seeds)(Gardener 1998).

2.4.2 Seedbank and recruitment

Germination of viable seed has been observed to occur in two distinct flushes, spring and autumn, as regulated by rainfall (Duncan 1993) and light (Slay 2002b). (Duncan 1993) claims that CNG will germinate at other times of the year given adequate soil moisture and temperature. In glasshouse germination experiments, CNG seed requires either a 16 hour photo period with small temperature fluctuations (18-25^{o}C) or a large temperature fluctuation if in darkness (Duncan 1993). From these results it can be assumed that for winter dominant rainfall areas, germination of CNG can be expected in autumn (once the pasture opens up and creates bare soil patches), or in both autumn and spring if in cultivated/fallowed soils (Bourdot and Hurrell 1992). This hypothesis is supported by Slay (2002b), who observed that soil patches bared by herbicides with a high soil seedbank were a cause for CNG re-infestation. Gardener *et al.* (1998) also claims that the triggers for the germination of CNG may be bare soil and light.

Once flowering has concluded and the reproductive stems become senescent, the stems may rupture and release cleistogenes. Likewise, if the flowering process was interrupted (e.g. sprayed with herbicide or grazed/mown), terminal buds of future tillers can become activated (Slay 2002a). Cleistogene seeds are the first seeds to germinate in bare soil over autumn. Panicle seed may not germinate until mid winter when the hardened palea and lemma have softened and allow germination (Gardener *et al.* 1998). Basal cleistogenes are initiated during vegetative growth of tillers (Gardener 1998).

CNG seedbanks have been recorded to have between 4,000-18,000 seeds/m^2 under old pasture in New Zealand or up to 11,377 seeds/m^2 in New South Wales (Bourdot and Hurrell 1992; Gardener *et al.* 2003b).

The seedbank of CNG has been shown to persist for at least 3 years with an estimation of 12.4 years for the soil seedbank to reach 10 viable seeds/m^2 from a seedbank of 7123 seeds/m^2 (Gardener 1998; Gardener *et al.* 2003b).

The seed bank of CNG can therefore be maintained with very low inputs of seeds even in poor years (Gardener *et al.* 1998). The persistence of the seedbank is due to the dormancy and after ripening effects of the seeds. The palea and lemma surround the caryopsis (endosperm, embryo and seed coat) and provide mechanical restraint to growth of the root and the shoot by restricting water and gas uptake, supplying chemical inhibitors and modifying the caryopsis response to light (Gardener 1998).

2.4.3 Flowering and seed production

CNG flowering can be determinant (one flowering period) if the plant is not disturbed by grazing and the seasonal conditions are suitable for further growth (Gardener 1998). The main flush of reproductive tillers occurs in spring (September to October) with anthesis occurring in the middle of October. If flowering is disturbed (e.g. by grazing) then flowering will be indeterminant and may occur throughout the summer period when water is available (Figure 2.4). The seeds of CNG are considered to be viable after the formation of the milky endosperm (Gardener 1998), referred to as the milky dough stage. The viability of individual seeds can be assessed using tetrazolium or by squeezing with tweezers to ensure seeds are full (Pritchard 2003).

Figure 2.4 Paddock view and close up view of Chilean needle grass flowering (Greenvale, November 2003).

The basal cleistogenes of CNG are mature prior to the time of panicle seed flowering but are retained until the plant dies and the leaf sheath decays or is destroyed (Slay 2002b). Thus, cleistogenes, representing up to 25% of total seed production, could be released by dead vegetative tillers and assure regeneration of CNG in the absence of panicle seeds (Gardener *et al.* 1998; Slay 2002c). In New Zealand, viable panicle seed has been harvested within 8 days of flowering. Axillary cleistogenes of CNG growing in northern New South Wales have been found to be mature four weeks after panicle anthesis (Gardener *et al.* 2003a). The axillary cleistogenes are retained until the stem ruptures or breaks down (Slay 2002b).

2.4.4 Seed fall

Over the summer months, the mature panicle seeds fall out of the seed heads onto the ground or attach to moving vectors. The awn of the panicle seeds facilitates the attachment of seed or burial of these seeds into the ground or organic matter such as manure (Figure 2.5). The hydroscopic motion of the awn causes the seed to penetrate into the soil and organic matter after wetting and drying (Duncan 1993; Gardener 1998).

Figure 2.5 Chilean needle grass seed imbedded in cattle manure.

2.5 Seed dispersal

Most propagules of CNG will not naturally move far from the parent plant, although the panicle seeds will readily attach to certain moving objects via the callus (backwards facing hairs) at the point of the seed (Gardener *et al.* 2003a). The majority of seeds are spread by livestock, wildlife and machinery, with some spread by pets and infested hay (Duncan 1993; Slay 2002b).

2.5.1 Wind

Wind dispersal is negligible for the seeds of CNG (Duncan 1993). Over two thirds of CNG seed spread no more than 1 m from its parent plant with 31% falling between 1- 2 m and only 2.1% spreading greater than 2 m (Gardener 1998). Slay (2001) observed that panicle seeds can be shed in one strong wind event during summer once they are fully mature.

2.5.2 Cattle

The seeds of CNG are said to be unable to penetrate the hides of cattle (Gardener 1998), but they and have been known to pass through the gut of cattle without causing any gut damage (when mixed with supplements). Of the 1.7% and 5.3% of panicle and cleistogamous seeds respectively that passed through the gut of cattle undamaged 30% and 50% were viable respectively (Gardener 1998).

2.5.3 Sheep

Sheep are an effective means of dispersal as they can carry up to 25% of a given seed load for up to 5 months in their fleece – especially head and belly wool (Gardener 1998). However these seeds lacked awns after 5 months so their chance of penetrating the soil surface to germinate was reduced. Shearing at seed set of CNG significantly reduced the occurrence of seeds lodging in fleeces of sheep, but it should be noted that seed set can occur over an extended period in which time a sheep's fleece may regrow and seeds may become attached.

2.5.4 Vehicles and machinery

The basal cleistogenes of CNG can act as a means of CNG dispersal after cultivation as they can be transported around the paddock in dead tussocks and not be released for up to 18 months (Slay 2002b). Anecdotal evidence indicates that seeds will readily attach to vehicles and machinery such as tractors and slashers during the flowering period (Figure 2.6).

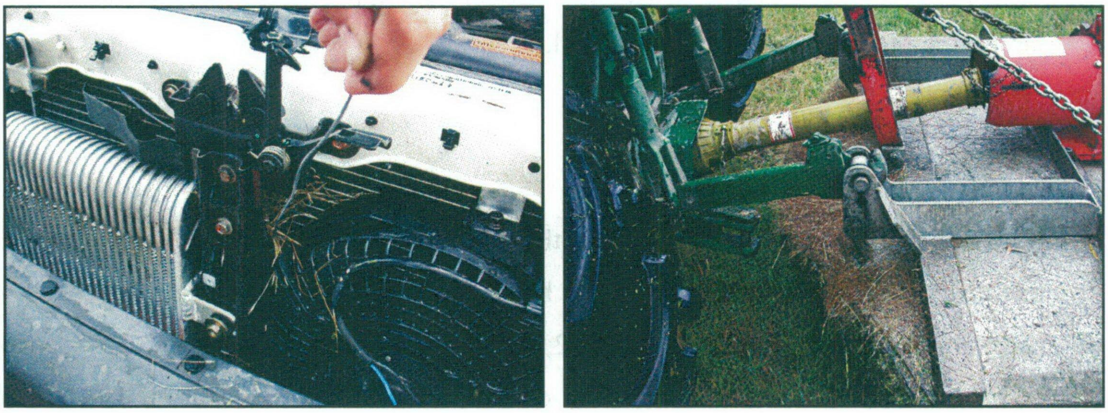

Figure 2.6 Chilean needle grass panicle seeds attached to vehicle radiator and slasher.

2.6 Management strategies

The directions and view of CNG management have changed as a result of recent research into CNG. In the past, some farmer organisations have claimed that the control of CNG is 'too big a job for farmers to handle themselves'(Nair 1993). A number of landholders on the New South Wales Tablelands have found it virtually impossible to control CNG and so are now adjusting their farm management to be able to live with it and utilise it to the best of their ability (Lowien 2002). Recent research indicates that once naturalised, eradication of CNG is unlikely with the current control options available (Slay 2002c). New South Wales Department of Primary Industries advises to not consider eradication once CNG is established and has set seed in an area (Storrie and Gardener 1998). Gardener (2003b) states 'the seedbank of CNG will remain despite any actions taken to control adult plants or reduce input into the seedbank.' For these reasons, the management ideals for CNG are changing to focus on the long term utilisation and management of CNG. In all instances of control, management should aim to reduce the soil seed bank and create conditions unfavourable for CNG growth in pasture (Storrie and Gardener 1998). The most difficult years in which to be able to achieve these goals will be during droughts when gaps in the pasture make it susceptible to invasion (Hawke's Bay Regional Council 2002). The seedbank of CNG in the soil can be reduced by suppressing the production of seed or increasing the decline of seed in the soil.

2.6.1 Reducing seed input

Reduced levels of re-infestations from the soil seed bank can be achieved within relatively few years if seed input is prevented. It has been hypothesised that this could be via annual herbicide applications (Campbell 2002; Gaur *et al.* 2005; Grech *et al.* 2004; Grech and McLaren 2005; Pritchard 2004) or by cultivation (Bourdot and Hurrell 1992). However, Gardener *et al.* (2003b) disagree with this theory, and state that it is almost impossible to prevent the input of seeds into the soil seed bank, especially cleistogenes, as they are able to survive slashing, heavy grazing and burning.

2.6.2 Increasing seed destruction

To remove viable seed from the seedbank, the seed needs to be stimulated to break dormancy and germinate (Gardener 1998). The seedbank can be stimulated to germinate by soil disturbance, increasing light intensities/decreasing plant canopies, and lowering competition for soil resources from other plants (Gardener 1998). To achieve these outcomes it may mean altering the environment of the top 25 mm of the soil profile, since this is where the majority of germination takes place (Bourdot and Hurrell 1992). Soil residual herbicides such as flupropanate have been known to limit CNG reinvasion from the soil seedbank (Taskforce 2006).

In germination trials Gardener (1998) found that 29.1% of emerged seedlings in a glasshouse were from cleistogenes where as 46.9% of emerged seedlings in the field were from cleistogenes – implicating cleistogenes as a major source of re-infestation in the field.

Decomposition of seeds was found to increase proportionally with the time in the ground but inversely with seed depth. After 2 years, 65% of seed was viable when buried at 25-50 mm whilst 48% of seed was viable when buried at 0-25mm (Gardener 1998). This observation is supported by Bourdot and Hurrell (1992), who had up to 24% of CNG seed remaining viable when buried at 250 mm for 6 years compared with only 5% or 0.1% at 25 mm or on the surface respectively. Farm management operations such as cultivation should not exceed 25 mm where CNG is a problem as an increasing proportion of buried seeds will attain a state of dormancy if buried at depth. This recommendation is supported by the fact that 99% of the seedbank is in the top 25 mm of the soil and deeper cultivations are not necessary to encourage seedbank germination (Bourdot and Hurrell 1992).

2.7 Experimental directions

The hypotheses to be tested in this thesis are as follows.

2.7.1 Feed value and utilisation analysis (Chapter 3)

- CNG is suitable as a source of fodder for grazing animals.
- The feed value of CNG can be improved by the addition of nitrogen fertiliser, phosphorus fertiliser and clipping.

2.7.2 Vegetative growth manipulation (Chapter 4)

- Manipulating soil phosphorus, nitrogen and pH can be used to suppress CNG growth.

2.7.3 Response of CNG to management treatments in different regions of Victoria and New South Wales (Chapter 5)

- Grazing management can reduce the CNG pasture population in different regions.
- Flupropanate will selectively control CNG in different regions.
- Regionally specific pasture renovation techniques will assist pastures to compete against CNG.

2.7.4 Limit seedhead production and maintain animal welfare in grazing systems (Chapter 6)

- Cattle are more suited to grazing CNG than sheep.
- Different grazing management methods can minimise CNG seed production.

Chapter 3 Feed evaluation of Chilean needle grass (*Nassella neesiana*) & cocksfoot (*Dactylis glomerata*) under clipping, with phosphorus and nitrogen fertiliser addition

3.1 Abstract

Chilean needle grass *(Nassella neesiana* (Trin. & Rupr.) Barkworth, CNG) is not considered to be a high value fodder grass as it produces unpalatable flower stalks and little leaf material in summer. However, its ability to persist and produce green feed in late autumn provides some desirable characteristics that make it comparable to other dryland grasses. This chapter describes an experiment that commenced in spring 2003, comparing the feed value of CNG to cocksfoot (*Dactylis glomerata*, CF) under clipping regimes with nitrogen and phosphorus fertiliser additions to keep plants vegetative and improve feed value.

The regrowth of clipped CNG and CF both had a more favourable feed value than unclipped plants. Clipped regrowth of both species, from September 2003 onwards, generally had significantly more crude protein, metabolisable energy, digestible dry matter, with significantly less dry matter and neutral detergent fibre than unclipped growth.

CF generally responded better to clipping than CNG plants throughout the season. Regrowth of clipped CF plants had significantly more crude protein, metabolisable energy, and digestible dry matter with less neutral detergent fibre and dry matter than CNG regrowth over the 2003 and 2004 seasons.

CF plants responded better to nitrogen fertiliser addition than CNG plants. During spring 2003, CF and CNG regrowth in nitrogen fertilised plots had significantly more crude protein, metabolisable energy and digestible dry matter with significantly less neutral

detergent fibre than unfertilised regrowth. Fertilised CF regrowth had a more favourable feed value for a longer period than CNG regrowth. The feed value response of CF to nitrogen fertiliser was significantly better than the feed value response of CNG in terms of crude protein (spring 2003).

Phosphorus fertiliser did not affect the feed value of either species. Therefore the application of phosphorus should not be undertaken for the sole purpose of increasing pasture feed value.

Clipping of both CNG and CF proved to be a useful tool to maintain the feed value of the species during reproductive growth periods. The addition of nitrogenous fertilisers provided some limited short term feed value gains, if any over the spring period. Phosphorus fertiliser was ineffective in increasing feed value.

3.2 Introduction

Chilean needle grass *(Nassella neesiana* (Trin. & Rupr.) Barkworth, CNG) is considered to be of modest grazing value and a good winter feed in Argentina (Gardener 1996; Rosengurtt *et al.* 1970) and New Zealand as its feed value is similar to other dryland grasses of Hawke's Bay, New Zealand (Slay 2002a). CNG has desirable perennial characteristics that allow it to provide persistent pasture in late autumn, winter and early spring (Gardener 2001; Slay 2002b). But once CNG plants mature they consist of numerous unpalatable flower stalks and little leaf material (Dalton 2000) and the seeds are hazardous to grazing stock (Rosengurtt *et al.* 1970).

In CNG samples tested by Slay (2001), vegetative CNG had more crude protein (CP) than vegetative perennial ryegrass (14.5:9.9%), yet by the reproductive phases CNG had less crude protein than perennial ryegrass (6.4:9.9%). In terms of metabolisable energy, CNG (7.5 MJ/kgDM) was lower than perennial ryegrass (11.0 MJ/kgDM) during its reproductive and vegetative stages (Slay 2001).

Given that the feed value of CNG declines during the reproductive phases, management processes need to be put in place to prolong or increase the feed value of CNG during the reproductive phases.

Modifying the soil fertility has been known to enhance plant growth. Phosphorus (P) is a constituent of compounds involved in plant respiration, photosynthesis, energy expenditure, cell division and growth (Cayley and Saul 2001). Compounds that contain P are responsible for transport of substances across cell membranes, including the uptake of nutrients from soil and their movement through an organism. In the paddock, P moves between the soil, plants and animals.

Soil nitrogen (N) is linked to the production of amino acids and protein in plants (Gastal and Durand 2000) and has been used in unreplicated trials to increase the feed value of CNG in northern New South Wales (Gardener 2001). In 1996, June and May applications of 250kg/ha and 500kg/ha Nitram® (34% N) raised CNG crude protein to 13% and 19.9% respectively when measured during October. Other treatments of Nitram® at 125 kg/ha, molybdenum super phosphate (8.8% P, 11% S, 20% Ca, 0.05% Mo) at 125 kg/ha and 250 kg/ha and sulfur (98%S) at 20kg/ha and 40kg/ha did not significantly increase CNG crude protein. CP values of plants in the other treatments ranged from 5.5-8.7%. Most of the fertiliser treatments resulted in CNG having a greater digestible dry matter (DDM) than CNG in the control plots (Gardener 2001). The greatest DDM recorded was 64.3%, in plots where Nitrogen was applied at 500kg/ha Nitram®. In terms of pasture yield, no obvious trends were observed (Gardener 2001).

Physically modifying the plant such that it remains vegetative has been known to maintain plant feed values (Campbell 1997; DNRE 2002; NSW-Agriculture 1998). This can be done by means of rotational grazing with high stocking rates to reduce grazing selectivity, or by mechanical topping. Both means rely on removing mature plant growth such that new growth is stimulated.

CNG is commonly found growing in Victoria in pastures that contain cocksfoot (*Dactylis glomerata*, CF). CF is considered to be a desirable pasture as it has a modest feed value and is known to be tolerant of aluminium toxicity associated with acid soils (Morrow and

Brown 1997). CF is a suitable grass to use as a reference species for the feed evaluation comparison of CNG as they both grow in similar conditions yet CF is not perceived as a weed.

This experiment aimed to examine the effect of nitrogen and phosphorus and clipping of plants at different physiological growth stages throughout the year on comparative feed values of CNG and CF.

3.3 Materials and methods

3.3.1 Location

The experiment was conducted in an ungrazed field at Greenvale Victoria, on the property 'The Elms' (144.87°E, 37.63°S). The farm is on grey brown fine to very fine sandy loam soils with an Olsen P of 10 mg/kg (7.5mg/kg Bray1) pH 5.3 (1:5 water) and average annual rainfall of 543 mm. The pasture within the paddock was comprised of CNG, CF, Phalaris (*Phalaris aquatica*), Ryegrass (*Lolium perenne*) and subterranean clover (*Trifolium subterraneum*) with a recent history of sheep grazing. Background weeds include cape weed (*Arctotheca calendula*), oxalis (*Oxalis pes-caprae*) and onion grass (*Romulea rosea*).

3.3.2 Design and treatments

The trial consisted of five treatments in a randomised block design replicated three times. Treatments included addition of P fertiliser, N fertiliser and clipping, as separate treatments and in combinations (Table 3.1). Each treatment plot was 8 x 10m, marked by wooden posts, further subdivided into 6 subplots. A different subplot was used for each sampling event. Clipping treatments were applied using a petrol driven rotary mower with a catcher at the different physiological stages of growth, on or soon after sampling dates (Table 3.2). Fertiliser treatments were broadcast on 18 September 2003 with follow up N fertiliser application on 28 October 2003.

Table 3.1 CNG and CF feed evaluation (clipping and fertiliser) experimental treatments.

Treatment	P (kg/ha)	N (kg/ha)	Clipping
1	Control	Control	No
2	0	0	Yes
3	22^A	0	Yes
4	0	92^B	Yes
5	22^A	92^B	Yes

^{A} 250 kg/ha single super phosphate (8.8%P, 11%S, 19%Ca).

^{B} 200 kg/ha urea (46%N) – two split fertiliser applications each of 100 kg/ha over spring 2003.

Figure 3.1 Using the petrol driven catcher mower & mown plots.

3.3.3 Sampling

Sampling occurred at different physiological growth stages of CNG. The physiological growth stages of CNG were determined by observing CNG plants in the control subplots that were growing naturally (Figure 3.2, Figure 3.3).

At each sampling event, monocultures of CNG and CF were cut at grazing height using hand shears, collected for analysis and dried to constant mass (50°C) to determine dry matter content (% fresh wt). The herbage samples were then analysed by FEEDTEST, Department of Primary Industries, Hamilton, Victoria, for crude protein (CP as %DM) (nitrogen x 6.25), neutral detergent fibre (NDF as %DM), and dry matter digestibility (DDM as %DM). Values were estimated using near infrared spectroscopy (NIR). NIR spectra were collected on all samples using a Foss-NIRSystems 5000 scanning monochromator in conjunction with Infrasoft International (ISI) software. NIR calibrations for CP, NDF, and estimated *in vivo* DDM had previously been derived on large sample populations using the procedures of Shenk and Westerhaus (1991).

Reference methods used for NIR calibrations were as follows: CP using the Kjeldahl method, NDF by the method of Van Soest and Wine (1967) but using ANKOM® equipment and DDM using a pepsin-cellulase technique based on that of Clarke *et al.* (1982), with analytical values adjusted using a linear regression based on similar samples of known *in vivo* DDM. Any spectral outliers from the calibrations were analysed by wet chemistry techniques as described above.

Metabolisable energy (ME as MJ/kg DM) values were calculated from predicted DDM values, after first converting them to Digestible Organic Matter in the Dry matter (DOMD), then using the formula:
ME = 0.168 (DOMD% + EE%) – 1.19 (AFIA 2005). In this equation, DOMD is the percentage of digestible organic matter in the dry matter, and EE is ether extract (or crude fat), assumed to have a value of 2.0 for fodder samples (hay, silage and pasture).

Table 3.2 Feed evaluation sampling times.

Sampling event	Season	Growth stage	Sampling date	Clipping date
1	Spring	Vegetative	17 September 2003	24 September 2003
2	Spring	Seedhead development	24 October 2003	27 October 2003
3	Spring	Flowering	19 November 2003	20 November 2003
4	Summer	Seed fall	4 December 2003	-
5	Autumn	Vegetative	31 May 2004	31 May 2004
6	Spring	Vegetative	2 September 2004	14 September 2004
7	Spring	Seedhead development	19 October 2004	22 October 2004
8	Summer	Flowering/Seed fall	1 December 2004	1 December 2004
9	Spring	Vegetative	2 September 2005	-

Figure 3.2 Close up view of CNG physiological growth stages (left to right: CNG vegetative, CNG seedhead development, CNG flowering).

Figure 3.3 Paddock view of CNG physiological growth stages (left to right: CNG vegetative, CNG seedhead development, CNG flowering).

3.3.4 Statistical analysis

At each sampling event, each measurement was analysed using an analysis of variance using the reading obtained for one species (CNG or CF) as the unit of analysis (Table 3.3).

Table 3.3 Structure of each analysis of variance.

Terms	Degrees of freedom
Block Stratum	
Residual	2
Plot Stratum	
Clip (Clipping vs non-Clipping)	1
Nitrogen (0 vs 92 kg/ha) within Clipped	1
Phosphorus (0 vs 22 kg/ha) within Clipped	1
Nitrogen.Phosphorus within Clipped	1
Residual	8
Unit Stratum	
Species (CNG vs CF)	1
Species.Clip	1
Species.(Nitrogen within Clipped)	1
Species.(Phosphorus within Clipped)	1
Species.(Nitrogen.Phosphorus within Clipped)	1
Residual	10

3.4 Results

The effects of N and P on feed quality were relatively small and transient. Consequently, results are firstly presented with clipped plots averaged over nitrogen and phosphorus application rates.

3.4.1 Difference between CNG and CF feed value

Compared with CNG, CF had a more favourable feed value when considered across both clipped and unclipped treatments (Figure 3.5, Figure 3.6). Throughout the experimental period, CF had significantly higher crude protein percentage ($P < 0.05$), metabolisable energy content ($P < 0.001$) and digestibility ($P < 0.01$) with significantly less neutral detergent fibre ($P < 0.01$) and dry matter ($P < 0.01$)(See Table A3.1).

3.4.2 Effect of clipping across both CNG and CF

The feed value of regrowth from clipped CNG and CF was more favourable than unclipped vegetative material (Figure 3.4, Figure 3.5, Figure 3.6). (crude protein $P < 0.001$, metabolisable energy $P < 0.001$, neutral detergent fibre $P < 0.01$, digestible dry matter $P < 0.001$ and dry matter $P < 0.05$)(See Table A3.1).

3.4.3 Effect of interaction between species and clipping

CF generally responded better to clipping than CNG and had a greater benefit to feed value from clipping (Figure 3.5, Figure 3.6). The feed value gains were in terms of significantly more crude protein ($P < 0.05$) and metabolisable energy ($P < 0.01$) in late spring/early summer of 2003 and 2004, with significantly greater digestibility ($P < 0.01$) in late spring/early summer 2004 (See Table A3.1). However, the digestibility of CNG increased significantly more when compared with CF during November 2003 ($P < 0.01$) as the unclipped CNG had very low digestibility.

3.4.4 Effect of nitrogen fertiliser application across both CNG and CF

There was little evidence of interaction between nitrogen and phosphorus application. Thus the effect of nitrogen in CNG and CF, within clipped treatments, is averaged over phosphorus application rates.

Regrowth of CF and CNG in plots that were fertilised with nitrogen generally had a better feed value immediately following the fertiliser application. CF plants responded better to nitrogen fertiliser than CNG plants. (Figure 3.7, Figure 3.8, see Table A3.2). In November 2003, CF and CNG regrowth in fertilised plots had significantly more crude protein ($P = 0.00034$), metabolisable energy ($P = 0.0019$) and digestible dry matter ($P = 0.0019$) with significantly less neutral detergent fibre ($P = 0.00059$) than unfertilised regrowth. This trend did not continue for CNG regrowth past November 2003. In December 2003, CF plants in fertilised plots were still responding to the fertiliser and had significantly more crude protein ($P = 0.0022$), metabolisable energy ($P = 0.018$) and digestible dry matter ($P = 0.018$) with significantly less neutral detergent fibre ($P = 0.0063$) than unfertilised CF plants (Figure 3.7, Figure 3.8, see Table A3.2).

3.4.5 Interaction between species and nitrogen fertiliser application

Nitrogen fertilised CF plants responded significantly better and had more crude protein at November 2003 (P = 0.028) and December 2003 (P = 0.014) when compared with nitrogen fertilised CNG (See Table A3.2). Other significant responses between the species for digestible dry matter (day 351 and day 398) and metabolisable energy (day 398 and day 441) are deemed to be unreliable.

Figure 3.4 CNG feed value plots mowed at September 2003, and regrowth 30 days after September 2003 clipping.

3.4.6 Effect of phosphorus fertiliser application across both CNG and CF

There was little evidence of interaction between phosphorus application with either nitrogen application or species. Thus the effect of phosphorus, within clipped treatments, is presented after averaging over nitrogen application rates and species.

Phosphorous fertiliser did not affect the feed value of the individual species or the combined value of the two species to a significant level for management purposes (Figure 3.9, Figure 3.10, see Table A3.3). Significant responses during September 2003 (crude protein, metabolisable energy, neutral detergent fibre, digestible dry matter and dry matter) were observed prior to fertiliser application and are pretreatment data. Responses for crude protein (P = 0.027; Oct 2004), neutral detergent fibre (P = 0.049; Sept 2005) and dry matter (P = 0.033; Nov 2003) are independent responses that have little effect on the overall trends (See Table A3.3).

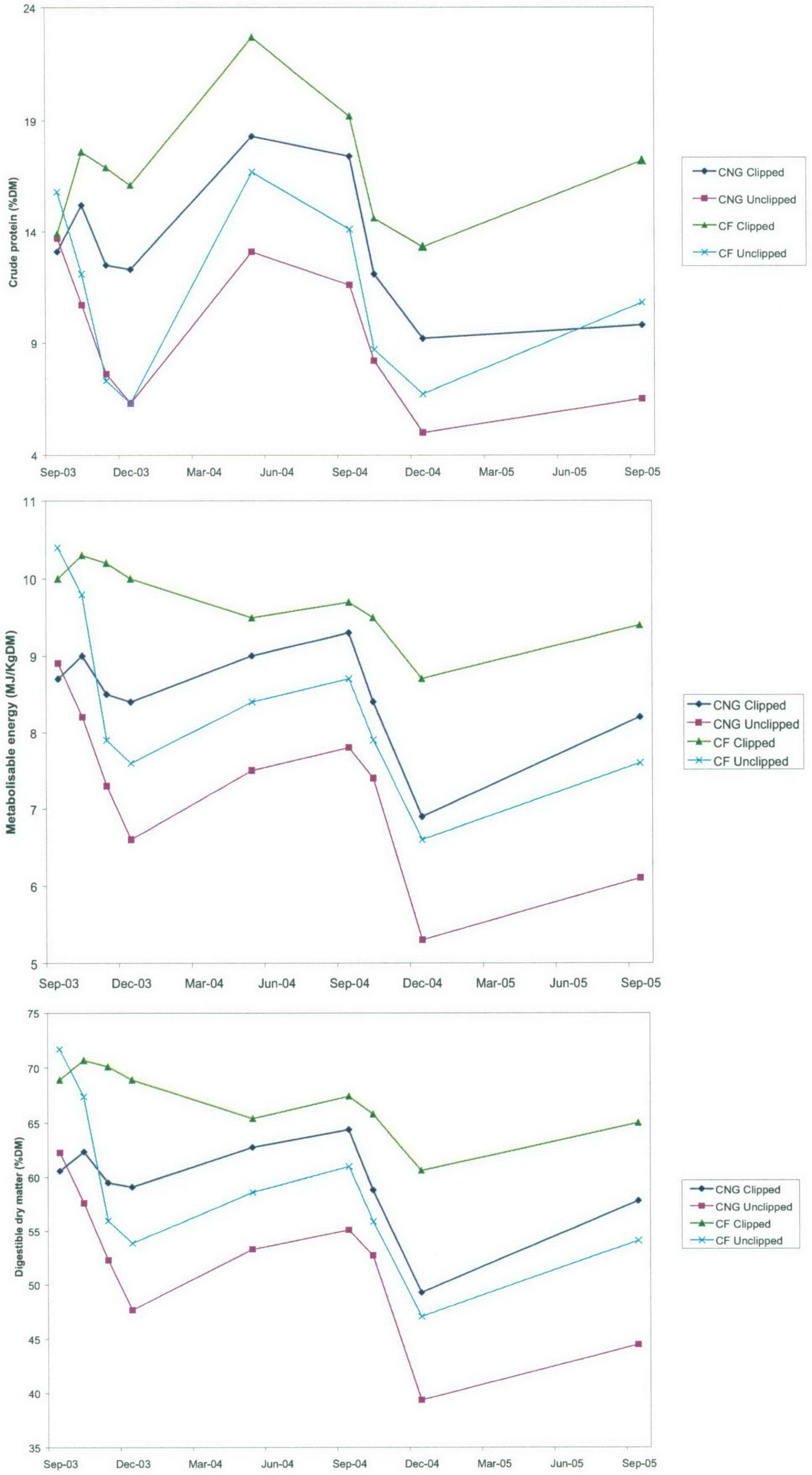

Figure 3.5 Effect of Clipping on the crude protein, metabolisable energy and digestible dry matter value of CNG and CF.

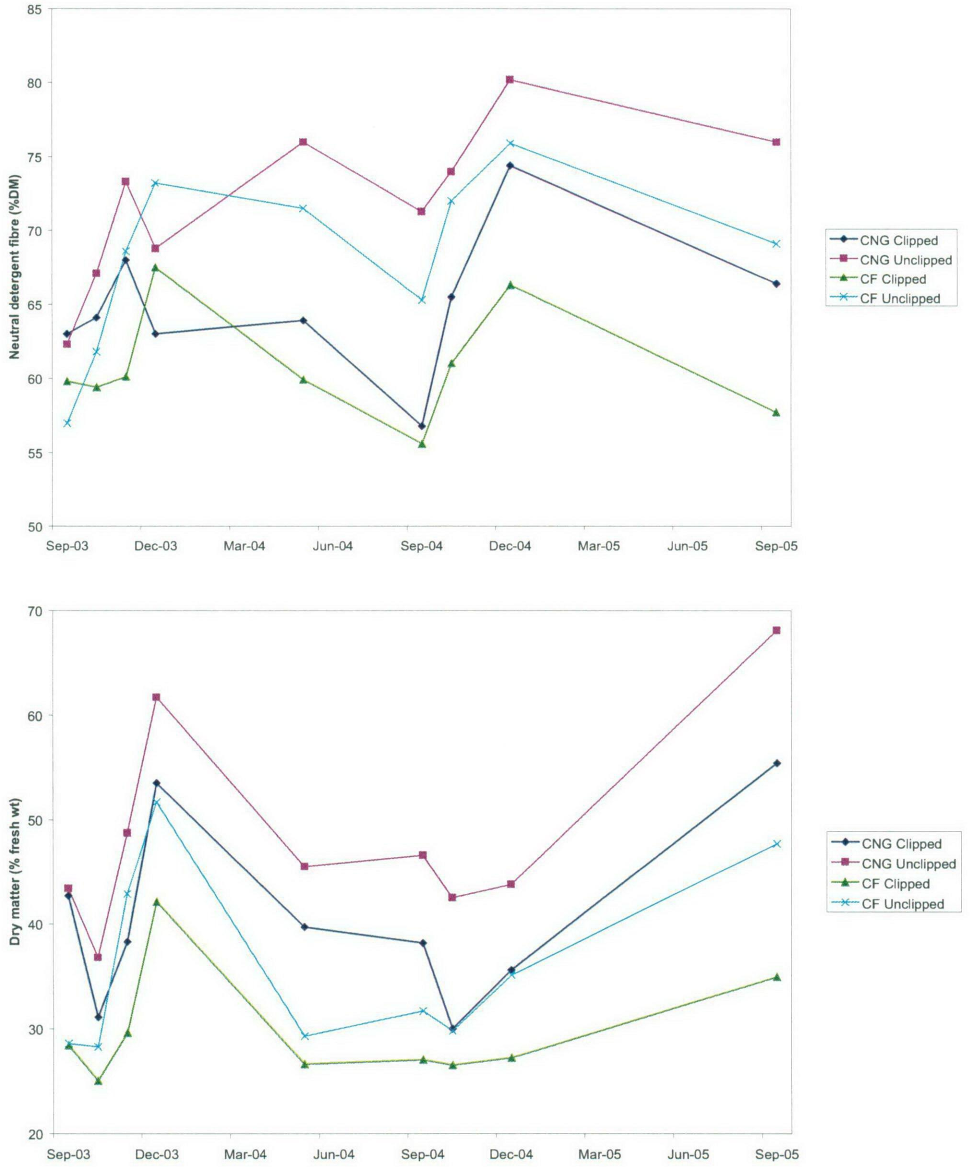

Figure 3.6 Effect of Clipping on the neutral detergent fibre and dry matter value of CNG and CF.

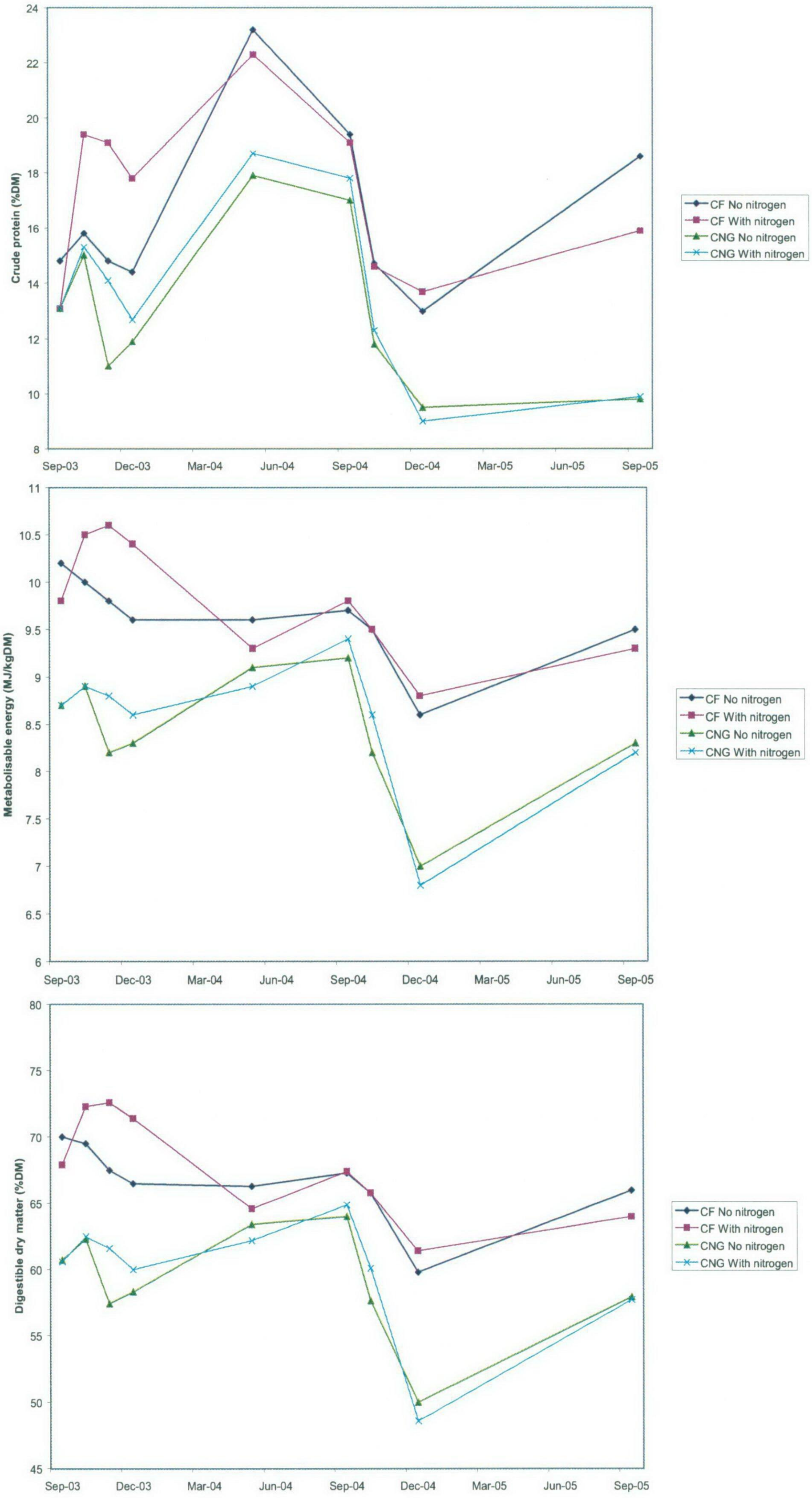

Figure 3.7 Effect of nitrogen fertiliser on the crude protein, metabolisable energy and digestible dry matter value of CNG and CF.

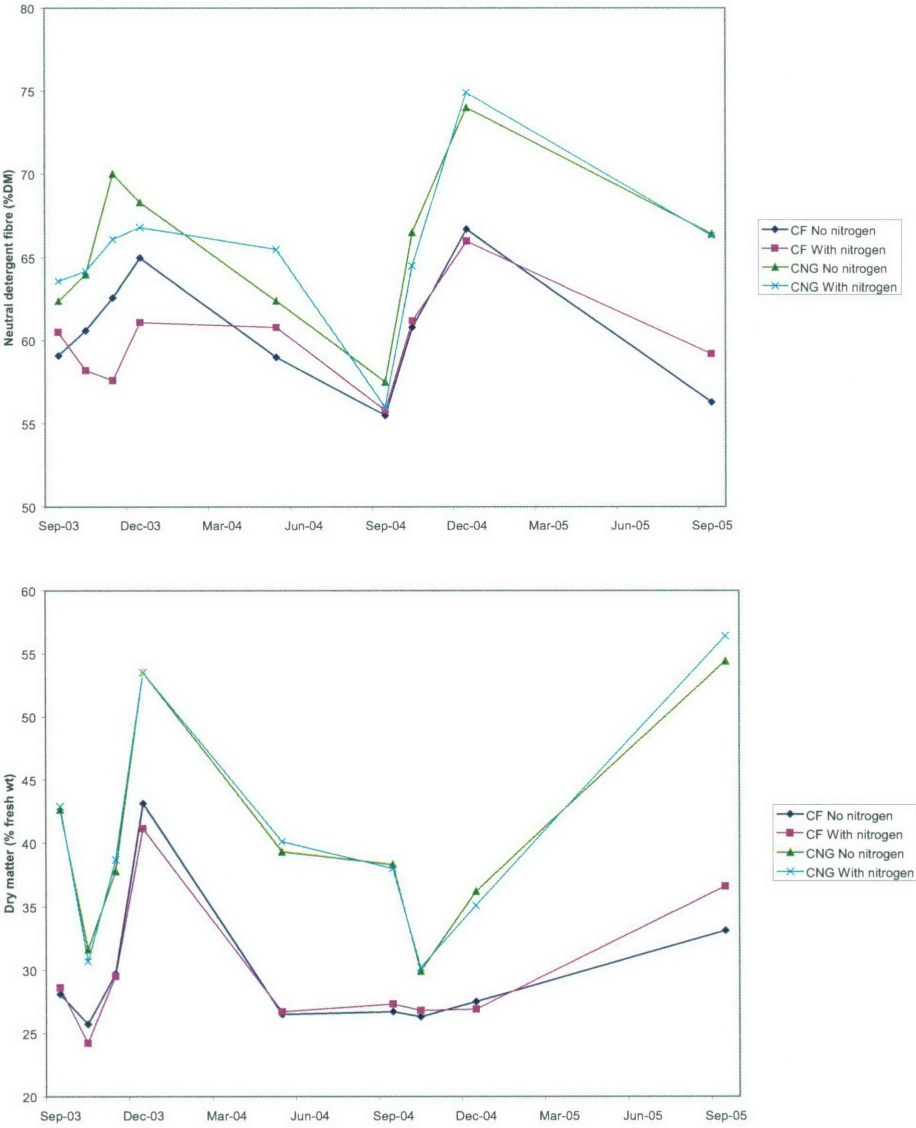

Figure 3.8 Effect of nitrogen fertiliser on the neutral detergent fibre and dry matter value of CNG and CF.

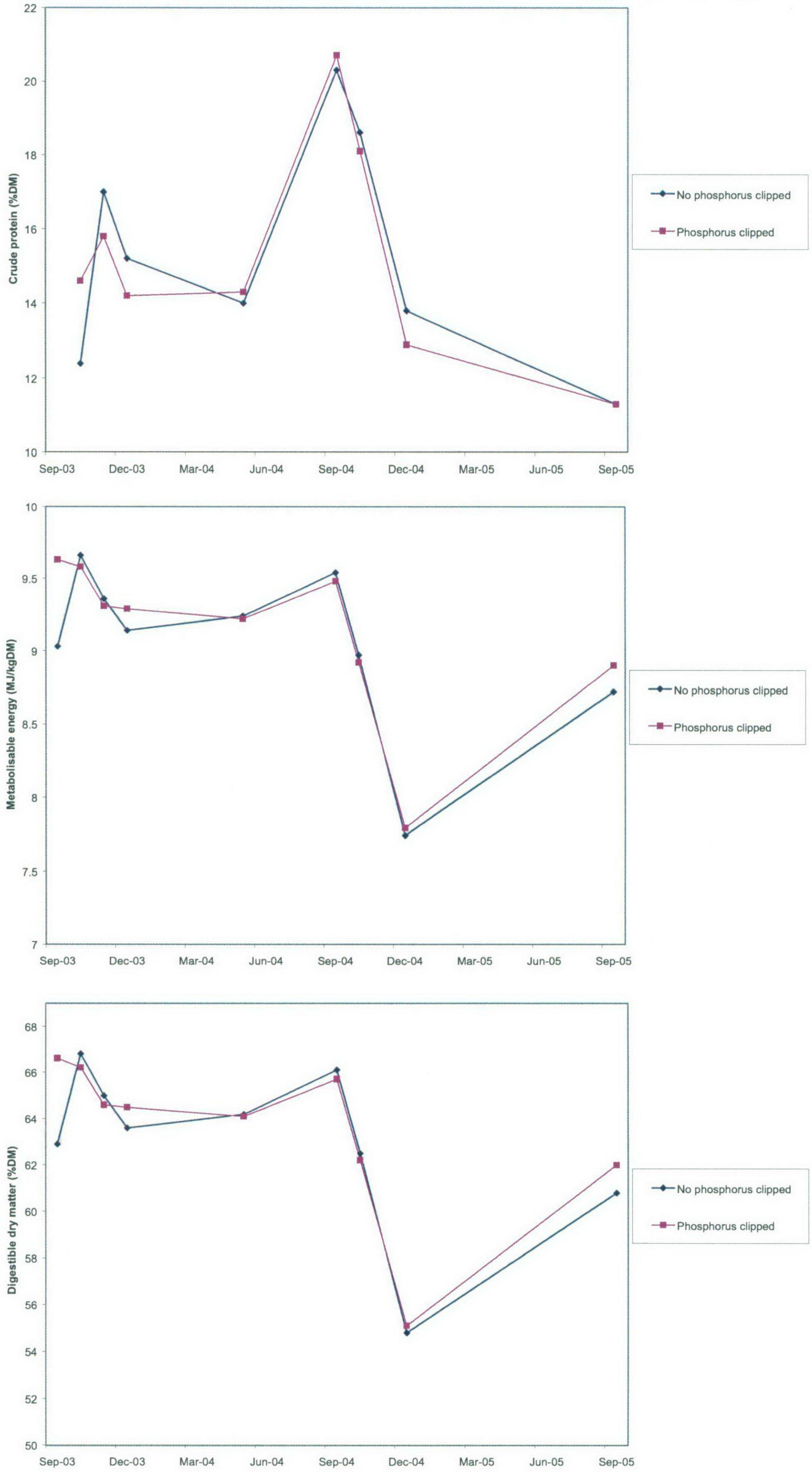

Figure 3.9 Effect of phosphorus fertiliser on the crude protein, metabolisable energy and digestible dry matter value of CNG and CF.

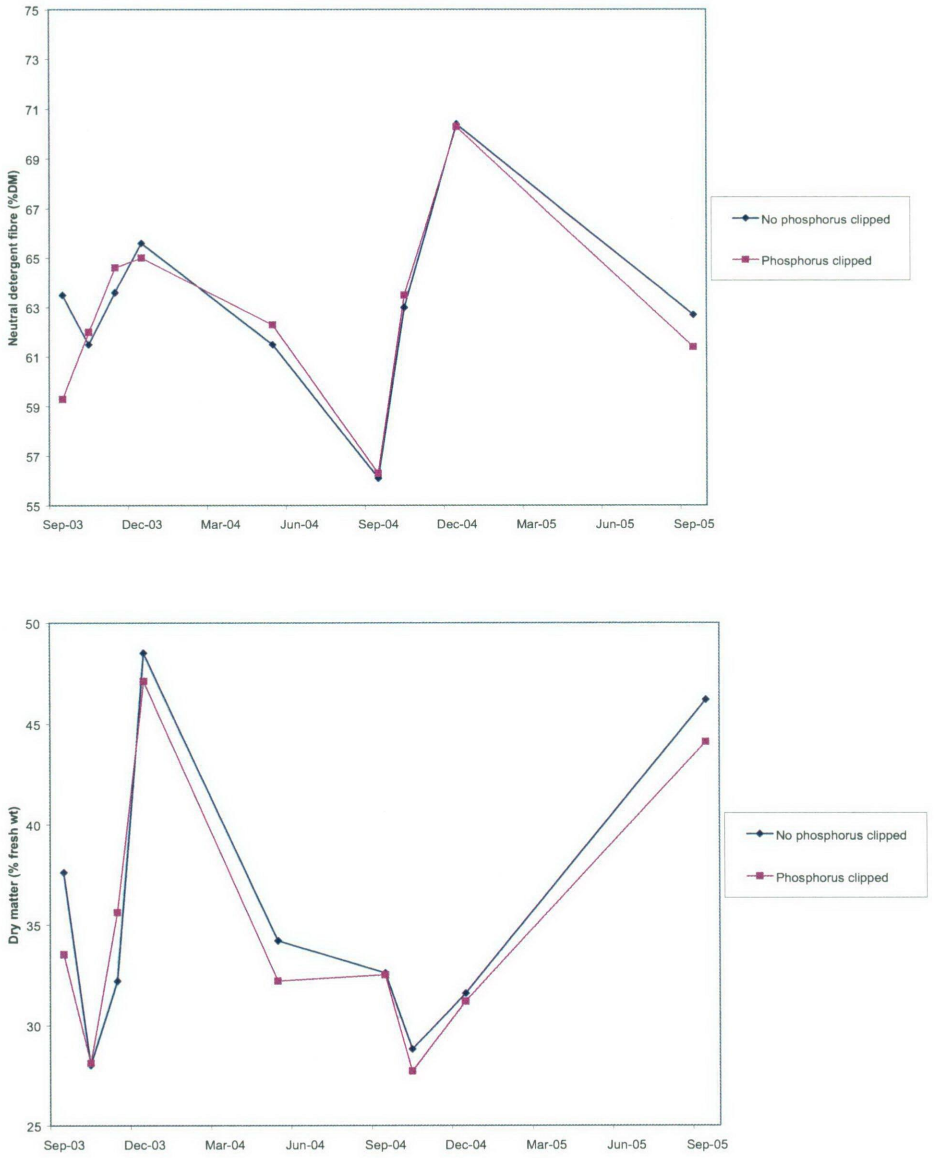

Figure 3.10 Effect of phosphorus fertiliser on neutral detergent fibre and dry matter value of CNG and CF.

3.5 Discussion

3.5.1 Clipping

Management of CNG pastures by means of controlled clipping at each physiological growth stage, or the addition of nitrogen fertiliser increased the feed value of both CNG and CF.

Clipped CNG regrowth was able to maintain crude protein contents above 9% during the reproductive period although its digestibility during these periods was as low as 49.3% DM and metabolisable energy as low as 6.9 MJ/kgDM. These feed values are lower than feed values quoted by Slay (2001) and Gardener (2001) implying that the nutritive value of CNG is not as expected. Since livestock require feed with an ME content of 7.7 MJ/kgDM with at least 55% digestibility (NSW-Agriculture 1998; Standing Committee on Agriculture 1990) to maintain live weight, CNG was clearly not sufficiently digestible and had too low an ME to maintain live weight during the reproductive periods.

Although the feed value of both species improved with clipping, the response of each species to clipping was significantly different at certain times of the season. As the season became drier, CF generally responded better to clipping than CNG. Implying that even under clipping regimes, the feed value of CNG will decline more rapidly than CF as the season progresses.

Clipping was used as a means of reducing the pasture mass to levels similar to crash grazing (~1200kgDM/ha;Figure 3.4). This method was used to encourage new growth of both CNG and CF and to limit the production of unpalatable CNG flower stalks. A petrol driven catcher mower was used instead of grazing livestock to reduce the pasture mass. This was undertaken as grazing was not feasible due to the small plot size, relative to true grazing plots, and would mean that the plots could not truly represent one cell of a rotational grazing system. If the small plots were grazed, nutrient transfer in dung, trampling and selective grazing for potentially better feed values may have compromised the regrowth of the target grasses and the integrity of the analysis. Mechanical clipping offered the advantage of consistency across the plots, irrespective of feed values across plots or between species. Mowing was also instantaneous thus enabling all plots to be clipped within hours of each other. The removal of all clippings off plots eliminated the risk of nutrient transfer across the plots as vegetative trash. Mechanical clipping, even as slashing in the context of a grazing system, is a viable alternative given the precise timing of grazing required to reduce the production of CNG seedheads.

3.5.2 Nitrogen fertiliser

Nitrogen fertiliser provided significant gains in the feed value of both the grasses immediately following the fertiliser application. Nitrogen is readily volatilised and immobilised from soil when it is applied in excess of the maintenance requirement of organic nitrogen fixing microorganisms (GRDC *et al.* 1998). The nitrogen fertiliser effect will be short lived, as any nitrogen that does not undergo nitrification and become plant available will be lost through leaching or immobilisation. The use of split nitrogen fertiliser applications was intended to prolong the nitrogen effect rather than providing excess nitrogen than required by nitrogen fixing microorganisms.

The response to the nitrogen fertiliser addition was small and short lived in CNG when compared to CF plants. This differential response to nitrogen fertiliser shows that CNG is less responsive to nitrogen soil fertility than CF. CF regrowth feed value responded significantly better to the addition of nitrogen, and also had a significantly more sustained effect. Implying that CNG either did not take up as much nitrogen from the soil than CF, or that CNG does not require high soil nitrogen rates to grow.

Given the cost of applying nitrogen fertiliser in a broadacre context, and the relatively small gain in feed value of CNG, this management technique would not be feasible, as extra plant utilisation by the livestock may not outweigh the costs of applying the nitrogen.

3.5.3 Phosphorus fertiliser

The addition of phosphorus fertiliser did not provide any significant difference in the feed value of the regrowth of both species throughout the experiment that could be used for management of these grasses.

Although phosphorus fertiliser is commonly applied to pastures to obtain increased pasture quality, it is reliant on adequate legume cover, as legumes respond better than grasses to phosphorus (NSW-Agriculture 1998; Taylor and Sindel 2000).

3.5.4 Future work

From this experiment and the results it has provided, future studies need to focus on best ways to keep CNG vegetative because this is likely to increase the feed value of CNG. To achieve this outcome, the ability of grazing to defoliate CNG to levels similar to the mechanical clipping used in this experiment need to be determined and the type of grazer, grazing system and length of rotation in different districts needs to be understood. For areas where grazing is not feasible (e.g. roadways), or for land that can't be grazed at the correct times, slashing or burning may provide an alternative means of limiting seedhead production. Given that this trial was conducted in central Victoria, the feed values of CNG in Victoria relative to the feed values of CNG in other states and districts needs to be better understood prior to making management assumptions for areas outside of the Greenvale district.

3.6 Conclusion

The feed value of CNG was significantly improved by clipping the plants during the spring reproductive periods of 2003 and 2004. Regrowth of clipped CNG plants had significantly more crude protein, metabolisable energy and digestible dry matter with significantly less dry matter and neutral detergent fibre than the unclipped grasses. Nevertheless the response to clipping by CF was significantly better than the response of CNG to clipping. Clipped CF for both spring 2003 and 2004, had significantly more crude protein, metabolisable energy and digestible dry matter, than clipped CNG.

Nitrogen fertiliser addition also provided a significant gain in feed value of CNG. Immediately following fertiliser addition in November 2003, fertilised regrowth of CNG had significantly more crude protein, metabolisable energy and digestible dry matter with significantly less neutral detergent fibre than unfertilised regrowth. The fertiliser effect lasted longer for CF plants than CNG plants. CNG was also less responsive to the fertiliser addition as CF regrowth had significantly more crude protein than CNG regrowth following fertiliser addition.

Phosphorus fertiliser addition did not provide any substantial gains in the feed value of the regrowth of either species.

Management of CNG pastures should aim to keep plants in the vegetative growth phase by means of clipping as this is when CNG has the greatest feed value. The gain in feed value by adding nitrogen fertiliser was short lived for CNG, and although CF was more responsive to nitrogen fertiliser, such a management practice may not be sustainable. An alternative source of nitrogen may be to increase legume composition in the pasture sward.