EFFECTS OF SOCIAL DOMINANCE ON MILK PRODUCTION AND GRAZING BEHAVIOUR OF LACTATING DAIRY COWS

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ABSTRACT of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

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In this study, three experiments were conducted to determine factors influencing social dominance in lactating, grazing dairy cows. Additionally, we investigated the effect of separating cows, based on social dominance, on milk production and grazing behaviour. Dominance in all experiments was quantified by calculating a dominance value (DV), which was measured through observation of wins and losses between cows in social interactions. A dominant cow which won all, or most, of its interactions would have a DV range between 60-90, a mid-ranking cow a DV between 30-60 and a subordinate cow which lost all, or most, of its interactions having a DV of 0-30. In New Zealand pastoral-based dairy farm systems, no information exists on the impact of social hierarchy, and its disruption, on animal productivity.

In experiment 1 (Chapter 3), an observational study was carried out to identify factors determining social dominance of grazing dairy cows and the subsequent relationship with milk production. Recognition of dominance among peers was evaluated for three groups of cows differing in stocking rate and herd size. The three groups of Friesian × Jersey cows used in this study were, a large group of 189 cows stocked at a medium stocking rate (4.2 cows/ ha; MSR), a small group of 34 cows stocked at a high stocking rate (5.0 cows/ ha; HSR), and another small group of 29 cows stocked at a low stocking rate (3.5 cows/ ha; LSR). All cows (n=252) ranged in age from 2 to 11 years old. Cow liveweight (LW) ranged from 340 kg to 648 kg. In each of the three groups, LSR, MSR and HSR, the DV was positively correlated with age (r = 0.646, 0.349, and 0.442 respectively, P<0.05) and liveweight (r = 0.472, 0.166 and 0.487, respectively, P

< 0.05). Dominance value was more strongly and positively correlated with milk production for the LSR group (r = 0.476, P <0.05), but less so for the MSR and HSR groups (r= and 0.291, P<0.05 and r=0.289, P<0.10 respectively). It is likely that dominant cows in the LSR group had higher milk yield because they were more successful when competing for feed, whereas in the higher stocked groups individual feeding of grain supplements in the shed probably buffered the competitive effect of dominance in the paddock. During the first experiment the stability of dominance in the large MSR group was also investigated by removing and returning 40 cows after three weeks. Observations before and after removal of cows showed that although the DV changed, the value stayed within the same range throughout the entire separation and re-grouping process indicating a stable hierarchy. Interestingly in the smaller HSR and LSR groups, (where no regrouping occurred) the social hierarchy was less stable as cows shifted in and out of DV range.

Given that MSR remained socially stable when a random group of cows were removed, a second experiment (Chapter 4), was carried out which was designed to test whether social disruption by separating dominant and subordinate cows would affect their milk production. Over 28 days, from 4 to 31 March 2015, 48 multiparous, late-lactation and pregnant Friesian × Jersey cows, were allocated to 6 treatment groups, based on observations of dominance recorded in MSR group. The groups were dominant only (n=12), subordinate only (n=12) or dominant and subordinate mixed together (n=24). To enhance competitive interactions each group was further divided and offered either high (target 16 kg DM/ cow/ day; 65 m^2/ cow) or low (target 12 kg DM/ cow/ day; 52 m^2/ cow) herbage allowance above 3.5 cm as grazed pasture. The results again showed higher milk yield and milksolids (MS) production in dominant compared with subordinate cows (16.5 vs 13.7 L of milk/ cow/ day; 1.58 vs 1.33 kg MS/ cow/ day). However, there was no effect of grouping based on social dominance in milk production of dominant or subordinate cows when they were mixed or kept apart (16.76 vs 16.34 L of milk/ cow/ day and 14.22 vs 13.24 kg MS/ cow/ day, respectively). Further, herbage allowance, did not affect milk production between dominant and subordinate cows when grouped apart or together.

However, when subordinate cows were grouped apart from the dominant cows, they achieved better liveweight gain (0.36 vs 0.05 kg/ day, respectively) than subordinate cows in the mixed rank group. Overall, there was no benefit of separating cows based on social dominance on milk production even when a low herbage allowance enhanced the social dominance interactions between cows.

More information on competition and social stability was needed to explain the lack of milk yield response and sensitivity of subordinate cows to mixing in experiment 2. Therefore experiment 3 (Chapter 5), was carried out to determine the effect of separating subordinate cows on milk production and behaviour under restricted feeding of pasture and fodder beet (FB) supplementation. The investigation was carried out over 19 days from 18 April to 6 May 2016. A total of 54 multiparous, late lactation and pregnant Friesian × Jersey cows were classified as dominant or subordinate prior to the experiment. A replicated factorial design was used whereby subordinate cows grazed in a mixed group together with dominant cows (n = 36) or in a separate group of subordinate cows (n = 18). The diet consisted of a supplement of 3 kg DM/ cow/ day of fodder beet (FB) grazed *in situ* on a 4.2 ± 0.16 m strip of FB/ cow offered from 0830 to 1130 h, followed by a herbage allowance of 12 kg DM/ cow/ day above 3.5 cm as grazed pasture, with mean space allocation of 94.3 ± 4.21 m^2/ cow/ day to be grazed throughout the day. The provision of feed supplement functioned to enhance the aggression between cows as a result of competition. The total number of agonistic interactions between cows was greater when cows were on FB than when they were on pasture (428 vs 16 interactions, respectively). The increase in interactions on the small area of FB showed that feeding supplement creates competition. Regardless of the variation in interaction on pasture or FB, there was no difference in milk yield of subordinate cows grazed as single rank or mixed rank group (9.2 ± 0.49 vs 8.3 ± 0.89 kg/ cow/ day). The results suggest there was no benefit in separating cows based on their social dominance even in an intense strip grazing of high dry matter yield crop situation was created to enhance competition.

In conclusion, dominance in grazing dairy cattle in a New Zealand pasture-based system was found to be most closely associated with age, LW and

to a lesser extent milk production. Dominant cows typically had greater milk production than subordinate cows but dominance value and milk production were more closely linked when individuals were not supplemented. However, there was no effect on milk production of separating cows according to their social rank, even under competitive conditions.

Keywords: Social dominance, dominance value, grazing dairy cows, milk production, grazing behaviour, herbage allowance, feed supplement, grouping management

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

˚C	Celsius
A	Apart
ADF	Acid detergent fibre
ANOVA	Analysis of variance
BCS	Body condition score
cm	Centimetre
CP	Crude protein
D	Dominant
DM / DM%	Dry matter / dry matter percentage
DMI	Dry matter intake
DOMD	Digestibility of organic dry matter
DV	Dominance value
FB	Fodder beet
FW	Fresh weight
G	Group
g	Gram
h	Hour
ha	Hectare
HA	High allowance
HSR	High stocking rate
kg	Kilogram
L	Litre
LA	Low allowance
LSR	Low stocking rate
LURDF	Lincoln University Research Dairy Farm
LW	Liveweight
LWG	Liveweight gain
M	Mix
m^2	Square meter (s)
ME	Metabolisable energy
min	Minute
MJ	Megajoules
MS	Milksolids
MSR	Medium stocking rate
NDF	Neutral detergent fibre
NIRS	Near-infrared reflectance spectroscopy
PA	Herbage allowance
S	Subordinate
SE	Standard error
SED	Standard error of difference
SEM	Standard error of mean
vs.	Versus
WSC	Water soluble carbohydrate

Chapter 1

Introduction

Dairy cattle are gregarious ungulates that form a strict social hierarchy within their herd through social dominance. Social hierarchy functions to distinguish between dominance and submissive forms, and to create a ranking system that is beneficial to the individuals that make up the hierarchy (Hermann, 2017). Dominance, in general, is the phenomenon that in a pair of animals, one individual can inhibit the behaviour of the other (Beilharz and Zeeb, 1982). The basic components of the social hierarchy establishment, maintenance and stability are the social interactions between members of the herd (Guhl and Atkeson, 1959; Kondo and Hurnik, 1990). These interactions include both physical interactions such as bunting, pushing, allogrooming and non-physical interactions such as threatening and avoiding (Dickson *et al.*, 1967). Through observations on these interactions, the animal's dominance order can be determined (Keeling and Gonyou, 2001).

Dominance has been recognised as the most important part of the animal social interactions (Syme and Syme 1979). Commonly, dominance is associated with higher-ranking animals having supremacy in the distribution of resources along with the advantage in winning more competitive interactions compared to the subordinate members of the group. This suggests that the lower ranking animals may suffer greater disadvantages caused by this competition. According to Judd *et al.* (1994), competition for resources such as feed and space caused aggressive interactions among members of the group, especially when the resources are limited. This competition may have adverse impacts on the animal, such as preventing the animal from achieving their optimum production (Judd *et al.*, 1994), reproductive performance (Moberg, 1991) or health (Galindo and Broom, 2000). Indeed, in the worst case scenario, aggression among group members caused a reduction in milk yield (Schein and Fohrman, 1955; Brantas, 1968; Brakel and Leis, 1976; Hasegawa *et al.*, 1997), a disrupted reproduction process

(Moberg, 1991) and increased an incidence of lameness (Galindo and Broom, 2000). This leads to the question of whether the understanding and importance of social dominance and manipulating this via grouping can be used to improve animal production. In studies using housed and grazing dairy cattle, it has been shown that productivity gains can be achieved through grouping animals based on social rank and manipulating their feed and space resources, whereby excessive competition among animals is alleviated, (Thompson *et al.*, 1991; Phelps, 1992; Judd *et al.*, 1994; Phillips and Rind, 2002). This leads to a hypothesis that having a better understanding of the importance of social dominance and its effects towards the herd production allows the farmers to improve the farm animal management system.

In New Zealand, dairy farming systems are predominantly pasture-based, with dairy cows typically grazing outdoors year round. This pastoral system has been reported to be an ideal social environment for cattle, where there is more opportunity for cattle to exhibit natural behaviours such as social interactions (Verkerk and Hemsworth, 2010). Generally, it is viewed that in outdoor grazing systems, each cow is more likely to have adequate space (Phillips and Rind, 2002), and the social dominance effects on cows' performance may be limited. However, there are several characteristics of New Zealand outdoor grazing system that promote competition for resources such as restricted space and feed supply. The first characteristic is the high and increasing stocking rate and herd size across all farms (Livestock Improvement Corporation Limited and DairyNZ Limited, 2018). Secondly, the grazing method used, particularly the rotational grazing of pasture in paddocks where cows were allocated with relatively low herbage allowance. In the New Zealand system, dairy cows are offered an allowance of 16 to 18 kg DM/ day of herbage above post-grazing residual; however, above ground, DM varies depending on the pre-grazing cover, area, and post-grazing residual (Bargo *et al.*, 2002; Al-Marashdeh *et al.*, 2016). Third, the used of intense strip grazing of high dry matter (DM) yield crops (e.g. fodder beet and kale) grazed *in situ*, either as a supplement to pasture or as a dry non-lactating cow feed (Edwards *et al.*, 2014). These characteristics may create high densities and low space allocations for cows, especially during feeding. In turn, this may accentuate competition and aggressive interactions between cows for resources and altering their behaviour, thus reducing performance. As the competition for space is considered as the main driver for aggressive interaction in cows (Potter and Broom, 1987), the importance of the effects of social dominance in cows under grazing conditions may be more pronounced. Though this is hypothesised, there is little data to support this view.

To date, there is little data on the relationship between dairy cows' social dominance and performance in the New Zealand pasture-based system. Therefore, the objectives of this thesis were to determine the effects of social dominance on milk production and grazing behaviour in a series of studies which both quantify and manipulate the dominance by rank and examine the production response of individuals when socially matched or mismatched. These studies were conducted at low and high herbage allowance, and with and without supplementation, to alter cow spacing allocation and competition amongst individuals for resources, and to examine under what specific conditions grouping cows based on social dominance may affect performance.

1.1 Objectives

The main objectives of this research were to determine the relationship between social dominance of grazing dairy cows and milk production and grazing behaviour and to examine the effect of grouping cows according to their social dominance under the New Zealand pasture-based system.

Specific objectives were to:

1. To measure factors determining social dominance in grazing dairy cows at pasture and the effects on milk production and grazing behaviour.
2. To determine the effects of social dominance on milk production and behaviour of grazing dairy cows in mid-lactation, when cows grazed in groups according to their social dominance or mixed social dominance, at two levels of herbage allowance.
3. To determine the effects of social dominance on the subordinate cow's milk production and grazing behaviour in late-lactation, when grouped according to their social dominance or when in mixed social dominance, with fodder beet offered as supplement, under intense strip grazing pattern.

These objectives were examined in three experiments (Table 1.1).

1.2 Hypothesis

The following hypotheses were tested in three experiments. The chapters in which each hypothesis is tested can be found in Table 1.1.

The null hypotheses tested were that:

1. Social dominance in dairy cows has no correlation with age, body size (liveweight and body condition score) or milk production.
2. Separating dominant and subordinate cows in grazing systems will alter milk production regardless of herbage allowance.

3. Restricting resources to encourage competition will affect milk production irrespective of how cows are socially grouped.

1.3 Thesis structure

This thesis is presented in six chapters (Table 1.1). In chapter 2, the literature is reviewed concerning the role of social dominance in dairy cattle management. In particular, the factors determining social dominance, measuring dominance and the effects of grouping according to social dominance were reviewed. Chapter 3 reports on a behavioural observational study, conducted in three herds over three months between spring and summer, examining factors determining dominance and the effects on milk production and grazing behaviour of spring-calving dairy cows in early-lactation. The results of Chapter 3 have been published in peer-reviewed conference proceedings (Hussein *et al.* 2016). Chapter 4 reports on the grazing experiment, conducted over 28 days in mid-autumn, measuring the effects of social dominance on the production and behaviour of grazing dairy cows in mid-lactation, when cows grazed in groups according to their social dominance or mixed social dominance, at two levels of herbage allowances. Chapter 5 reports on a further grazing experiment, conducted over 21 days in mid-autumn, measuring the effect of social dominance on the subordinate cows milk production and grazing behaviour of subordinate cows in late-lactation, when grouped according to their social dominance or when in mixed social dominance, with fodder beet offered as supplement, under intense strip grazing pattern. Chapter 6 contains the general discussion on all three experiments together and includes implications and limitations to the experiments as well as suggestions for future work. The chapters and their objectives and hypothesis can be found in Table 1.1.

Table 1.1. Diagram representing the thesis structure with objectives and hypothesis of the research presented in this thesis.

Chapter 1	**General introduction**	
Chapter 2	**Literature review**	
Chapter 3	**Objective:** To measure factors determining social dominance in grazing dairy cows at pasture and the effects on milk production and grazing behaviour.	**Hypothesis** no. 1
Chapter 4	**Objective:** To determine the effects of social dominance on milk production and behaviour of grazing dairy cows in mid-lactation, when cows grazed in groups according to their social dominance or mixed social dominance, at two levels of herbage allowance.	**Hypothesis** no. 2
Chapter 5	**Objective:** To determine the effect of social dominance on the subordinate cows milk production and grazing behaviour in late-lactation, when grouped according to their social dominance or when in mixed social dominance, with fodder beet offered as supplement, under intense strip grazing pattern.	**Hypothesis** no. 3
Chapter 6	**General discussion**	**Hypothesis** no. 1 - 3

Chapter 2
Literature review

2.1 Introduction

Cattle (*Bos taurus* and *Bos indicus*) are a domesticated animal that contribute to 18% of human protein intake and 9% of energy intake worldwide (Phillips, 2002). Dairy cattle are the main contributor to human dietary protein intake through their milk production (Statista, 2015). *Bos taurus* cattle play a fundamental role in the economy of New Zealand dairy industry. As the world's largest exporter of dairy commodities, New Zealand represents approximately one-third of international dairy trade each year, involving exports of 20.7 billion litres of milk, with 1.84 billion kg of milksolids produced by their local farmers (Livestock Improvement Corporation Limited and DairyNZ Limited, 2018). According to the same update, the production of milksolids recorded in 2018 was double that of 1998. This has been associated with the increase in cow numbers throughout the years. In the last three decades, the average size of a New Zealand dairy herd has tripled from 147 cows to 431 cows. It was also reported that between 1985/86 and 2017/18, the number of dairy herds in New Zealand has declined by approximately 130 herds/season and the stocking rate has increased from 2.10 to 2.84 cows/ ha, with more than 40% of herds having more than 400 cows. In the year of 2018, New Zealand's national dairy herd numbered 4.99 million cows, with an average production of 368 kg milksolids (207 kg milk fat and 161 kg protein) per cow respectively.

2.1.1 Social behaviour and management system

Farming systems have become more intensive and restrictive, suppressing the animal's natural behaviour, which causes them to live differently from their natural way of life (Bouissou, 1980). The increase in global cattle population combined with the increased stocking rates has resulted in growing concern about cattle welfare and social wellbeing. Since cattle are social animals, having an understanding of their social behaviour plays an important role in helping farmers to meet cattle welfare needs. Furthermore, by understanding cattle social behaviour under various environmental conditions, farmers can better analyse causes underlying animal actions, and thereby design more efficient production systems (Albright, 1984; Hafez and Lindsay, 1965; Stricklin and Kautz-Scanavy, 1983).

According to Kilgour and Dalton (1984), social behaviour acts as a form of communication that involve regular and predictable interactions between two or more animals. The term "behaviour" refers to the patterns of action observed in animals, which occurs either voluntarily or involuntarily. Social behaviour is exhibited through nine natural behaviours that are associated with feeding, excretion, mating (sexual reproduction), defensive actions, subordination, aggressiveness (herd social hierarchy), simulation, sense of self-awareness and cognition (Jezierskie, 1987). In the welfare of cattle, this includes the need to express natural behaviour freely. It also involves the requirements for food, water, rest and social behavioural needs such as having adequate space to move, interacting, allogrooming (e.g. licking, grooming), foraging and play. Since domestication involves highly social animals who live in a cohesive society, these animals cannot be managed successfully without regard given to their social behaviour (Kilgour and Dalton, 1984).

In 2014, New Zealand was placed among countries that have the best animal welfare standards in the index update of World Animal Protection (2014), confirming the quality of the Animal Welfare Act (1999) (Williams *et al.,* 2015). This act has initially been established to ensure the highest standard of animal husbandry practice in the New Zealand dairy farming industry. According to the New Zealand 2016 dairy cattle Code of Welfare under the Animal Welfare Act (1999), it is necessary to ensure that all animals get adequate resources such as feed, water and space. As part of their welfare needs, the Code of Welfare also states that animals must be given sufficient free space to be able to avoid any social aggression between or from any members of the herd. As mentioned earlier, current dairy farming practice has led to an increase in herd size and stocking rate. Furthermore, intense rotational grazing used at low herbage allowances may lead to an increase of agonistic interactions between animals that may cause social stress (Bouissou, 1980). Since dairy cattle are gregarious animals that live in a cohesive society, the increase in agonistic interactions within the herd, either to establish and maintain social rank or to compete for basic resources, can lead to behavioural stress to some of the animals in the herd.

Agonistic interactions can be seen in the event particularly when mixing a group of cattle; e.g. when introducing heifers into a milking group. Commonly, these animals will be challenged as strangers to the herd. These challenges can be aggressive and may lead to injury and distress, especially to the new members of the herd, which may also reduce their share of sufficient resources that can subsequently affect their production. According to Brakel and Leis (1976), the introduction of new cows into a herd full of strangers creates social tension and may result in slightly depressed milk yield. In a study of behavioural stress in domestic animals, Moberg (1991) found that behavioural stress affects the well-being of animals through the activation of the adrenal axis that disrupts the normal reproductive processes. Meanwhile, Hasegawa *et al.* (1997) found that social tension depresses the performance of cows through a decrease in dominance rank and milk production. Also, a study on the effects of social behaviour on the occurrence of lameness done by Galindo and Broom (2000), found that social rank and its aggressive interactions reduced the survival time to lameness. They reported that low ranking cows suffer a higher likelihood of becoming lame than high ranking cows. All of these studies indicate that such behavioural stress can and does have a significant negative effect on the cow's performance. With this, it has come to a reason that having an understanding of social behaviour plays a vital role in helping farmers to meet animal welfare needs. Thus, incorporating the knowledge to design a management system that complies with the animal behavioural needs and may benefit production.

2.2 Social behaviour and social dominance

Social organisation is a phenomenon that exists in groups of animals that live and move together in flocks, packs or herd. Within it, social behaviour can be observed whenever two or more members perform a pattern of behaviour indicating communication with each other, through interactions. This interaction can either be aggressive, non-aggressive, physical or non-physical. Through this, social dominance in an individual can easily be detected by observing the result of the interaction. In dairy cows, they form a strict social hierarchy within their herd through dominance establishment, which is maintained by agonistic interactions (Kondo and Hurnik, 1990). Every individual in the herd characteristically relates to one another and engages in agonistic social interactions to determine their dominance ranking. Agonistic interactions in cows include aggression, threats, displays, retreats and conciliation (Barrows, 2001). Generally, whenever two animals interact socially with each other either to establish or to maintain their ranking in the herd, it will result in a winner (dominant) and a loser (subordinate). The social interactions will carry on between all or most members in the herd resulting in the formation of a dominance order or social hierarchy, from most dominant to most subordinate (Hermann, 2016). Dominance order consists of dominant and subordinate animals, where dominance, in general, is the phenomenon observed in groups when certain individuals consistently elicit submissive behaviour from other individuals. In general, dominance is associated with higher-ranking animals having priority over the distribution of resources such as feed and space.

2.2.1 Dominance

The term dominance in the field of ethological science generally defines the higher status of an individual or group, relative to other individuals or groups. There are many different definitions of dominance based on empirical observation. According to some of the original definitions of dominance (Schjelderupp–Ebbe, 1922; Allee, 1938), dominance is associated with the pattern of repeated agonistic interactions between two individuals (dyad), with a consistent outcome in favour of the same dyad member and the immediate response of its opponent. The status of the consistent winner is known as dominant and the loser as subordinate. Dominance status refers to the link between two individuals, while dominance rank refers to the position of an individual in a social hierarchy (Drews, 1993). The definition of dominance in other studies considers it as either an attribute of the individual or as a relative measure attributed to the interactions of two individuals, or relationship and not as a property of individuals. According to Wilson (1975), dominance was defined as a privileged position or role that an animal has with respect to others. While in other studies, dominance has been defined as a trait that conveys rank, where dominant individuals consistently win interactions with others (Baenninger, 1981; Hand, 1986; Ens *et al.*, 1990). On the other hand, dominance can also be defined as individuals that have the priority of access over resources, from the result of successful agonistic interactions with others, present or past (Clutton-Brock *et al.*, 1979; Morse 1974). In this thesis, dominance will be defined as an individual who wins the majority of social interactions or in having supremacy over resources.

2.2.2 Dominant and subordinate behaviour

In behavioural studies, dominant behaviour is observed as an action where an individual exhibits agonistic or forceful action towards other individuals to gain priority in accessing resources. This behaviour has been defined by many behavioural studies with the earliest one been introduced as pecking-order or later referred to as dominance by Schjelderupp-Ebbe (1922). In dairy cattle, it was first introduced as hook order or bunt order by Woodbury (1941) referring to the animal horns use as a tool to determine dominance in agonistic interactions.

In a study on the social relationship of dairy cows in a feedlot by Dickson *et al.* (1967), dominance behaviour was divided into five categories; bunting, pushing, contact, forceful and non-forceful. Bunting and contact behaviour were characterised by almost similar actions. This is when an animal swings their head to displace another cow physically or in the direction of the other cow to attack them usually to either the head or flanks of the other animals. The force of the movement varies from a mild push to a severe blow. This type of behaviour can be observed during an aggressive fight between two animals. Pushing behaviour is characterised by the dominant cow when it uses parts of their body to displace another cow other than by using its head. This can also be when an individual forces its way through or towards other cows, resulting in pushing the other individual away or causing them to shift location. Forceful behaviour is when a cow shows a sign of threatening another individual by swinging its head in the direction of other individuals, resulting in submission or avoidance from the recipient. Non-forceful behaviour on the other hand, is when a cow is observed to purposely avoid another cow, preventing any form of interactions to occur. This can usually be observed from the subordinate animals, where they would avoid aggression by moving out of the way of their dominant peers, standing up from the lying position and searching for another place to rest if a given resting area had been chosen by a higher-ranking cow (Phillips, 2002). In addition to this, Phillips (2002) also stated that allogrooming or grooming could also be another form of dominance behaviour. This behaviour is not considered aggressive, but acts as affiliative behaviour, and is characterised by one cow licking any part of another individual body parts, that is similar or slightly lower in the position of the social rank. This behaviour is not just to maintain their dominant position in the hierarchy, but also to strengthen the bonds between the members of the herd. In this thesis, three main types of dominance behaviour are arbitrarily chosen such as bunting or contact, pushing and allogrooming in observing dominance as well as to determine the dominance ranking in cows. The main types of behaviour indicating dominance in cattle are shown in Figure 2.1.

Figure 2.1. Dominance behaviour in cattle

Bunting

Pushing

Allogrooming

2.3 Measuring dominance, sampling method and dominance value

For the past few decades, studies have developed methods of calculating an animal's dominance value (DV) through the observations of their social interactions. Social dominance in cattle can be determined through observations of agonistic interactions between their herd members (Schein and Fohrman, 1955; Beilharz and Mylrea, 1963). To best represent an animal's social status in dominance, measuring dominance should cover four important requirements (Beilharz and Zeeb, 1982). First, the measurement should be based on actual observations of the dominance relationship in the herd. Second, it should contain a sufficient number of observations to be reliable. Third, the behavioural data recorded should reflect the actual magnitude of differences between animals. Fourth, the statistical analysis used should be most efficient, reflecting the likely biological variation and be normally distributed. All the requirements can be fulfilled by using the method of Beilharz and Mylrea (1963).

2.3.1 Scoring dominance

In a study of social dominance and temperament of Holstein cows by Dickson *et al.* (1970), the cows temperament was scored using a rating system with a uniform basis from a score of one to four according to their milking temperament level. The most docile cows had the lowest score, and aggressive cows had the highest score. A similar methodology was used in a study investigating the effects of social hierarchy in a dairy cattle herd on milk yield by Sottysiak and Nogalski (2010). To determine cows DV, the type of agonistic behaviour performed by cows was given points based on the aggression level. Depending on the intensity of the agonistic behaviour performed, the scoring was divided into violent attacks (score three points), pushing (score two points) and threatening (score one point). Through observations, the animals with the highest score were known as the most dominant, followed by animals with the lowest score known as the most subordinate. The DV was then calculated based on the total score for each animal over the entire period of observation.

2.3.2 Sampling method

In all of the studies mentioned above, the number of observation hours, number of observers, frequency of observation days and number of animals observed were different between studies. However, the sampling method used in these behavioural studies was the same, as described by Altmann (1974), as an "all occurrences" sampling method. According to Altman (1974), this all occurrences sampling method is most suitable when the behavioural observation conditions are suitable and ideal, the type of behaviour observed is sufficiently "attention-attracting" to enable all cases to be noticeable, and the behavioural event did not occur too frequently throughout the observation period that it could not be recorded. In a study of the social hierarchy of domestic goats examining the effect on food habits and production, Barroso *et al.* (2000) chose the all occurrences sampling method to record all the social interactions between goats during the grazing period. As observations are usually done in a condition that allows observers to record as many occurrences as possible, this sampling method is one of the most suitable approaches in behavioural data recording. Thus, in this thesis, all observations on social interactions will be recorded using this all occurrences sampling method, as described by Altmann (1974).

In this thesis, methods from these various studies were adapted in the methods of observing, recording, sampling, scoring the type of dominance behaviour observed, and in calculating the DV for each animal based on their wins and losses of agonistic interaction with other animals.

2.3.3 Dominance value

In a study done by Beilharz and Mylrea (1963) on the social position and behaviour of heifers, DV was calculated through observations of interactions performed by the heifers, with one heifer recorded as a winner or loser. From this method, the number of heifers an individual dominates can be determined. The proportion of heifers dominated from the total encounters performed was then transformed into angles, with all observations in the group formed into a normal curve, giving an estimate of the individual's DV. The DV is the arcsine transformation of the square root of the proportion of heifers over which an individual is dominant to, compared against all heifers with which the individual has recorded relationships (Beilharz and Zeeb, 1982). Arbitrarily, Beilharz and Mylrea (1963) randomly set for each animal, a minimum of one agonistic encounter either won or lost with ten other animals before the animal's DV could be determined.

Dominance value derived from the calculation range from 0 to 90. Cows with the highest DV (90) has won all interactions and did not experience any defeats throughout the entire observation period, and cows with the lowest number of DV (0) has lost all interactions to all others. Other representatives of DVs are: DV of 60 represents a cow dominating three-quarters of the herd members; DV of 45 represents a cow dominating half of the herd members; DV of 30 represents a cow dominating one-quarter of the herd members. This method of calculating dominance has been adapted for the study of social behaviour and dominance in cattle by Beilharz and Zeeb (1982) and Phillips and Rind (2002).

In conclusion, one can decide on how many observed interactions per animal are sufficient enough to give an accurate estimate of the animal's DV in its study, given that the herd social hierarchy has been established and also has reached its stability.

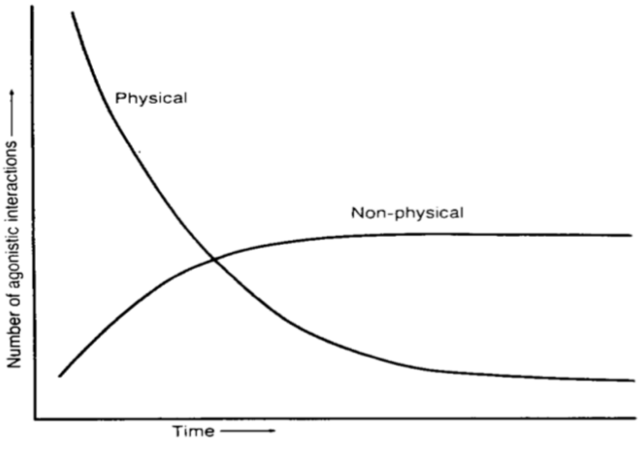
2.4 Social hierarchy

2.4.1 Establishment, maintenance and stability

The terms pecking-order, hook order, bunt order and boss cows have been developed by ethologists and farmers through the years to describe the dominant behaviour of cows (Dickson *et al.*, 1967). This "order" generally means the social hierarchy that existed in the group of animals that stayed or moved together in flocks or herds that organised themselves according to their social rank. In dairy cows, social hierarchy is formed within the herd through dominance establishment. According to Phillips (2002), the establishment of a social hierarchy within a group of dairy cattle can take three to seven days before the order stabilises. In between the establishment and stabilisation period, agonistic interactions between members of the herd will take place until it reaches stability, where the number of interactions between animals decreases. This is because a stable social hierarchy reduces the need for further aggression (Beilharz and Zeeb, 1982).

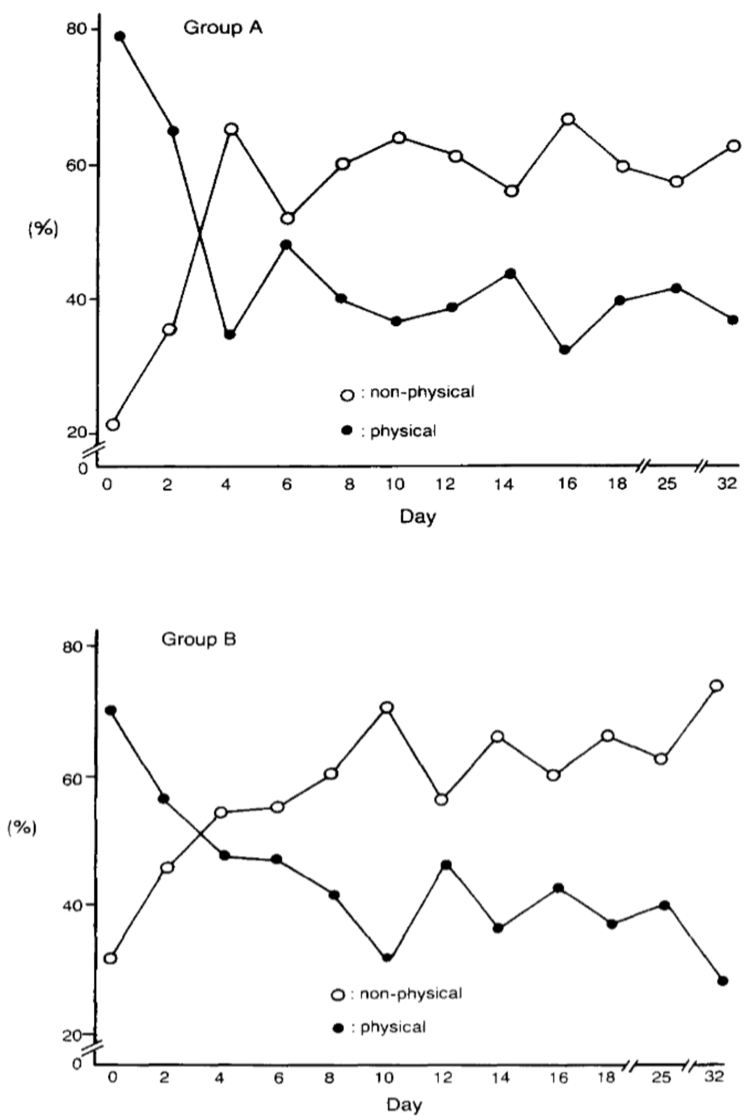
According to Kondo and Hurnik (1990), stabilisation of dairy cow social hierarchy can be determined by observing the frequency of physical and non-physical interactions within the herd (Figure 2.2).

Figure 2.2. Hypothetical outlines of agonistic interactions (physical and non-physical) between dairy cows after grouping through time (Kondo and Hurnik, 1990).



Agonistic physical interactions are actions that display threat involving body contact between two animals. Whereas, non-physical agonistic interactions are actions that display threat without involving physical contact towards another animal, resulting in the individual threatened, to retreat, avoid or flee. In the same study, they examined the social hierarchy stability in two groups of 16 cows with similar age, by looking into the changes between physical and non-physical interactions of the herd members after grouping (Figure 2.3).

Figure 2.3. Proportions (%) of physical and non-physical agonistic interactions performed by dairy cows after grouping, in two groups (group A and B), according to time (Kondo and Hurnik, 1990).



In the first two days after grouping, they reported that in both group A and B, 60 to 80% of the interactions displayed by cows involved physical interactions. However, from day three onwards, the number of physical interactions between cows slowly decreased, and the number of non-physical interactions increased. The high number of physical interactions frequency between cows after grouping agrees with Bouissou (1972), indicating dominance establishment. While the increase in non-physical interactions between cows that follow afterwards was identified as a "ritualised" behaviour by Bryant (1972), to maintain dominance rank. Overall, for groups of moderate size (i.e. 16 cows), this study shows that the social hierarchy establishment began soon after grouping, and stabilised within seven days. This was indicated by the number of non-physical interactions which was higher than the number of physical interactions, followed by the ratio of physical to non-physical interactions became comparatively stable throughout the days (Kondo and Hurnik, 1990).

2.4.2 Social groups

According to Kowalski (2000), an individual in a herd's social hierarchy can be grouped into three to five different classes or ranks. The three social classes represent the upper-ranking, mid-ranking and bottom-ranking animals in the social ladder. However, the most common linear structure is comprised of five classes of animals; dominant, subdominant, subordinate, submissive and marginal animals (Kowalski, 2000). In a herd, dominant cows are those who displace other animals from obtaining resources and resting places, are never harassed by subordinate peers and dominate all other cows. Subdominant cows show submissive behaviour towards the dominant cows but exhibit superiority over lower-ranking animals. Subordinate cows are servile towards superiors and aggressive towards inferiors. Submissive cows are subordinate to representatives of the earlier mentioned classes and aggressive only against the lowest ranking individual. Last is the marginal cows, which are subordinate to all other animals in the previously mentioned ranks (Kowalski, 2000).

2.4.3 Effects of social dominance through time (social re-ranking)

Mixing of groups can create social tension and can interrupt the establishment of the social hierarchy (Phillips, 2002), and such new-comers will be challenged to determine social rank. As the group size increases, the frequency of aggression between individuals will also increase, which may extend the time taken to establish a social hierarchy. In a study on the effect of group size and space allowance on the agonistic and spacing behaviour of outdoor grazing cattle by Kondo *et al.* (1989), a significant ($P < 0.05$) positive correlation between the number of aggressive interactions and the group size was found, but decreased rapidly when the space allowance was increased to more than 20 m^2 per animal. This is due to the animals having difficulty in memorising the social status of all animals in the herd (Hurnik, 1982) and it is suggested that cows can only recognise 50 to 70 of their herd mates (Fraser and Broom, 1990). Therefore, by having a larger herd, individual recognition among herd mates becomes increasingly difficult. This may lead to an increase in the number of agonistic interactions within the herd or may lead to a relationship breakdown where the herd members tend to form subgroups within the herd (Lindberg, 2001).

Although dominant animals are often known as being aggressive, once dominance has been asserted, it takes very little aggression to maintain that position. For example, a simple toss of the head may be all that is required to remind others of the hierarchy (Beilharz and Zeeb, 1982). McPhee *et al.* (1964) found that when the social order has been established, aggressive interactions between cattle become less frequent and the agonistic behaviour only occurred during the competition for feed and space especially at the feed trough during feeding. Heifers, though inexperienced, can learn swiftly on how to move up the ranks, particularly those that are socially adapted to being reared in a group, compared to heifers reared in an individual pen (Bouissou, 1980). Since aggressive interactions are found to be the basic component in the establishment of an animal social hierarchy, the number of interactions occurring in a herd and the types of interactions performed by each animal can indicate the stability of a social hierarchy.

2.5 Factors determining and enhancing dominance

Based on previous studies, many factors are associated with determining dominance in dairy cattle. These factors can be categorised into two main groups; animal and environmental factors (Table 2.1). The animal factors in determining dominance noted in numerous studies are age, physical measurement, breed and milk production. The environmental factors noted in previous studies are space, group size and feed or type of feed. Below are the descriptions for both animal and environmental factors in determining dominance, in dairy cattle.

Table 2.1. The animal and environmental factors determining and enhancing dominance in dairy cattle.

<table>
<tr><th colspan="3">Animal</th></tr>
<tr><td>▪ Age
- Lactation number
- Seniority
- Experience</td><td>▪ Physical measurement
- Liveweight
- Body condition score
- Chest girth
- Wither height
- Presence of horn</td><td>▪ Breed
▪ Production
- Milk yield</td></tr>
<tr><th colspan="3">Environmental</th></tr>
<tr><td>▪ Space
- Feeding space
- Resting space</td><td>▪ Group size
- Number of animals per group</td><td>▪ Feed
- Allowance
- Type</td></tr>
</table>

2.5.1 Animal factors

In dairy cattle, cow age, breed, physical measurement and milk production have been associated with dominance. Following are the details of each type of animal factor having a determining influence on dominance behaviour in dairy cattle.

2.5.1.1 Age and physical measurement

The most common factors relating to dominance in dairy cattle were found to be age or lactation number and the physical measurement of the animal's body such as liveweight (LW), body condition score (BCS), chest girth, wither height and the presence of horns. In one of the earliest studies on dairy cattle social dominance, Schein and Fohrman (1955) found that social dominance in dairy cattle grazing pasture was significantly related to age ($r = 0.93$, $P < 0.01$) and LW ($r = 0.87$, $P < 0.01$). In a study done by Guhl and Atkeson (1959) involving two separate herds of cattle on pasture, dominance was also related to age ($r = 0.38$, $P < 0.05$ to $r = 0.43$, $P < 0.01$) and LW ($r = 0.54$, $P < 0.01$ to $r = 0.82$, $P < 0.01$). Phillips and Rind (2002), found a positive correlation between social rank and the cow's lactation number ($r = 0.18$ to 0.23) and LW ($r = 0.35$, $P < 0.05$ to $r = 0.47$, $P < 0.001$) in mixed age cows on pasture. Beilharz and Mylrea (1963) found that dominance was significantly correlated to chest girth ($r = 0.27$, $P < 0.05$ to $r = 0.5$, $P < 0.01$) rather than the wither height in dairy heifers in yards. However, in another study, McPhee *et al.* (1964) found that wither height ($r = 1.0$, $P < 0.005$) was a better predictor of dominance in steers in yards. All of these studies reported that dominance mostly related to age and LW. For age or lactation number, it is a good index of the cow's seniority. This is because older cows are more experienced in having interactions with other cows compared to younger members of the group (Guhl and Atkeson, 1959). On the other hand, the animal's liveweight used as an index of strength, where bigger (chest girth), taller (wither height) and heavier (liveweight) cows have the advantage in performing more successful agonistic behaviour compared to smaller or lighter weight cows.

Although most studies of social rank in dairy cattle found age, seniority, LW and size play an important part in determining dominance, most of the research has been done on adult animals where their "past experience" was unknown. Bouissou (1980), reported that the most important factor acquired by the animal for dominance is their experience in having social interaction with others; the animal for each individual and the relative importance of other factors determining dominance, seems to be dependent on this experience. This is due to the reason that, when an animal accepts the superiority of another animal, even without the need of having an interaction, knowing the animal's past experience with social interaction becomes very important, particularly in understanding this dominance phenomenon. Studies have also shown that more experienced animals are able to determine their relationship 65 - 66% better than the less experienced animals even without fighting (Bouissou, 1974a, 1974b, 1975). In a study done by Guhl and Atkeson (1959) involving two separate herds of cattle, the seniority of the animal (number of months in the herd) was significantly related to dominance ($r = 0.37$, $P < 0.01$ to $r = 0.57$, $P < 0.01$). It is apparent that without knowing the cows "past social experience", it is hard to take into consideration their "experience" in determining dominance. Therefore, in this thesis, age will be used to represent the seniority of the animal, and it will assume that older cows are more experienced in having interactions compare to younger cows.

2.5.2 Environmental factors

Management factors such as the quantity of space, herd or group size, feed allowances, type of feed and the duration of feeding given to the animals also play an important role in determining the existence of dominance in cattle. Many studies had found that social dominance is exhibited more when there was a restriction of these basic resources, which will be elaborated further below.

2.5.2.1 Space and group size

The main environmental factors determining and enhancing dominance in cattle are associated with the competition for space (Potter and Broom, 1987; Judd *et al.*, 1994) and group size (Kondo *et al.*, 1989; Phillips and Rind, 1999). These two factors are closely related and are considered as the main drivers for aggressiveness in dairy cattle.

In a study on the effect of group size and space allowance on the agonistic and spacing behaviour of cattle, Kondo *et al.* (1989) reported that when the group size increased from 8 to 91 animals, and space between each animal decreased from 2800 to 12 m^2 per animal, the frequency of aggressive interactions between adult cattle (2 to 12 years old) increased. However, the agonistic interactions between adult cattle decreased rapidly when the space allowance increased from < 20 m^2 per animal. In the same study, they reported that in calves (6 to 13 months old), space allowance showed a significant negative correlation ($r = -0.48$, $P < 0.01$) with the occurrence of agonistic interactions; when space allowance was higher (4 to 73.4 m^2 per calf), the incidence of agonistic interactions becomes lower. They suggested that these results indicate different social and spatial structures in calves, due to the insufficient development of calves dominance rank. Furthermore, Schein and Fohrman (1955) and Stricklin *et al.* (1980) suggested that the social hierarchy in calves only established at 3 to 6 months of age, or soon after weaning.

Phillips and Rind (1999) did a further investigation on the effects of group size on the ingestive and social behaviour of grazing dairy cows. In the study, three different group sizes of 4, 8 and 16 animals were compared. All groups were grazed on three equal-sized pasture paddocks in a daily rotation with access to the same herbage type. Cows in the large group (16 animals) were found to be more aggressive compared to both small (4 animals) and medium (8 animals) group. This finding was similar to the results of Kondo *et al.* (1989) study. The suggested reason behind these results was that in a large group, an individual cow's space and flight distance were regularly disrupted, causing them to be more aggressive (Phillips and Rind, 1999). Furthermore, as herd size increases, each herd member needs more regular social status confirmation with other members, hence the increase in agonistic interactions (Kondo *et al.*, 1989). In the Phillips and Rind (1999) study, they also found that cows in the large and medium groups performed more self-grooming (licking) as a sign of social de-stressing behaviour due to the tension of increased competition in the group (Jensen, 1995). Also, cows in large groups increased their stepping rate while grazing, suggesting an increase in competition for the best herbage patches among the higher number of animals in a large group. Results from this study indicate that group size in cattle affects certain aspects of their social and grazing behaviour but not their production.

In a study done by Judd *et al.* (1994) on the behaviour of heifers and cows under different grazing systems in New Zealand, comparisons were made between block (cows confined with temporary electric fences, and shifted daily to a new area) and paddock wintering systems using heifers and dry cows on pasture. In the block treatment, heifers and cows given a space allowance of 25 m^2/ cow were found to have twice the number of aggressive interactions compared to heifers and cows in the paddock with a space allowance of 125 m^2/ cow. Animals in the block treatment experienced a loss (6 kg) in their liveweight (LW), especially the heifers, whereas animals in the paddock treatment gained 5 to 10 kg of LW. The smaller space allocated for the cows in the block system enhanced competition for space between cows leading to higher interactions that negatively affected the cows liveweight gain (LWG). In the same study, when supplement (silage) was offered to heifers and cows in the paddock system, the number of aggressive interactions increased to levels similar to animals in the block group. This shows that supplement feeding enhances competition for feed, where the total area available per cow was no longer the factor influencing cow dominance behaviour.

There is a debate that for cows managed on pasture, regardless of group size, space may not be a major concern and that space will be more available compared to cows in confinement. However, under such conditions, the priority to the best grazing spots, having longer and undisturbed feeding time or having a preferred area to lie down, maybe the major drivers of cow dominance behaviour (Barroso *et al.,* 2000; Phillips and Rind 2002).

2.5.2.2 Feed

In outdoor grazing systems, although space may not be as limited compared to the indoor feeding system such as cow stalls and feedlot systems, feed allowance can create competition between cows during grazing sessions, especially when the herbage allowance is low. Baker *et al.* (1981) examined the effect of herbage allowance upon the herbage intake and performance of suckler cows and calves. Calves and their dam were allocated to three herbage allowances of 17, 34 and 51 g dry matter/kg cow plus calf liveweight. The study reported that when herbage allowance is low, calves were unable to compete with their dam to maintain intake, thus resulted in a lower dry matter intake (DMI). This leads to a negative energy balance (Drackley, 1999), which may affect production performance, such as LW in calves or milk production in cows. Therefore, this indicated that herbage allowance is a key factor in determining the animal's DMI and their productive performance (Chilibroste *et al.,* 2012).

A study on the effect of increasing competition per indoor feeding station from 1 to 4 cows under the condition of limited and unlimited feed was tested by Olofsson (1999). The study showed that when feed was limited, competition between cows increased and dominant cows were found to monopolise the total eating time, resulting in 14% higher DMI than the subordinate cows. When the number of cows was increased from 1 to 3 cows per feeding station, the DMI difference increased to 23%. This shows that when feed was limited, competition increased, and DMI of the subordinate cows suffered.

2.6 Effects of social dominance on production

During the establishment period of social hierarchy, animal production performance such as milk production can be reduced as social interactions take priority over feeding. This period of change and establishment of order can also be stressful, especially for younger or smaller members such as heifers or primiparous cows (Grant and Albright, 2001), where these animals were frequently found at the lower rank of the herd’s hierarchy. For example, Brakel and Leis (1976) and Arave *et al.* (1973) found a small short-term reduction of less than 5% on milk yield following a herd's re-organisation. Due to the competition over resources such as feed, lower ranking animals may have lower feed intake compared to the higher-ranking cows (Phillips and Rind, 2002). In a study comparing the average dry matter intake (DMI) between primiparous and multiparous cows, the average DMI of primiparous cows were 15% less than multiparous cows within the first five weeks of lactation (Kertz *et al.*, 1991). This shows that social disorganisation does have a negative effect on animal production, especially subordinate animals.

The problem with the increase in social aggressiveness in relation to aggressive interactions towards heifers by the dominant cows become greater at the water point and the feeding facilities (Kilgour and Dalton, 1984). In a free stall situation, dominant cows have been observed lying closest to the hay feeder, deliberately making access more difficult for subordinate cows (Nakanishi *et al.,* 1993). Unless there is enough space and feed for the subordinate animals to compensate, this could explain why subordinate animals were found to eat and gain less compared to other high ranking animals (Metz and Mekking, 1978). Such conditions prevent subordinate animals from getting sufficient resources as well as preventing them from retreating in defeat, which will cause social stress to them (Lindberg, 2001). Thus, having a proper animal grouping would help to reduce the competition and may improve feed intake, especially for the subordinate cows (Grant and Albright, 2000).

2.6.1 Milk production

The correlation between dominance value (DV) and milk production has been found to be significant in some studies (Sambraus, 1970; Sambraus, 1979; Phillips and Rind, 2002; Sottysiak and Nogalski, 2010) and insignificant in others (Schein and Fohrman, 1955; Collis *et al.,* 1979; Lamb, 1976; Soffie *et al.,* 1976). In the early study done by Schein and Fohrman (1955), they found a significant low ($r = 0.25$, $P < 0.05$) correlation between social rank and milk production of cows. In a study done by Phillips and Rind (2002) on the effects of social dominance on the production and behaviour of grazing dairy cows offered forage supplements, they found that a group of cows grazed pasture only had a low (non-significant) positive correlation ($r = 0.14$) between milk yield and dominance. Also, another lower (non-significant) positive correlation ($r = 0.08$) was found between social dominance and milk production in another herd that was supplemented with silage between afternoon and morning milking indoors (Phillips and Rind, 2002). Sottysiak and Nogalski (2010) stated that during a standard-length lactation (305 days) in a herd composed of cows of a similar age, higher ranking cows were characterised by 20% higher milk production compared to the lower ranking cows, but no correlation between dominance and milk production were recorded in the study. However, they did find a positive correlation ($P < 0.01$) between the cow's social rank and their LW and body condition. Reinhardt (1973) also found that dominant cows produce more milk than subordinate cows.

2.6.2 Grazing behaviour and feed intake

In pastoral grazing systems, dominance rank may form based on the priority of access to the best grazing spot (Reinhardt, 1973). This may explain why dominant animals are sometimes found to graze for longer (Stobbs, 1979), having higher intake (Barrosso *et al.*, 2000) and have a better production performance (e.g. better milk production) than the subordinate animals (Reinhardt, 1973). This may be accentuated when there is a competition in feed resources. In a study on free stall and feed bunk requirement relative to behaviour, intake and production of dairy cows, Friend *et al.*, (1977) reported that when competition for feed increased, the correlation (r = 0.71, P < 0.001) between intake and DV became stronger, where dominant cows had higher intake than subordinate cows. Since dominant cows are known to exhibit dominance behaviour towards other individuals to gain priority in accessing resources, restricting feed resources will only favour the dominant cow more in having higher intake by winning competitions with the subordinate cows.

As mentioned earlier, dominant animals are known to have the priority to graze the best quality of herbage (Barroso *et al.*, 2000). As more feed becomes available, they become more selective (Barrosso *et al.*, 2000). Le Du *et al.* (1981) stated that the digestibility of herbage chosen by cattle was on average, 150 to 200 g/kg of DM greater than that of the herbage on offer. Therefore, having the priority to ingest feed of higher nutrient content with lower crude fibre, may explain why dominant cows tend to produce 38% more milk (P < 0.001) than subordinates cows (Le du *et al.*, 1981).

Dominant cows were reported to have a longer feeding time than the subordinate cows resulting in greater DMI (Olofsson, 1990). The effects of feed competition from dominant cows resulted in low DMI and milk production of subordinate cows (Phelps, 1992). Due to the competition, subordinate cows tended to increase their grazing time to compensate for the lower nutrient content of the forage left (Stobbs, 1978; Ungerfeld *et al.*, 2014). Furthermore, in a study on deer (Thoules, 1990) and goats (Lovari and Rosto, 1985), dominant animals were found to be more efficient grazers compared to the subordinate animals. Subordinate animals were reported to perform more head lifting presumably due to a greater vigilance from dominant peers, which in turn resulted in a lower bite rate.

2.7 Effects of grouping animals according to social rank

Grouping strategy can have a significant impact on the feeding behaviour and feed intake of dairy cattle. According to Albright and Arave (1997), when dairy cows are grouped according to social hierarchy, social behaviour modifies DMI and productivity leading them to be less fearful, more contented, healthy and more productive. However, grouping is a component of the cow's feeding environment that can modulate intake due to the impact on cow comfort, competition for feed and other resources, as well as herd health. In a study done by Phelps (1992), lower ranking animals such as primiparous cows benefited from separate grouping from larger mature cows, showing increased intake and milk production. In a study involving two-year-old heifers and mature cows wintered in mixed and separate groups, Thomson *et al.* (1991) found that heifers and mature cows that were kept apart in separate groups improved their liveweight gain compared to cows and heifers in the mixed group. Konggaard and Krohn (1978) found that keeping younger cows apart from mature cows increases their DMI, feeding and lying time. Furthermore, Phillips and Rind (2002) reported that keeping dominant and subordinate cows apart improved the milk production of dominant cows when they were offered pasture and feed supplement (e.g. silage). The study also reported that keeping dominant and subordinate cows apart, resulting in both ranks to lie down for longer (190 minutes/ day) than cows in the mixed group, which contributed to the LWG of dominant cows. In the situation where they were grazed in a mixed group with subordinate cows, dominant cows produced more milk than the subordinate cows due to the dominant cows faster biting rate (68 bites/ minute).

In a further study done by Ungerfeld *et al.* (2014) on the time budget differences of high and low-social rank grazing dairy cows, they found that when high and low-rank cows grazed separately, different time budgets were observed, with high ranking cows grazing and walking less but ruminating more than low-rank cows. Low-rank cows, on the other hand, increased the amount of grazing between morning and afternoon grazing bouts, mainly by continuing grazing from mid-morning, when the high ranking cows stopped grazing. This supports the suggestion of Manson and Appleby (1990) that high ranking cows have priority on where and when to graze, whereas low ranking cows tend to feed away from the high ranking cows to avoid any interactions, causing an increase in the frequency of their grazing bouts. From these findings, subordinate cows require more grazing time when grazing together with dominant cows, suggesting that keeping them in a separate group would benefit the low ranking cows in terms of their grazing behaviour.

An event such as the introduction of new members into the herd or by any change in the herd members itself contributes to the disturbance of social relationship and may lead to an increase in aggressiveness among cows (Bouissou, 1980). Due to this disturbance, the feeding behaviour of cattle may be disturbed due to the competition for food between the higher and lower ranking cows. Previous findings regarding the feed intake difference between dominant and subordinate cows serve as an argument for the need of separating cows according to social rank (Grant and Albright, 2001). Numerous studies in a grazing system have shown that grouping strategy benefits either one or both rank’s production. Therefore, a proper grouping strategy may minimise the negative impact of excessive competition on intake and enhance the beneficial effects of group feeding, such as social facilitation. However, whether similar effects occur in New Zealand dairy systems where a high proportion of pasture occurs in the diet, is not clear.

2.8 Conclusion

Social dominance in dairy cattle is correlated with the cow's production performance such as milk yield, liveweight or grazing behaviour in a few studies. Social dominance in cattle has also been related to higher ranking animals having supremacy over resources and has been found to reflect their production performances, where lower-ranking animals tend to suffer the most from the dominance effect which prevents them from achieving their maximum production performance. Therefore, grouping cows according to their social rank is believed to be beneficial to reduce adverse effects, especially for the subordinate members of the herd, and to allow production performances similar to their dominant peers.

Different types of management systems have different types of social hierarchy, as well as having different levels of dominance that can be detected between animals. In an intensive housing system, the hierarchy is based on competition for space, whereas in a grazing situation, the priority of access to the best grazing may form the basis of the herd hierarchy. Dairy systems in New Zealand are predominantly pasture-based, where herbage availability, supplement feeding and space for grazing and resting may be the factor that creates competition among cows as well as the main drivers for social dominance in cattle. However, there is limited data regarding this subject in the New Zealand pasture-based system context. Therefore, to validate the claim that grouping cows according to their social rank helps the cows to perform better in production as well as their grazing behaviour, a series of studies on the effects of social dominance on milk production and grazing behaviour of lactating dairy cows at different herbage allowances and offered feed supplement would be appropriate, for the New Zealand pasture-based system.

Chapter 3

Relationship between social dominance and milk production and social hierarchy stability of grazing dairy cows

3.1 Introduction

Dairy cattle are innately gregarious animals and form a strict social hierarchy in their cohesive herd through dominance establishment (Phillips, 2002). In general, dominance is associated with higher-ranking individuals having supremacy in the distribution of resources, mainly feed and space. The fundamental component of dairy cattle's social hierarchy is agonistic interactions between the herd members (Guhl and Atkeson 1959). Agonistic interactions in cows include aggression, threats, displays, retreats and conciliation, whereby, recording these interactions can quantify a cow's unique dominance value (DV; Beilharz and Mylrea, 1963). By determining DV of each member of the herd, a better understanding of dairy cattle's social hierarchy component, structure and its stabilisation can be achieved (Beilharz and Mylrea, 1963; Kondo and Hurnik, 1990). A better understanding of the dairy cattle social behaviour may help farmers to design a better herd management system that suits the animals social needs and improve production.

The New Zealand outdoor grazing dairy systems typically involve cows grazing pasture in a large group. According to the statistics of Livestock Improvement Corporation Limited and DairyNZ Limited (2018), the average size of a New Zealand dairy herd has tripled in the last three decades. More than 40% of the New Zealand dairy herds have 400 to 1500 cows in one herd, at an average stocking rate of 2.84 cows/ ha. Competition is created by access to pasture, herbage allowance used, and intense strip grazing of high dry matter (DM) yield crop grazed *in situ*. For example, on a 24-hour herbage allocation, 500 cows allocated to a 5 ha paddock with 3000 kg DM/ ha of pasture, and a daily allocation of 30 kg DM cow/ day above ground level, would have a stocking density of 100 cows/ ha with a space allowance of 100 m^2 per cow. Other than feed, space is known as one of the main drivers for aggressive behaviour between cows. Therefore, having to decrease the amount of space allocation/ cow may increase the number of aggressive interactions between animals.

According to Lindberg (2001), the level of aggressive behaviour in a group of animals is partly dependent on it size, where a small group would have a little number of aggressions between herd members, whereas, a slightly larger group may contain slightly higher levels of aggressive interactions. However, once the group is very large, aggression tends be lower due to the lack of recognition between herd mates. In dairy cows, Fraser and Broom (1990) suggested that cows could only recognise up to 50 to 70 of their herd mates. Therefore, having cows in a very large group may cause a relationship breakdown on the social hierarchy structure, due to the lack of recognition between herd mates. In a study of agonistic behaviour in domestic hens, Hughes *et al.* (1997) reported that in a very large groups, birds could be in close proximity without having aggression, whereas in smaller groups, aggressive interaction tended to occur when moving past or being close to a flockmate (Grigor *et al.*, 1995). Since social hierarchy in cows involves recognition, grouping cows in a large herd may result in an increase of aggressive interactions between cows due to establishing individual recognition and social status.

Social dominance in cattle has been positively correlated to age, measurements of size such as liveweight (LW) and body condition score (BCS) and sometimes milk production (Schein and Fohrman 1955; Dickson *et al.*, 1970; Phillips and Rind 2002; Sottysiak and Nogalski 2010). However, previous studies also showed contradictory results for the relationship between milk production and dominance of cows, ranging from no effect (Beilharz *et al.*, 1966; Schein and Fohrman 1955) to a strong positive relationship (Sambraus 1970; Sottysiak and Nogalski 2010). In general, age is related to the animal’s experience in having social interactions and liveweight is associated with the animal’s strength.

Meanwhile, milk production was suggested to be the outcome of dominant individuals having priority over resources, that leads to a better production. In an indoor feeding system, factors relating to dominance in dairy cattle mainly related to competition for space and considered as the main driver for aggressive interactions between cows in confined spaces (Potter and Broom 1987). For cows managed at pasture, adequate space is generally assured. Therefore, priority to the best grazing spots, having longer and undisturbed feeding time or having a preferred area to lie down can be the major drivers for the cows dominance behaviour (Barroso *et al.*, 2000; Phillips and Rind 2002).

In New Zealand, dairy systems typically involve cows grazing pasture in a large group. This practice may influence cow's social dominance resulting in an increase in social interactions. Aggressive social interactions create stress conditions between dominant and subordinate cows, which may affect milk production (Schein & Fohrman 1955), especially for the subordinate cow. Brakel & Leis (1976) reported a reduction in milk production following a series of aggressive social interactions. On the other hand, compared to the subordinate cows, dominant cows have greater opportunity to obtain basic resources such as feed and space (Arave & Albright, 1981), which may explain the greater milk yield sometimes found in dominant cows (Reinhardt 1973). Previous studies, however, have shown contradictory results for the relationship between milk production and DV, ranging from no effect (Beilharz *et al.* 1966; Schein & Fohrman 1955) to a strong positive relationship (Sambraus 1970; Sottysiak & Nogalski 2010). Many of the studies to date have been conducted with cows under confinement systems, and limited data are available on social dominance of dairy cows in relation to milk production, especially in the New Zealand pasture-based system.

Therefore, the objectives of this experiment were to study factors determining social dominance of dairy cows and to investigate the relationship between dominance and milk production of dairy cows under the New Zealand pasture-based system.

3.2 Materials and methods

3.2.1 Experimental site

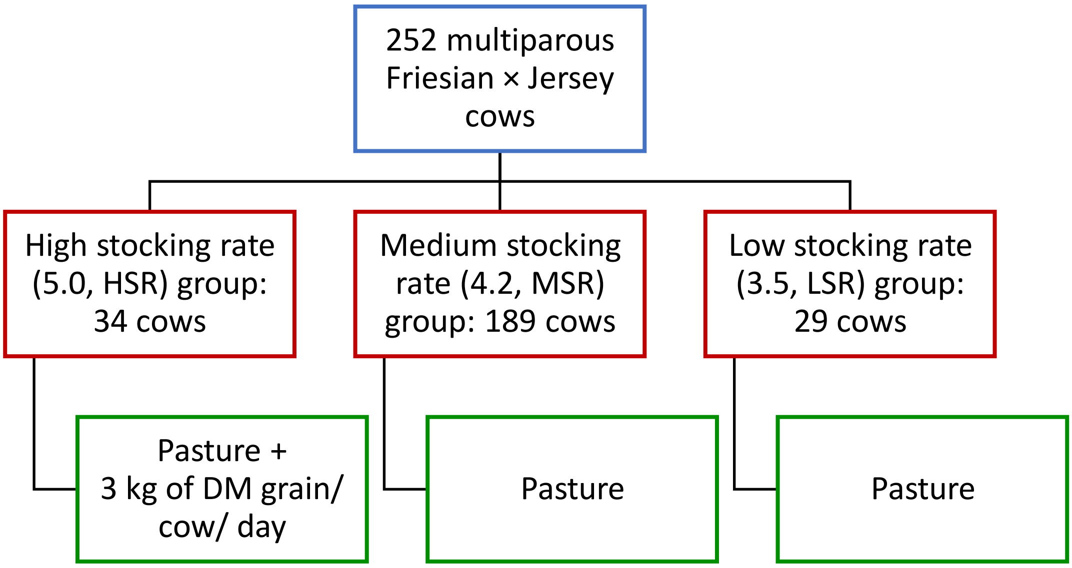
This observational study was conducted at the Lincoln University Research Dairy Farm, Canterbury, New Zealand (43°38S', 172°27E') in early spring to early summer, from 29 September till 19 December 2014.

3.2.2 Animals and herd management

A total of 252 multiparous, early lactation, Friesian × Jersey cows, managed in three distinct groups were involved in this study (Figure 3.1). The three groups of cows used in this study were, a large group of 189 cows stocked at a medium stocking rate (4.2 cows/ ha; MSR), a small group of 34 cows stocked at high stocking rate (5.0 cows/ ha; HSR), and another small group of 29 cows stocked at a low stocking rate (3.5 cows/ ha; LSR). The large group were managed separately under the Lincoln University Research Dairy Farm management, and the two smaller groups were part of a long-term farm systems trial (details described by Clement *et al.*, 2016). All cows calved in spring between 17 July and 17 September 2014 and were used in this research for the behavioural observational study purpose only.

Cows ranged from two to 11 years of age and ranged from 340 to 648 kg of LW. Throughout the study, cows were milked twice daily at 0600 and 1430 h according to their respective group. During milking, the HSR group were supplemented with 3 kg DM grain/ cow/ day, while the LSR and MSR group received none. After morning milking, all cows were kept in paddocks to grazed on perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pastures according to their respective group and were offered herbage allowance above post-grazing herbage mass of 1400 to 1500 kg DM/ ha/ day, with *ad libitum* access to water. The MSR and HSR group were offered herbage allowance of 11 to 14 kg DM/ cow/ day, while the LSR group were offered herbage allowance of 12 to 16 kg DM/ cow/ day. Based on the pre-grazing herbage mass and paddock size, daily space allocation offered per cow on pasture ranged from 32 to 81 m^2 for MSR group, 129 m^2 for LSR group and 110 m^2 for HSR group.

Figure 3.1. Three groups of multiparous, Friesian × Jersey cows in low, medium and high stocking rate group.



Daily herbage allocations were estimated from a compressed height using an electronic rising plate meter (Kellaway *et al.*, 1993). The national calibration equation derived from the manufacturer's default calibration equation for perennial ryegrass and white clover pasture mixture (kg DM/ ha = 140 × RPM reading + 500, where a RPM is equal to 0.5 cm units) was used by the management to allocate forage. Daily allocated areas were calculated from estimates by controlling area allocated to groups of cows with electric fences, with the area (m^2) allocated determined by herbage mass estimate and the number of cows per group.

3.2.1 Milk yield and samples

Daily milk yield was recorded for each cow using an automatic system (DeLaval Alpro Herd Management System, DeLaval, Tumba, Sweden). Milk samples from each cow in the MSR group were collected once every two weeks during morning and afternoon milking, to determine milk composition. Milk composition was analysed by Livestock Improvement Corporation Ltd Laboratory (Christchurch, New Zealand) to determine milk fat, protein and lactose by MilkoScan^{TM} (Foss Electric, Hillerod, Denmark).

3.2.2 Liveweight and body condition score

Liveweight was recorded manually using an electronic walk-over scale (TRU-Test XR3000, TRU-Test Corporation Limited) and cow body condition score (BCS) was assessed based on a ten-point scale scoring system (Roche *et al.,* 2004), once every two weeks after morning milking by two observers.

3.2.3 Behaviour observations

3.2.3.1 Social interactions

Direct visual observations on cows social and grazing behaviour were conducted for 12 weeks between September and December 2014. All 189, 34 and 29 cows in the MSR, HSR and LSR group respectively, were observed on one occasion each week by the same single trained observer, where each group was observed on separate days. One week prior to the study, pre-observation was conducted in the paddock on each group on separate days as a transition period for cows to become familiar with the presence of the observer and to prevent distraction during observations. Observations were conducted in the paddock between morning and afternoon milking, soon after the cows received a fresh break of herbage allocation. The approximate total observation time on each group/ day/ week was six hours between 0800 to 1400 h. Permanent rubber ear tags, with the cow identification number, were used to identify cows. Due to the size of the group, not every interaction was recorded. Therefore, recordings were made over 12 weeks to increase the total number of social interactions recorded, especially for the 189 cows in the MSR group.

Although using one observer increases the risk of missing interactions, it reduces the potential source of variability associated with multiple observers (e.g. cow distraction, mistaking the identity of cows, misinterpretation on types of behaviour performed by cows). On each study week, observations were done only on days when the weather provided clear visibility of all cows in the paddock.

Social interactions between cows were recorded using an 'all-occurrences' sampling method (Altman, 1974). Each time a social interaction occurs, the individual initiating the interaction (indicating dominance) and the individual(s) subjected to the initiation (indicating submission) were observed, and the outcome of the interaction was recorded as win and loss basis (Beilharz and Mylrea 1963). The type of social behaviour observed was bunting, pushing and allogrooming (Phillips, 2002). Each type of behaviours was given a score depending on the level of intensity of aggression performed by cows (Sottysiak and Nogalski, 2010; Table 3.1).

Table 3.1. Types of dominance behaviours and its score

Type of behaviour	Description	Score
Bunting	Swinging or pushing their head in the direction of the other animals to displace them	4
Pushing	Uses part of their body other than the head to displace another cow	3
Allogrooming	One cow licks the body regions of another cow	1

The number of animals each cow interacted with and the total win and loss score a cow accumulates from the interactions was recorded and plotted onto a master chart (MC) on which was entered every animal in the herd (Schein and Fohrman, 1955). A section of the MC showing details of the recording system (Figure 3.2), where each underlined number on the chart represent a total score for an individual contest with another animal. The total score won by an animal for that observation period can be determined by reading through the row. While reading down the column would determine the animal’s total losses. The number of interactions performed by cows was also counted at the side of the total score list.

During the observation, interactions involving many individuals at once sometimes occurred. Therefore, only the clear-cut win and losses in the interactions were recorded to avoid misinterpretation in observing. Because of the high degree of social activity following the milking period, there were days when observations on social interactions were extended for an hour or two following the afternoon milking, once a month in the paddock to maximise the number of interactions recorded (1600 to 1800 h).

Figure 3.2. Example of the master chart for LSR group in the third week

	LOSSES																													
Cow (WINS)	25	44	75	79	81	103	109	110	112	116	122	124	125	130	142	158	164	174	177	197	215	232	278	315	329	334	342	345	355	Score wins	No. cows interacted
25	25	1					4							2															9	16	4
44	1	44			1												4													6	3
75			75						4					1																5	2
79				79						3									4		1								4	12	4
81		12			81							4		4			5		4							4		4		37	7
103						103																								0	0
109							109																							0	0
110				4		3		110															3							10	3
112		1						1	112																					2	2
116										116									4	3										7	2
122											122																			0	0
124												124																		0	0
125							4						125	4			4								4					16	4
130		3	9											130																12	2
142					1	1									142			4												6	3
158																158														0	0
164	1				1												164		4											6	3
174																		174			1				8					9	2
177																			177											0	0
197																				197					4					4	1
215																					215			3						3	1
232	3						3	4									4		4			232		4	4					26	7
278																						1	278							1	1
315																								315	4					4	1
329																									329	1				1	1
334	1			1																						334				2	2
342																									4		342	4		8	2
345									1																			345		1	1
355																													355	0	0
Score lost	6	17	9	5	3	4	11	5	5	3	0	4	0	11	0	0	17	4	20	3	2	1	3	7	28	5	0	8	13	194	
No. cows interacted	4	4	1	2	3	2	3	2	2	1	0	1	0	4	0	0	4	1	5	1	2	1	1	2	6	2	0	2	2		58

3.2.3.2 Grazing behaviour

Grazing behaviour of cows in the HSR and LSR group was recorded by the same trained observer, on one occasion each week, for five hours (0800 to 1300 h) at the same time social behaviour was observed. The grazing behaviour that was observed was grazing, ruminating, standing and lying down. Description of these behaviours are further described in Table 3.2. Due to the large size of the MSR group and the inability to record, no grazing behaviour data was recorded for the group. The duration spent on each grazing activity was calculated by multiplying the total frequency of each activity with 10 minutes interval. Total duration (in minutes) derived from the multiplication becomes the estimation of time spent on each particular behaviour for the six hours of observation.

Table 3.2. Grazing behaviour and its definition

Behaviour	Definition
Grazing	Actively prehending herbage with the head lowered
Ruminating	Rhythmic chewing of herbage accompanied by regular regurgitation of boli from the rumen
Standing	Maintaining an upright position on extended legs
Lying	Lying down in any resting position

Grazing behavioural data were recorded through visual observations by one-zero sampling with a maximum of one recording/ 10 minutes interval (Mitlohner *et al.*, 2001) using an instantaneous-scan sampling method as described by Altman (1974). At each time point of the 10-minutes interval during the grazing behaviour observation, the activity of each cow was scored as 1 or 0.

3.2.4 Dominance value and social group

Referring to the master chart, DV was then determined based on each cow total won or lost interactions, with the ratio of wins to losses transformed into a normal distribution using the following formula:

$$DV = \sin^{-1} (\Sigma x/x + y)^{1/2}$$

Where x = number of wins, and y = number of losses (Beilharz and Mylrea 1963; Phillips and Rind, 2002).

Dominance value derived from the calculation range from 0 to 90. Cows with the highest DV (90) has won all interactions and did not experience any defeats throughout the entire observation period, and cows with the lowest number of DV (0) has lost all interactions to all others. Other representatives of DVs are: DV of 60.0 represents a cow dominating three-quarters of the herd members; DV of 45.0 represents a cow dominating half of the herd members; DV of 30.0 represents a cow dominating one-quarter of the herd members. To determine the social group of cows in the social hierarchy, cows were categorised into three levels of social rank. The lowest social rank being the subordinate group with the DV ranging from 0 to 30. The second level of social rank being the mid-ranking group with the DV ranging from 30.1 to 60.0, and the highest level of social rank being the dominant group, with the DV ranging from 60.1 to 90 (Beilharz and Zeeb, 1982; Kowalski, 2000; Sottysiak and Nogalski, 2010; Table 3.3).

Table 3.3. Social groups according to the range of dominance value (DV) and its criteria

Social group	DV range	Criteria
Dominant	60.1 to 90.0	Cows that were dominant to all other cows or at least 2/3 and more of the herd
Mid-ranking	30.1 to 60.0	Cows that dominated more than 1/3 and less than 2/3 of the herd
Subordinate	0 to 30.0	Cows that were dominating less than 1/3 of the herd or none

3.2.5 Re-grouping of cows

In the third week of study, 40 random cows were removed from the MSR group for three weeks to be used as part of another experimental study, before being re-grouped back into the herd on the sixth week. The removal of cows provided an opportunity to observe any changes on DV and types of behaviour (bunting, pushing and allogrooming) of the remaining 149 cows before the removal, during the absence and after the return of the 40 cows back into the group.

3.2.6 Statistical analysis

Milk production, LW measures and grazing behaviour for each cow were averaged across sampling days according to the LSR, MSR and HSR group. The relationships between milk yield, age, LW, BCS and grazing behaviour and dominance were examined using Pearson's correlation coefficient separately for each group, using the statistical package GenStat (18^{th} Edition VSN International).

Changes of the remaining 149 cows DV was determined, on a week before, during and two weeks after the removal of 40 cows from the MSR group. Regression analysis of the change in the average DV of cows within social group of dominant (D), mid-ranking (M) and subordinate (S) over time was analysed, with time (week 2 to 7) transformed to a natural logarithm and used as an independent variable, in keeping with the methods of Kondo and Hurnik (1990).

To determine changes in the proportion of bunting, pushing and allogrooming throughout the study weeks, a regression analysis of the change in these behaviours within each group over time (weeks) was analysed, with time (week) transformed to a natural logarithm and used as an independent variable. The amount of each type of behaviour performed by cows in each group over the study weeks was calculated as a percentage using the equation below:

$$\%\ \text{type of behaviour} = \frac{\text{total no. of (type of behaviour) performed}}{\text{Total no. of interactions in the group}} \times 100$$

All regression analysis was done using Microsoft Excel 2017 data analysis package (Version 15.33).

To determine any changes of DV throughout the study period, DV for each cow within each group of the first three weeks and last three consecutive weeks of the study were averaged and combined (Week 1 to 3, and Week 10 to 12). Correlation between the two average DV was then tested using Kendall's rank correlation method (Kondo and Hurnik, 1990), using the statistical package SPSS Statistics.

3.3 Results

3.3.1 Dominance value, production measures and grazing behaviour

The mean DV for LSR, MSR and HSR group was 40.6, 41.3 and 43.9, respectively (Table 3.4). In the LSR and HSR group, the highest DV in each group was 73.2 and 67.9 respectively, and the lowest DV in each group was 7 and 18, respectively. However, in the MSR group, the lowest DV reach a minimum of 0 and the highest DV reached a maximum of 90.

The mean milk yield for cows in LSR, MSR and HSR group, was 27, 22.3 and 25.9 L/ day, respectively, and the mean LW for cows in LSR, MSR and HSR group was 530.4, 477.3 and 509.2 kg, respectively (Table 3.4). The average BCS for cows in LSR and MSR group was 4.1, and 4.2 for cows in HSR group, and the average age for cows in LSR group was five years old and 4.7 years old for cows in both MSR and HSR group.

Over the five hours after new herbage allocation were offered, cows in both LSR and HSR group spent more than 50% of the time grazing (167 and 176 minutes, respectively; Table 3.5). On average, cows spent 77 and 53 minutes ruminating for LSR and HSR groups respectively, and the amount of time spent lying was 130 and 92 minutes for the LSR and HSR groups respectively.

Table 3.4. The mean and standard error of mean (SEM) for dominance value, milk production, liveweight, body condition score and age according to group; low-stocking-rate (LSR); medium-stocking-rate (MSR); high-stocking-rate (HSR); minimum (Min); maximum (Max). No milk composition data recorded for LSR and HSR group.

	LSR				MSR				HSR			
Production parameter	Mean	SEM	Min	Max	Mean	SEM	Min	Max	Mean	SEM	Min	Max
Dominance value	40.6	3.14	7	73.2	41.3	1.87	0	90	43.9	2.10	18	67.9
Milk yield (L/ day)	27	0.84	15.8	33.6	22.3	0.35	3.9	31.6	25.9	0.76	17.3	35.7
Fat (%/ day)^	-	-	-	-	4.9	0.05	3.4	6.7	-	-	-	-
Protein (%/ day)^	-	-	-	-	3.6	0.03	2.5	4.4	-	-	-	-
Lactose (%/ day)^	-	-	-	-	4.8	0.03	3.5	5.3	-	-	-	-
Somatic cell (count/ day)^	-	-	-	-	550	66.7	0	5141	-	-	-	-
Milksolids (kg MS/ day)^	-	-	-	-	1.6	0.05	0	2.7	-	-	-	-
Liveweight (kg)	530.4	11.45	388	648	477.3	4.27	340	648	509.2	8.85	393	603
Body condition score	4.1	0.05	3.5	5	4.1	0.05	0	6	4.2	0.06	3.5	5
Age (years old)	5	0.39	2	10	4.7	0.16	2	10	4.7	0.45	2	11

^Milk composition data for LSR and HSR group was copyrighted by DairyNZ, P21 research project.

Table 3.5. The mean and standard error of mean (SEM) of grazing behaviour (minutes/ 5 hours) according to group; low-stocking-rate (LSR); high-stocking-rate (HSR); minimum (Min); maximum (Max).

Behaviour	LSR				HSR			
	Mean	SEM	Min	Max	Mean	SEM	Min	Max
Grazing time	167	4.78	123	220	176	2.72	143	200
Ruminating time	77	4.34	38	135	53	2.18	23	80
Standing time	3	1.07	0	23	32	1.75	15	55
Lying time	130	5.25	70	178	92	2.66	65	133

3.3.2 Factors determining dominance

Milk yield was positively correlated with DV in LSR ($r = 0.476$; $P = 0.009$) and MSR ($r = 0.291$; $P < 0.001$) group but not in the HSR group (Table 3.6). Milksolids was also found to be positively correlated with DV in the MSR group ($r = 0.345$; $P < 0.001$). There was a significant positive correlation between DV and age found in all three groups of LSR, MSR and HSR ($r = 0.646$, $r = 0.349$ and $r = 0.442$; $P < 0.001$, $P < 0.001$ and $P = 0.014$, respectively). For LSR, MSR and HSR, there was also a significant positive correlation between DV and LW ($r = 0.472$, $r = 0.166$ and $r = 0.487$; $P = 0.009$, $P = 0.025$ and $P = 0.003$, respectively). However, there was no significant correlation between DV and BCS or grazing behaviour found in this study.

Table 3.6. Pearson's correlation coefficient between dominance value and milk production, liveweight, body condition score (BCS), age and grazing behaviour according to group; low-stocking-rate (LSR); medium-stocking-rate (MSR); high-stocking-rate (HSR); correlation coefficient (Corr.). No milksolids data recorded for LSR and HSR group and no grazing behaviour data recorded for MSR group.

Production/ Behaviour parameter	LSR		MSR		HSR	
	Corr.	*P* Value	Corr.	*P* Value	Corr.	*P* Value
Milk yield	0.476	0.009	0.291	<0.001	0.289	0.096
Milksolids^	-	-	0.345	<0.001	-	-
Liveweight	0.472	0.009	0.166	0.025	0.487	0.003
BCS	0.131	0.497	0.061	0.419	0.147	0.406
Age	0.646	<0.001	0.349	<0.001	0.442	0.014
Grazing time	-0.236	0.217	*	*	-0.206	0.242
Ruminating time	0.085	0.659	*	*	-0.042	0.811
Standing time	-0.243	0.203	*	*	0.103	0.560
Lying time	0.264	0.164	*	*	0.142	0.420

*No grazing behaviour data was collected for MSR group. ^Milksolids data for LSR and HSR group was copyrighted to DairyNZ P21 research project.

3.3.3 Social interactions and social group

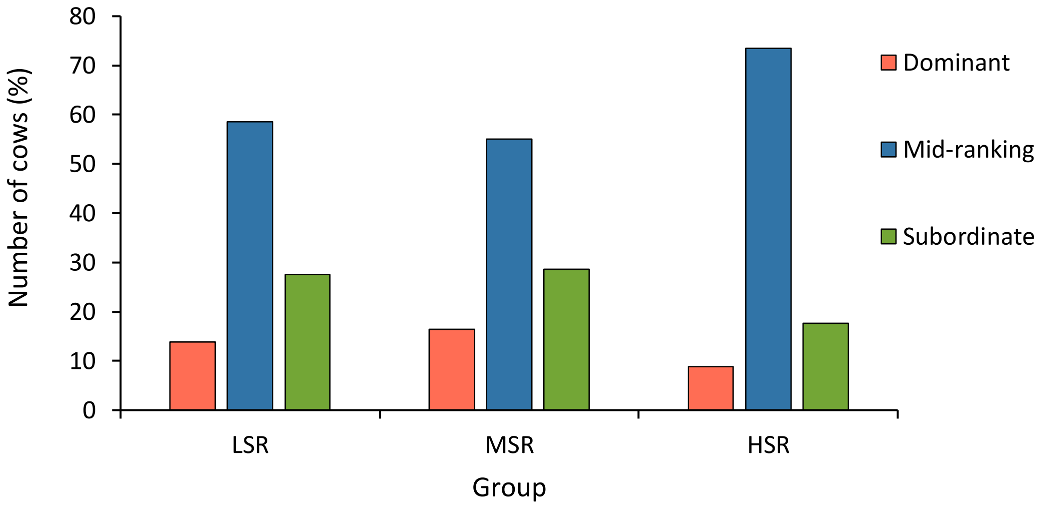
The total number of interactions observed was 297, 589 and 475 for LSR, MSR and HSR group, respectively (Table 3.7). The average number of social interactions/ cow observed in the MSR group is 3 interactions/ cow, and for LSR and HSR group were 10 and 14 interactions/ cow, respectively.

Table 3.7. Total number of interactions, score and number of interactions/ cow according to group; low-stocking-rate (LSR); medium-stocking-rate (MSR); high-stocking-rate (HSR).

Group	LSR	MSR	HSR
Total number of interactions	297	589	475
Average number of interactions/ cow	10	3	14

Figure 3.3 shows that 55 to 74% of the cows in each group were in the mid-ranking social group. Whereas the percentage of the subordinate group made up 18 to 29% of the herd population, and the dominant group were found to be the smallest part of the whole herd population (9 to 16%) in all three groups.

Figure 3.3. Percentage number of cows according to social group of dominant, mid-ranking and subordinate in low-stocking-rate (LSR), medium-stocking-rate (MSR) and high-stocking-rate (HSR) group.



The average number of interactions per cow according to social group of dominant, mid-ranking and subordinate is presented in Table 3.8. The number of interactions/ cow in the dominant group was higher than cows in the mid-ranking and subordinate group for both LSR and HSR groups. On the other hand, in MSR group, the number of interactions/ cow in the mid-ranking group was double the number of interactions/ cow in the dominant and subordinate groups (8 and 4 interactions, respectively).

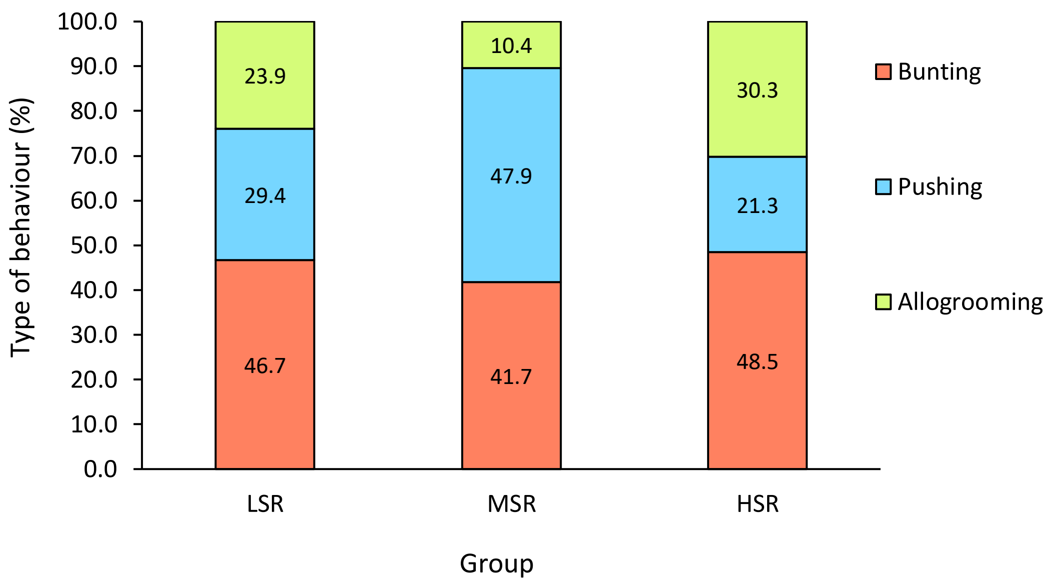
Table 3.8. The average number of social interactions/ cow according to social group of dominant, mid-ranking and subordinate group for the low-stocking-rate (LSR), medium-stocking-rate (MSR) and high-stocking-rate (HSR) group.

Social group	Average no. of interactions per cow		
	LSR	MSR	HSR
Dominant	31	4	38
Mid-ranking	21	8	27
Subordinate	14	4	25

3.3.4 Types of dominance behaviour

The average percentage of bunting, pushing and allogrooming according to group is presented in Figure 3.4. The amount of pushing (47.9%) was higher than bunting (41.7%) in the MSR group, and the percentage of allogrooming (10.4%) performed by the herd members was low. In the HSR and LSR group, the amount of bunting performed was higher than pushing. On the other hand, the percentage of allogrooming observed in the LSR group was almost a quarter (23.9%) of the percentage of the total interactions. Meanwhile, in the HSR group, the amount of allogrooming observed was more than a quarter (30.3%) of the percentage of the total interactions.

Figure 3.4. Average percentage of bunting, pushing and allogrooming according to group; low-stocking-rate (LSR); medium-stocking-rate (MSR); high-stocking-rate (HSR).



A regression analysis of the change in proportions of types of behaviour (bunting, pushing and allogrooming) within each group over time (week) was analysed, with time transformed to a natural logarithm and used as an independent variable. The following equations were obtained;

LSR group:

$y_B = 47.3 - 0.43 \ln x$, $R^2 = 0.0002$, $P = 0.964$

$y_P = 48.5 - 11.51 \ln x$, $R^2 = 0.15$, $P = 0.205$

$y_A = 4.01 + 11.94 \ln x$, $R^2 = 0.25$, $P = 0.095$

MSR group:

$y_B = - 1.8 + 26.19 \ln x$, $R^2 = 0.6$, $P = 0.002$

$y_P = 92.3 - 26.7 \ln x$, $R^2 = 0.62$, $P = 0.002$

$y_A = 9.5 + 0.5 \ln x$, $R^2 = 0.0012$, $P = 0.913$

HSR group:

$y_B = 43.4 + 3.02 \ln x$, $R^2 = 0.02$, $P = 0.611$

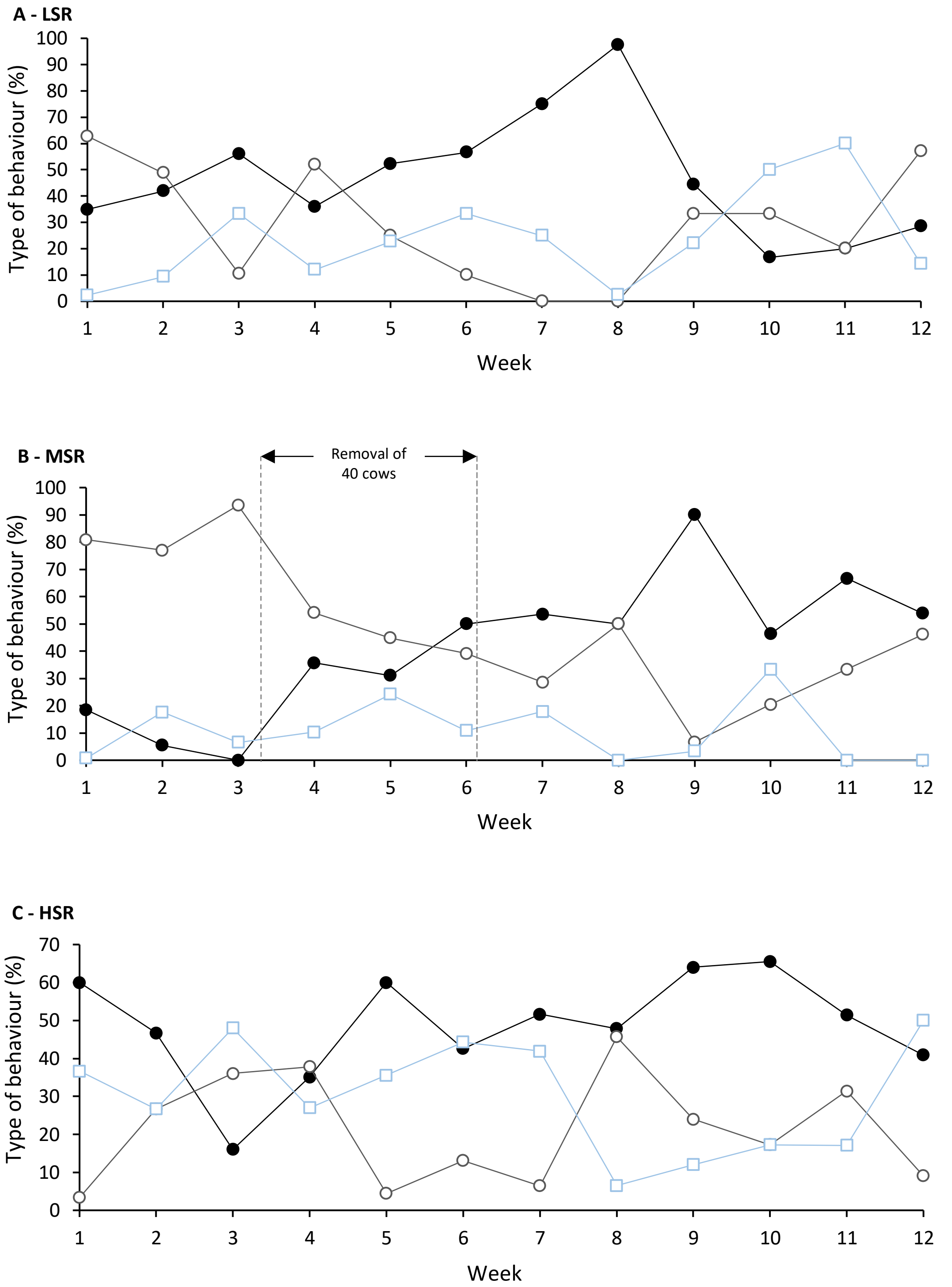
$y_P = 17.6 + 2.2 \ln x$, $R^2 = 0.01$, $P = 0.720$

$y_A = 38.9 – 5.22 \ln x$, $R^2 = 0.07$, $P = 0.397$

where y_B, y_P and y_A were the proportions (%) of bunting, pushing and allogrooming of total encounters, respectively, and the x variable is time according to week. There was no significant relationship found between the change in proportions of types of behaviour (bunting, pushing and allogrooming) in LSR and HSR groups over time. However, there was a significant relationship found between the change in proportions of bunting and pushing over time in MSR group.

Figure 3.5 shows the proportion of bunting, pushing and allogrooming in LSR group, MSR group and HSR group throughout week one to 12. The intercepts did not differ significantly for LSR and HSR group. However, the effect of regression was significant in MSR group, where the contribution of time (week) was high on the bunting and pushing, but not on allogrooming (P = 0.044 and P = 0.001, respectively).

Figure 3.5. Percentage of bunting (—●—), pushing (—○—) and allogrooming (—□—) of cows in A, low-stocking-rate (LSR), B, medium-stocking-rate (MSR) and C, high-stocking-rate (HSR) group.



3.3.5 Re-grouping of cows

The following equations were obtained from regression analysis of the change on average DV of the remaining 149 cows (before, during and after removal of 40 cows) according to social group of dominant, mid-ranking and subordinate in MSR group, over time;

MSR group:

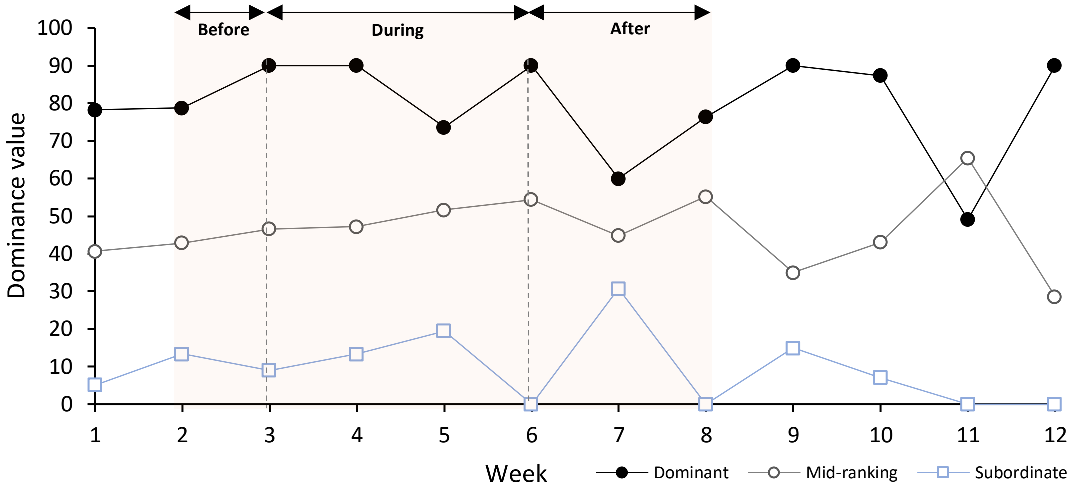
$y_D = 94.3 - 9.83 \ln x$, $R^2 = 0.14$, $P = 0.462$

$y_M = 40.5 + 5.15 \ln x$, $R^2 = 0.3$, $P = 0.251$

$y_S = 5.4 + 6.22 \ln x$, $R^2 = 0.07$, $P = 0.589$

Where y_D, y_M and y_S were the average DV for dominant, mid-ranking and subordinate group respectively, and the x variable is time in weeks. There was no significant relationship found between the average DV of all social groups of dominant, mid-ranking and subordinate over time. The average DV of dominant, mid-ranking and subordinate cows according to week is shown in Figure 3.6. The intercepts did not differ significantly for all groups between week two to seven (Figure 3.6; highlighted area), even during or after the return of 40 cows back into the MSR group.

Figure 3.6. Average dominance value of 149 dominant, mid-ranking and subordinate cows in the medium-stocking-rate (MSR) group according to week; Before = one week before removal of 40 cows; During = during removal of 40 cows for three weeks; After = two weeks after re-grouping of 40 cows into MSR group.



3.3.5.1 Dominance rank stability

In the MSR group, the correlation coefficients were significant between the average DV of the first three and last three weeks (0.257, P = 0.009; Table 3.9). The dominant, mid-ranking and subordinate cows ranked were the same or varied marginally between the first three week and the last three adjacent weeks of the study. However, there was no significant correlation coefficient between the average DV of the first three and last three weeks in LSR and HSR group.

Table 3.9. Kendall's rank correlation coefficient between dominance value (DV) of the first three and last three weeks of the study according to group; low-stocking-rate (LSR); medium-stocking-rate (MSR); high-stocking-rate (HSR).

Group	DV of week 1 to 3 and week 10 to 12	
	Corr.	*P* Value
LSR	0.081	0.591
MSR	0.257	0.009
HSR	0.058	0.642

3.1 Discussion

3.1.1 Factor determining dominance

In this study, the key factors found to be related to dominance in all groups were LW and age. This result is in agreement with previous studies for cows under grazing (Schein and Fohrman 1955; Sottysiak and Nogalski 2010; Phillips and Rind 2002) and confinement systems (Guhl and Atkeson 1959; Dickson *et al.*, 1970).

Social dominance correlation with LW was found to be strong in the Schein and Fohrman (1955) study (r = 0.85, P <0.001) and medium in the Phillips and Rind (2002) study (r = from 0.35 to 0.47, P <0.001 to P <0.05). In this study, the correlation coefficient was similar to Phillips and Rind (2002) for LSR and HSR group (r = 0.472 and r = 0.487, P = 0.009 and P <0.05, respectively), but not in MSR group which was low (r = 0.166, P <0.05). Weight is used as an index of strength (Schein and Fohrman 1955) where larger and heavier cows have the advantage in performing more successful agonistic interactions compared to smaller or lighter weight cows. In a study done by Hohenbrink and Meinecke-Tillman (2012), they found a positive correlation between DV and BCS. However, in this study correlation between these two variables was insignificant, which suggests that dominance is primarily based on the liveweight of the animals, not the level of fat reserve (Phillips and Rind, 2002).

The correlation between dominance and age was found to be strong in Schein and Fohrman's (1955) study (r = 0.93, P <0.001). In this study, the correlation was found to be medium in the LSR, MSR and HSR groups (r = 0.646, r = 0.349 and r = 0.442, P <0.001, P <0.001 and P <0.05, respectively). Age is an index of seniority (length of time in a herd), where higher-ranking cows usually associated with seniority in a herd due to the fact that older cows were more experienced in having interactions with other cows compared to younger cows (Guhl and Atkeson, 1959). In a common hierarchy cycle, changes in rank will occur once the animal passes the juvenile subordinate stage to the more experienced adult stage and later taking over the existing dominant individual place in the higher rank (Lindberg, 2001). However, seniority may be lost once the animal is introduced into a new group of strangers regardless of age and weight (Arave and Albright, 1981).

In previous studies, the relationship between milk production and DV was inconsistent; significant for some studies (Schein and Fohrman, 1955; Barton *et al.*, 1974; Sottysiak and Nogalski, 2010) and non-significant in other studies (Beilharz *et al.*, 1966; Dickson *et al.,* 1970; Reinhardt, 1973; Soffie *et al.,* 1976; Friend and Polan, 1978; Collis *et al.,* 1979, Phillips and Rind, 2002). In this study, the relationship between milk production and DV was significantly positively correlated in the LSR and MSR group, but not in the HSR group. The correlation between dominance and milk production was found to be significantly low, but significant in MSR group ($r = 0.291$, $P < 0.001$), which is similar to the study of Schein and Fohrman's (1955) ($r = 0.25$, $P < 0.05$). On the other hand, the relationship found in the LSR group was a medium correlation ($r = 0.476$, $P < 0.05$). The absence of a significant correlation between dominance and milk yield in the HSR group could be due to the fact that cows in the HSR group were fed pasture and grain while cows in the LSR and MSR group were fed only pasture. As social dominance in cows is usually derived from competing for feed, supplementing grain to the HSR group may have compensated for the competitive effects of social dominance on herbage intake. Thus, this may have explained the absence of the effect of dominance on milk production in this group. However, it is not the intention of this study to compare between groups due to the three herds differed in many characteristics including the number of cows, stocking rate, space allocations, herbage allowance, milk yield, age, liveweight and BCS, which are confounded. Therefore, it is not possible to make comparison across the three groups on the differences in dominance found in each group. Overall, it is notable that a number of relationship were found to be consistent.

Phillips and Rind (2002) found a negative correlation coefficient between dominance and grazing time ($r = -0.23$, $P < 0.05$). According to Le Du *et al.*, (1981), in the grazing situation, dominant animals might spend time and effort maintaining their position in the rank at the expense of grazing. In this study, the correlation coefficient between dominance and grazing time in the HSR and LSR groups was found to be similar to Phillips and Rind (2002) study ($r = -0.236$ and $r = -0.206$, respectively) though not significant. As behaviour was only recorded over a short period, caution is needed in interpreting this result. Grazing behaviour was only observed in a five-hour grazing period and did not cover a complete cycle of grazing in a day, including full depletion of pasture. In a study carried out by Wierenga (1990) on cows in an indoor housing system, the time spent lying per cow per 24 hours in a cubicle was found to be correlated with the cow's dominance. From this, a significant correlation between dominance and the time spent in the cubicle in overcrowded conditions (high-stocking-rate) was found. Over a 24 hour observation, the study showed that the higher-ranking cows had a longer resting time in the cubicle than those in the lower rank. Therefore, this suggests that a longer observation time may have given a better correlation between the cow's DV and their behaviour. Stobbs (1978) indicated that bite size and bite rate are more accurate parameters in evaluating grazing behaviour compared to grazing time alone. Therefore, further research needs to be done on these parameters as Phillips and Rind (2002) found that dominant animals had faster bite rates than S cows, and milk production is also known to be linearly related to these parameters (Reinhardt 1973).

3.1.2 Social interactions

In this study, it was observed that cows in the HSR group had a total of 475 interactions, whereas cows in the LSR group had 297 interactions. The average number of interactions/ cow was also higher in the HSR group (14 interactions/ cow) compared to the number of interactions/ cow in the LSR group (10 interactions/ cow). Although this study was not designed to compare results between groups, it is possible that the higher stocking rate effect in the HSR group (5.0 cows/ ha) may have contributed to the increase in social interactions among cows in the group. Space allocation/ cow was 19 m^2 lower in the HSR group (110 m^2/ cow) compared to the space allocated for cows in the LSR group (3.5 cows/ ha; 129 m^2/ cow). In an indoor feeding system, competition for space was considered as the main driver for aggressive interactions between cows in confined spaces (Potter and Broom 1987). For cows managed at pasture, adequate space is generally assured. Therefore, priority to the best grazing spots, having longer and undisturbed feeding time or having a preferred area to lie down can be the primary drivers of the increase in aggressive interactions between cows (Barroso *et al.*, 2000; Phillips and Rind 2002). Also, cows in the HSR group were found to spend 25 minutes less time ruminating and 38 minutes less time lying than cows in the LSR group. This result could suggest that cows in the HSR group spent more time engaging in activities determining dominance, thus affecting their time spent ruminating and lying.

The lower number of social interactions/ cow observed in MSR group (3 interactions/ cow) could reflect the lack of recognition between cows in the group, due to the large size of the group. According to Lindberg and Nicol (1996), larger groups have factors minimising agonistic interactions that lead to fewer agonistic social interactions. This is due to the lack of recognition between herd mates causing relationship breakdown, leading to the reduced aggression behaviour performed in the herd. Furthermore, an individual animal's ability to maintain their dominance is based on its memory of the past interactions which was used to establish its social status (Lindberg 2001). Although little is known about the recognition memory of cattle, Fraser and Broom (1990) suggested that cows could only recognise up to 50 to 70 of their herd mates. Therefore, having a group of cows with a number larger than this may cause relationship breakdown due to the lack of recognition between individuals.

The lower number of social interactions/ cow observed in MSR group could also be caused by social interactions that missed recording during the observations. Although using one observer increases the risk of missing interactions, it reduces potential sources of variability associated with multiple observers (e.g. cow distraction). However, in this study, recordings were made over 12 weeks to increase the total number of social interactions recorded, which in total exceeded 500 interactions in the MSR group.

3.1.3 Social group

The largest proportion of the herd population was the mid-ranking group, followed by the subordinate group, with the smallest percentage being the dominant group. This finding is in agreement with the study done by Sottysiak and Nogalski (2010) where mid-ranking animals formed the largest part of a dairy cattle herd (94.4%), and only a few animals were found to be in the highest ranking (2.4%) and the lowest ranking group (3.2%). However, in that study, cows were divided into five social groups instead of three, based on the values of the competitive index derived from the herd indices of aggression, dominance and social rank. Furthermore, according to Sottysiak and Nogalski (2010), fewer animals were found to be in the top-ranking position, once the social hierarchy was established and reached its stability. This is in agreement with the result of this study, wherein all the LSR, MSR and HSR groups, the dominant group made up the smallest part of the herd population (14%, 16% and 9%, respectively).

In the LSR and HSR groups, the highest DV was 73.2 and 67.9, respectively, whereas the lowest DV was 7 and 18, respectively. This indicates that none of the groups had an individual who was dominant over all others, nor subordinate to all others. This result is similar to a study on the dominance structure of three dairy herds in stable and yards, done by Beilharz and Zeeb (1982). In that study, they found that there was no single cow that was dominant over every other cow in all herds. In the MSR group, the lowest DV recorded was 0, and the highest DV recorded was 90. This shows that in such a large herd, there are a few individuals that dominate over all others, and there are individuals that are subordinate to all others in the herd. Examination of the number of interactions/ cow in each social group shows that the dominant cows in the LSR and HSR groups had the highest number of interactions with 31 and 38 interactions/ cow, respectively. Furthermore, as the DV decreased, the number of interactions decreased. However, in the MSR group, the dominant and subordinate cows both performed fewer interactions compared to the mid-ranking cows. According to Lindberg (2001), the highest-ranking animals may not perform as many interactions as their middle ranking herd mates. In a stable social hierarchy, it is expected that a decreasing pattern in the average number of interactions performed by each cow is seen, where dominant cows initiate more interactions compared to their lower ranking herd mates (Arave and Albright, 1981). However, the fewer interactions performed by the dominant cows found in the MSR group may explain that the position of higher ranking individuals in the group was highly stable. As stated by Beilharz and Zeeb (1982), dominant animals probably have been aggressive in the early stage of establishing their dominant position, but once their position has stabilised they do not need to always be aggressive. A similar situation was found in an earlier study done by Alba and Asdell (1946) where their top-ranking cows did not fight with each other. These cows dominated all other cows in the herd yet the mid-ranking group was found to be fighting against each other in order to determine dominance. Schein and Fohrman (1955) stated that it is common for aggressive interactions to occur between neighbours in social rank rather than among other animals in the same rank, which was found in this study. Undoubtedly, dominant animals do not need to perform further aggression throughout the entire time to maintain their present status.

McPhee *et al.* (1964) found that when the social order has been established, aggressive interactions between cattle become less frequent and the agonistic behaviour only occurred during competition for feed and space, especially at the feed trough during feeding. Since aggressive interactions are found to be the basic component in the establishment of an animal social hierarchy, the amount of interaction occurring in a herd and the types of interactions performed by each animal can indicate the stability of a social hierarchy. Therefore, this may suggest that the social hierarchy in both LSR and HSR groups may not have reached it stability yet as in the MSR group, due to the cows continuously challenging each other in determining the highest dominance in the herd.

3.1.4 Types of dominance behaviour

The high number of interactions in the LSR and HSR groups coincided with the high amount of allogrooming observed in both groups. Allogrooming is known as a conciliatory behaviour (Reinhardt and Reinhardt, 1981), that occurs mostly among closely ranked individuals. This type of behaviour acts as an essential effect on the maintenance of a stable social structure (Arave and Albright, 1981). As self-grooming is believed to function as a replacement activity (Jensen, 1995), this could indicate that the high percentage of allogrooming observed in LSR and HSR groups could function to alleviate some of the tension caused by the high number of aggressive interactions in the group. Furthermore, allogrooming could also be an act of appeasement or confirmation of dominance from the lower ranked animals to the higher-ranked animals (Fraser and Broom, 1990). On the other hand, the lack of this conciliatory behaviour among the herd's members in the MSR group could be due to the lack of individual recognition among animals, which also could be an indicator that cows in a larger group have weaker bonding between herd members.

In Figure 3.5, the effect of regression was significant in MSR group, where the contribution of time (week) was high for bunting and pushing, but not for allogrooming (P = 0.044 and P = 0.001, respectively). Through time, the amount of bunting increased and the amount of pushing decreased. Reasons for the changes in the amount of bunting and pushing are unclear.

3.1.5 Re-grouping of cows

According to Oberosler et al., (1982), the highest and lowest in the dominance order were usually constant while the middle ranking animals occasionally changed their positions. However, the result of this study does not agree with Oberosler et al., (1982). In Figure 3.6, cows in the MSR social group managed to maintain their DV within range regardless of the removal or the return of the 40 cows into the group. Although there were slight changes in DV of all social groups during the removal of the 40 cows and after re-grouping them into the group, the changes remained within their DV range. This result is similar to a finding in a study done by Hughes et al. (1997) on a large group of domestic hens. They reported that even when re-grouping with previous separate flocks, there was no evidence of any increase in aggression in laying hens. However, it is noticeable that in week 11 of this study, the average DV of the dominant group dropped drastically from 87 to 49, before increasing back to the dominant range of 90 in week 12. A similar result was observed in the mid-ranking group DV, where it increases from 43 in week 10 to 66 in week 11, before decreasing below its range in week 12. Despite all the changes that occur during the last three weeks of the study, it was still not significant. Therefore, this may indicate that despite the removal and re-grouping of cows in and out of the herd, the social hierarchy remains stable throughout the weeks.

3.1.6 Dominance stability

A further analysis was done to determine the dominance rank stabilisation. The correlation coefficient between average DV of the first three and last three weeks in MSR group was tested by Kendall's Rank correlation method and was found to be significant (0.257, $P = 0.009$; Table 3.9). This shows that in the MSR group, the dominant, mid-ranking and subordinate cow ranking was the same or varied marginally between the first three week and the last three adjacent weeks of the study. However, this was not the case for the LSR and HSR groups, indicating that the social hierarchy in both groups may not have reached its stability yet, due to the cows DV varying significantly with each other between average DV of the first three and last three weeks of the study.

3.2 Conclusion

In conclusion, for cows rotationally grazed at pasture, it was found that dominance was positively correlated with LW and age of cows, but not BCS. Having identified the positive effect of LW and age on dominance and the subsequent effect on milk production, future research is required to test whether separating animals, based on these variables, or feeding differentially, could improve milk production. This may mainly be the case when competition in feeding is enhanced. Therefore, this is addressed in the next experiment (Chapter 4) by grouping subordinate and dominant cows apart, offered two herbage allowances and comparing when both ranks are mixed. Overall, using these determinants for social dominance may also contribute to better grouping management in the current New Zealand dairying system.

Chapter 4

Effects of social dominance on milk production and grazing behaviour of lactating dairy cows at different levels of herbage allowances

4.1 Introduction

Cattle are gregarious animals who establish a strong social hierarchy within the herd. The effects of social hierarchy result in individuals having unequal access to various resources such as feed, water and space. This is due to the agonistic interactions between dominant (D) and subordinate (S) members of the herd in determining the priority of access to basic resources, which generally result in dominant cows having superiority in gaining access to these basic resources (Mendl and Held, 2001) over their lower ranking members.

Social interactions between cows are essential in maintaining the herd social structure. However, there are some adverse effects of aggressive social interactions between cows reported in previous studies. These effects range from the reduction in milk yield following regrouping of cows (Brantas, 1986; Schein and Fohrman, 1955), preventing cows from achieving normal reproduction success (Moberg, 1991), increase feeding frequency or time in the lower rank cows compared to the higher ranking cows when grazed together on pasture (Phillips and Rind, 2002, Ungerfeld *et al.*, 2014), as well as decreasing the survivability of cows from lameness, where low ranking cows suffer a higher chances to become lame following aggressive social interactions(Galindo and Broom, 2000). These findings lead to a hypothesis that grouping cows according to their social ranks may reduce aggressive social interactions between cows, preventing these adverse effects from occuring, which may contribute to an increase in the cow's desired performances. This hypothesis has been tested in a study done by Phillips and Rind (2002) on the effects of social dominance on the production and behaviour of grazing dairy cows offered hay as supplement. Through the study, they found by keeping D and S cows grazing separately on pasture appeared to reduce the competition between both ranks, as they increase their total time lying down by 45 minutes, compare to ranks that grazed together. When supplement feeding was made available, grouping D cows separately from the S cows, improved the D cows milk production, liveweight gain, and ruminating time. These results were due to the absence of competition from the S cows during feeding where D cows were able to feed undisturbed, leading a higher weight gain and having undisturbed resting time while ruminating.

The study of Phillips and Rind (2002) also found that, compared to keeping both ranks apart, keeping them together increased D and S cows supplement eating rate, with D cows having faster hay chewing and pasture biting rate. Keeping them together also increased the S cows supplement feeding time. This is believed due to the competition that exists between both ranks in gaining feed resources during feeding and grazing that causes S cows to increase their feeding time to compensate with the feed intake. The same hypothesis was tested in a study done by Ungerfeld *et al.* (2014) on the time budget differences between high and low ranking grazing dairy cows. They found that keeping the two ranks grazing in separate groupings, the time budget spent on grazing behaviour was significantly different, with high ranking cows spending less time grazing and walking but ruminating more than low-rank cows. These studies indicate the benefits of grouping cows based on social rank. However, no studies are found on the effects of grouping cows according to their social dominance, particularly in the New Zealand pasture-based system.

The most crucial factor that influences the cow's dry matter intake (DMI) and hence, the productivity of cows is the feed accessibility for every cow within a herd (Grant and Albright, 2001). Barroso *et al.* (2000) found that grazing animals used their dominance more when herbage was made available *ad libitum*. This is because when there is no feed allowance restriction, animals will compete for the best grazing spots, especially when there is a greater diversity of pasture to graze. The feeding behaviour of cows may be disturbed due to the competition for feed between D and S cows. Such competition often results in D cows obtaining greater DMI compared with S cows (Manson and Appleby, 1990). This may also be due to D cows having a better chance for a longer eating and resting time, and higher intake rate (e.g., bite rate) compared to S cows (Reinhardt, 1973; Albright and Arave, 1981). Unless there is sufficient resource for all cows to eat simultaneously, this leaves the S cows no choice but to feed on what is left by the D cows, denying those S cows the option of selecting a high-quality diet, hence reducing intake. As nutrient intake is the key driver for milk production, there may, therefore, be an opportunity to use grouping management, to minimise the negative impact of excessive competition on feed resources and hence intake (Grant and Albright, 2001). As mentioned earlier, Phillips and Rind (2002) showed that feeding cows with pasture and forage supplement increased both D and S cows resting time and improved milk production of D cows, due to less competition during feeding time. Such effect may be accentuated in grazing systems with restricted herbage allowance. As herbage allowance becomes limited, cows tend to get closer together, which may enhance competition among them. Consequently, it was hypothesised that when having a lower herbage allowance, grouping D and S cows apart may reduce feeding competition and subsequently lead to an increase in feed intake and milk production in both ranks.

The study conducted in Chapter 3, showed that social dominance was positively correlated with age, liveweight and consequently, milk production. However, there was no significant correlation found between social dominance and BCS or time spent grazing during the day. Having identified the positive effect of age and LW on dominance and the subsequent effect on milk production leads to a hypothesis that grouping management such as keeping S cows apart from the D cows may improve the S cow production performance. This may mainly be the case when feed resources are restricted, increasing the need to compete for feed. Cows which are typically less successful in their interactions are more at risk of acquiring insufficient resources. Therefore, the objectives of this experiment were to investigate the effects of grouping subordinate and dominant cows apart or mixed on milk production, when offered two herbage allowances.

4.2 Materials and methods

4.2.1 Experimental site

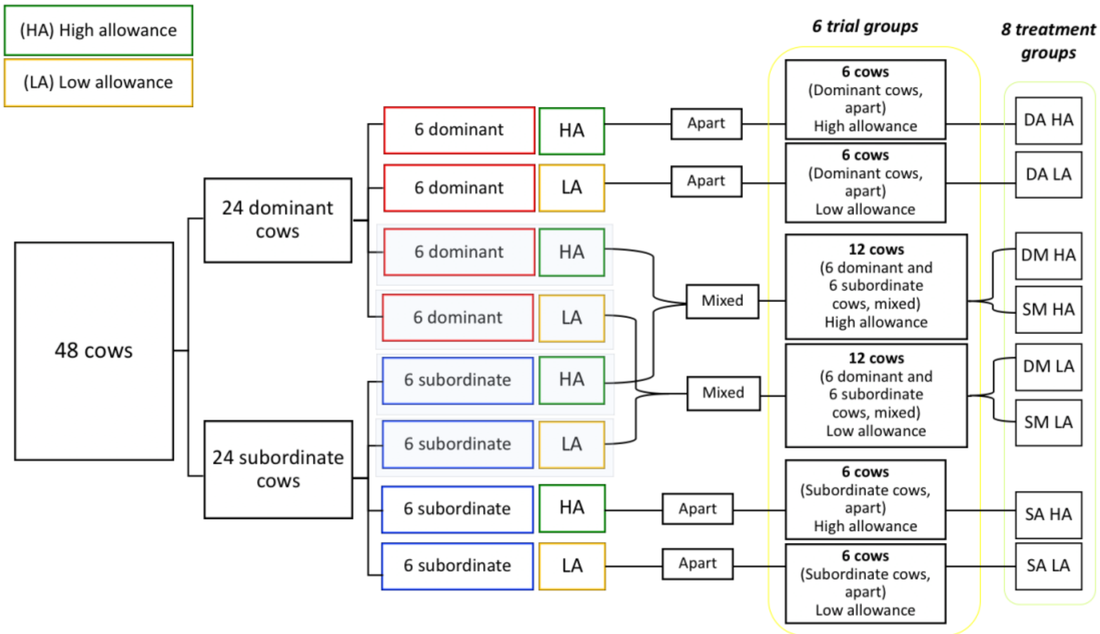
This study was conducted following the approval of the Lincoln University Animal Ethics Committee (AEC; No. 604). The experiment was done at the Lincoln University Research Dairy Farm, Canterbury, New Zealand (43°38S', 172°27E') for 28 days in early autumn, from the 4 till 31 of March 2015. Prior to the actual experimental study, another study was conducted between September 29th till December 19th 2014 (three months) on a larger group of 189 cows as part of another experiment (Chapter 3), to determine the DV of cows for selection in the grazing experiment.

4.2.2 Animals, experimental design and management

A total of 48 multiparous, late-lactation and pregnant, spring-calving, Friesian × Jersey cows previously scored for DV were selected and used in this experimental study. The selected cows represented the highest (D cows, n = 24) and lowest (S cows, n = 24) ranking of cows when studied within a larger group of 189 cows as part of another experiment.

The selected cows were then blocked to eight groups of six cows primarily based on their DV (D = 61.5 ± 1.8, S = 27.4 ± 1.1*;* mean ± SEM), with covariate of milk production (D = 17.2 ± 0.6 L/ day, S = 14.9 ± 0.8 L/ day), age (D = 5.8 ± 0.4 years of age, S = 3.7 ± 0.4 years of age), LW (D = 504.4 ± 10.3 kg, S = 451.5 ± 8.8 kg) and body condition score (D = 4.1 ± 0.1, S = 4.2 ± 0.1). The eight groups were then randomly assigned to two experimental factors (mixed or apart group) with two feeding levels in each factor (high or low herbage allowance); D cows and S cows grazed in mixed (M) group or apart (A) throughout the entire experimental period with high (HA; target of 16 kg DM/ cow/ day) or low (LA; target of 12 kg DM/ cow/ day) herbage allowance above grazing height. The experimental design can be referred to Table 4.1. All cows were kept in paddocks to graze on perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pasture in their respective experimental treatment groups and had *ad libitum* access to water through a portable water trough. Each group received a new break of herbage allocation daily, after morning milking. During the experiment, animals were milked twice daily at 0600 h and 1430 h.

Table 4.1. The experimental design; a group of 48 cows consist of 24 dominant (D) cows and 24 subordinate (S) cows. One-half of each rank subgroups offered high herbage allowance (HA), and the other half offered low herbage allowance (LA). One-half of each rank subgroups grazed in a mixed (M) group, and the other half grazed apart (A).



Daily herbage allocations during the experiment were estimated from a compressed height using an electronic rising plate meter (Kellaway *et al.*, 1993). The national calibration equation derived from the manufacturer's default calibration equation for perennial ryegrass and white clover pasture mixture (kg DM/ ha = 140 × RPM reading + 500, where a RPM is equal to 0.5 cm units) was used during the experiment to allocate forage. Daily allocated areas were calculated from estimates by controlling area allocated to groups of cows with electric fences, with the area (m^2) allocated determined by herbage mass estimate and the number of cows per group.

4.2.3 Herbage measurements and dry matter intake

At least 30 compressed herbage height measurements were taken daily pre- and post-grazing using a calibrated rising plate meter (RPM, Jenquip, Feilding, New Zealand). Pre-grazing measurements were taken in the area estimated to be allocated in the next herbage allocation. A total of 52 quadrats (each 0.2 m^2; 26 pre- and 26 post-grazing quadrats) were randomly collected for each group of cows (n = 312) during the experiment to calibrate the height measurement of sward. By using an electronic rising plate meter (RPM, Jenquip, Feilding, New Zealand), two height readings were taken at the sites of the quadrat, and all herbage in the quadrate was cut to ground level. All cut samples were then oven dried at 60°C for 48 h before being weighed, to determine the herbage DM content. During the study, samples were taken in the morning once every two days. A calibration equation was then derived from it to estimate the herbage DM (kg/ ha) in relation to the RPM measurement. The calibration equation derived from the pre- and post- herbage cuts was:

Kg DM/ ha = 109.2 (RPM) + 61.6, where a RPM is equal to 0.5 cm units (R^2 = 0.85).

By using the calibration equation derived from the study's data set and the grazing areas, the herbage mass allocated was 13.7 and 9.6 kg of DM/ cow/ day for HA and LA, respectively.

Apparent group DMI was determined by herbage disappearance difference between pre- and post-grazing calibrated RPM measurements and areas allocated. A back-calculated DMI was calculated from the energy requirement for production, maintenance, LW change, pregnancy, lactation and feed energy (ME) content (Nicol and Brookes, 2007), where data for each cow was averaged across sampling days. Data were then analysed using the same method as production measures and grazing behaviour.

Herbage samples (fresh weight; FW = 400 g) were collected by cutting herbage to grazing height (3.5 cm) every second day before (pre-) and after (post-) grazing. Fresh samples were then mixed and split into three sub-samples. The first sub-sample of approximately 40 g of FW was weighed and oven dried at 60°C for determination of dry matter percentage (DM%). A second sub-sample (150 g of FW) was sorted into perennial ryegrass, white clover, weed and dead material before oven dried at 60°C for 48 hours and weighed. The third sub-sample of approximately 150 g of FW was frozen at -20°C, freeze-dried and later ground through 1 mm sieves and scanned by near-infrared reflectance spectrophotometry (Feed and Forage Analyzer, FOSS Analytical, Hillerød, Denmark) to determine crude protein (CP), digestible organic matter (DOMD), acid detergent fibre (ADF), neutral detergent fibre (NDF) and water-soluble carbohydrates (WSC) (Lincoln University Analytical Laboratory). Metabolisable energy (ME) was calculated as MJ ME/ kg DM = 0.16 x DOMD (CSIRO, 2007).

4.2.4 Milk yield and samples

Daily milk yield was recorded for each cow using an automatic system (DeLaval Alpro Herd Management System, DeLaval, Tumba, Sweden). Milk samples were collected every three days for each cow during morning and afternoon milking, to determine the milk composition. Milk composition was analysed by Livestock Improvement Corporation Ltd Laboratory (Christchurch, New Zealand) to determine milk fat, protein and lactose by MilkoScan™ (Foss Electric, Hillerod, Denmark).

4.2.5 Liveweight and body condition score

Cow body condition score (BCS) was assessed based on a ten-point scale scoring system (Roche *et al.,* 2004), and LW was recorded manually using an electronic walk-over scale (TRU-Test XR3000, TRU-Test Corporation Limited) once a week after morning milking.

4.2.6 Behaviour observation

Observations on cows grazing behaviour were carried out on day 6, 13, 20 and 27 during the experiment. Each behavioural observation started at the beginning of the first grazing session of the day soon after the new herbage break was allocated, and behavioural data were recorded for five hours (from 0800 to 1300 h). Grazing behaviour of each cow in each group was observed by six trained observers (one group one observer), where each observer was randomly assigned to each group. Inter-observer reliability was evaluated before the start of the actual observation and was found to be consistent across the observers. Behaviour observed in this study was grazing, ruminating, standing and lying down. Description of these behaviours is further described in Table 4.2. Behavioural data were recorded through visual observations by one-zero sampling with a maximum of one recording/ 10 minutes interval (Mitlohner *et al.*, 2001) using an instantaneous-scan sampling method as described by Altman (1974).

Table 4.2. Definitions of the cow grazing behaviours observed by trained observers in the experiment.

Behaviour	Definition
Grazing	Actively prehending herbage with the head lowered
Ruminating	Rhythmic chewing of herbage accompanied by regular regurgitation of boli from the rumen
Standing	Maintaining an upright position on extended legs
Lying	Lying down in any resting position

Other than grazing behaviour, bite rate (number of bites in prehending herbage during grazing) were also recorded for 1 minute for each cow by the same trained observers at 0 and 60 minutes soon after the observation session commence (Bryant *et al.*, 2012). The duration spent on each grazing activity was then calculated by multiplying the total frequency of each activity with 10 minutes interval. Total duration (in minutes) derived from the multiplication becomes the estimation of time spent on each particular behaviour for the five hours of observation.

4.2.7 Statistical analysis

Data were tested for normality using a W-test (Saphiro Wilk test). All data were found to be normally distributed except for lactose percentage and ruminating time. Data that were normally distributed were analysed using parametric statistical methods using the statistical package GenStat (18th Edition VSN International). An initial analysis tested the significance of differences using 6 treatment groups (D and S cows in mixed group, D cows in apart group, S cows in apart group; offered HA, and, D and S cows in mixed group, D cows in apart group, S cows in apart group; offered LA). Following this, a second analysis was tested, comparing cows in 8 treatment groups (D cows in mixed group, S cows in mixed group, D cows in apart group, S cows in apart group; offered HA, and, D cows in mixed group, S cows in mixed group, D cows in apart group, S cows in apart group; offered LA). Both grazing behaviour and production measures for each cow were averaged across sampling days and analysed as a three-factor (dominance, herbage allowance and grouping) ANOVA with all possible interactions using cows as replicate (40 degrees of freedom of error). A repeated measures ANOVA was used to compare the milk production over time (week), with DV, herbage allowance and grouping included as fixed effects and the individual in each group included as a random effect. The apparent herbage DMI was analysed by ANOVA, using day as replicate but only the effect of herbage allowance could be determined in this study, as it was not possible to distinguish between D and S cows in the mixed group. Data that were not normally distributed (lactose percentage and ruminating time) were analysed by generalized linear model with three factors with Poisson distribution.

Behaviour measures such as grazing behaviour, involve interactions between animals, and therefore, individual animals may not be considered as independent. Therefore, caution must be used when interpreting the results, particularly on grazing behaviour (Phillips and Rind, 2001). The use of individual animals as replicates in behavioural analysis has been considered in a series of papers (e.g. Phillips, 1998, 2000; Iason and Elston, 2002), with the conclusion that the practice is acceptable for most behaviours, but only as a preliminary indicator of behaviours where interactions exist.

4.3 Results

4.3.1 Herbage nutrient composition, space allocation and dry matter intake

The pre- and post-grazing herbage mass, space allocated, apparent DMI and nutritive value of herbage offered in this study are presented in Table 4.3. Nutrient composition of herbage used in this study contained an average of 91.2% organic matter, 11.8 ME (MJ/ kg) DM, 253.1 g CP, 432 g NDF, 245 g ADF, 84.5 g WSC with 74% digestibility. The space area allocated for cows in HA and LA was 76.2 to 93.6 and 52.2 to 69.2 m^2/ cow/ day, respectively.

The apparent DMI calculated from herbage disappearance was higher for cows at HA than LA (11.8 vs 9.6 kg of DM/ cow/ day, respectively; $P < 0.001$; Table 4.3). Cows offered HA had a higher estimated DMI than cows in the LA (15.9 vs 12.57 kg of DM/ cow/ day, respectively; $P < 0.001$; Table 4.4). The average DMI back calculated from milk production, LW gain, pregnancy, lactation and feed energy (ME) content, was higher for D cows than S cows (14.9 vs 13.6 kg of DM/ cow/ day respectively; $P = 0.004$).

It was not possible to calculate the herbage intake pre- grazing from herbage disappearance in the mixed group. However, there were significant interactions between dominance and grouping for back-calculation DMI ($P = 0.027$). The average daily DMI for D cows, when mixed with the S cows, was 1.14 kg greater than D cows in the apart group. On the other hand, the average daily DMI for S cows when grouped apart from D cows was 0.99 kg greater than S cows in the mixed group.

Table 4.3. Grazing herbage mass, space area, apparent dry matter intake (DMI), nutritive value and the composition of feed offered in the experiment (HA = high herbage allowance; LA = low herbage allowance; D = Dominant cows; S = subordinate cows; M = mixed group of D and S cows; A = D and S cows kept apart).

	HA			LA			SEM
Items	D S M	D A	S A	D S M	D A	S A	
Pre-grazing herbage mass (kg DM/ ha)	3269	3992	4198	3155	3844	3890	170.2
Post-grazing herbage mass (kg DM/ ha)	1710	1725	1845	1470	1538	1558	57.78
Apparent DMI (kg DM/ cow/ day)*	13.4	11.3	10.8	10.3	9.2	9.2	0.29
Space area (m^2/ cow/ day)	93.6	69.2	60.8	76.2	52.2	52.2	1.84
Metabolisable energy (MJ/ kg DM)	12	11.6	11.8	12	11.9	11.8	0.06
Crude protein (g/ kg)	266	244	248	266	250	245	4.15
Neutral detergent fibre (g/ kg)	387	465	451	383	447	459	15.09
Acid detergent fibre (g/ kg)	235	257	251	233	244	253	4.03
Water-soluble carbohydrates (g/ kg)	93	71	83	90	88	82	3.19
Digestibility (%)	74.9	72.7	73.5	74.9	74.4	73.7	0.36
Organic matter (%)	91.1	91.3	91.3	90.9	91.4	91.3	0.08
Perennial ryegrass (%)	61.9	75.5	75.4	52.4	81.5	70.3	4.34
White clover (%)	33.6	15.5	19.7	42.6	14.4	17.8	4.69
Dead material (%)	4.1	8.8	4.4	4.6	3.7	4.9	0.76
Weed (%)	0.4	0.2	0.5	0.4	0.4	7.0	1.10

*P value < 0.001, SEM = Standard error of means between two treatments

4.3.2 Milk production and liveweight gain

The results derived from the analysis using 6 treatment groups and 8 treatment groups, shows no difference outcome between the 2 statistical tests. Based on the analysis using 6 treatments groups, milk production and milksolids for D cows in the apart group (16.3 L and 1.52 kg/ cow/ day) was greater than cows in the subordinate apart group (13.2 L and 1.31 kg/ cow/ day) and both dominant and subordinate cows in the mixed group (15.4 L and 1.48 kg/ cow/ day; P = 0.021 and P =0.055, respectively). Analysis using 8 treatment groups, milk production in D cows was greater than S cows (16.5 L, 1.6 kg vs 13.7 L, 1.3 kg/ cow/ day, respectively; P < 0.001; Table 4.4). However, production was unaffected by herbage allowance or grouping.

A repeated measures ANOVA on milksolids production over time (Figure 4.1 and 4.2) showed significantly higher milksolids production in week 1 and 2 than in week 3 and 4 (1.4 and 1.5 vs 1.4 and 1.4 kg/ day, respectively; P = 0.003), but no effect of interaction of treatment over time.

Cows offered HA gained weight while cows offered LA lost weight (0.56 vs -0.34 kg/ day, respectively; P < 0.001). There were no significant effects of individual factors, such as dominance or grouping on the cow LW gain found in this study. However, there were significant interactions between dominance and grouping (P = 0.006) on the cow LW gain. Dominant cows gained 0.17 kg more per day when mixed with S cows than apart. However, S cows gained 0.36 kg more when they were grouped apart from the D cows.

Table 4.4. The effects of dominance, herbage allowance, grouping and interactions of these factors on milk parameters, liveweight, liveweight gain, body condition score and back-calculation dry matter intake (DMI) for each treatment (HA = high herbage allowance; LA = low herbage allowance; D = Dominant cows; S = subordinate cows; M = D and S cows mixed; A = D and S cows apart; DV = dominance value; PA = herbage allowance; G = grouping).

	Treatments								LSD			SED			*P Value*					
	HA				LA				[1] DV PA G	[2] DV × PA DV × G PA × G	[3] DV × PA × G	[1] DV PA G	[2] DV×PA DV × G PA × G	[3] DV × PA × G						
Items	D M	D A	S M	S A	D M	D A	S M	S A							DV	PA	G	DV × G	PA × G	DV × PA × G
Milk yield, (L/ day)	17.13^{a}	16.91^{a}	14.64^{bc}	13.66^{d}	16.38^{a}	15.78^{ab}	13.79^{cd}	12.81^{d}	1.538	2.176	3.077	0.76	1.08	1.52	<.001	0.247	0.367	0.712	0.898	0.902
Fat (%)	5.65	5.75	5.23	5.67	5.93	5.03	5.67	6.10	0.426	0.602	0.851	0.21	0.30	0.42	0.716	0.608	0.942	0.055	0.238	0.241
Protein (%)	4.28	4.07	3.98	4.10	4.15	3.76	4.25	4.03	0.207	0.293	0.414	0.10	0.15	0.21	0.790	0.566	0.096	0.234	0.207	0.687
Lactose (%)	5.02	5.00	4.99	4.88	4.93	4.60	4.87	4.82	0.182	0.257	0.363	0.09	0.13	0.18	0.978	0.069	0.143	0.600	0.489	0.311
Milksolids (kg MS/ day)	1.65^{a}	1.65^{a}	1.32^{b}	1.34^{b}	1.63^{a}	1.40^{b}	1.36^{b}	1.29^{b}	0.117	0.165	0.233	0.06	0.08	0.12	<.001	0.213	0.264	0.448	0.181	0.527
End liveweight (kg)	526^{a}	524^{a}	481^{bc}	494^{b}	510^{a}	503^{ab}	471^{c}	453^{d}	27.46	38.84	54.92	13.59	19.22	27.17	0.004	0.111	0.805	0.949	0.490	0.633
Liveweight gain (kg/ day)	0.65^{ab}	0.27^{c}	0.5^{b}	0.82^{a}	-0.31^{de}	-0.56^{f}	-0.40^{ef}	-0.10^{d}	0.216	0.306	0.433	0.11	0.15	0.21	0.081	<.001	0.993	0.006	0.789	0.747
Body condition score	4.08	4.17	4.25	3.92	4.08	4.33	4.17	4.00	0.208	0.295	0.417	0.10	0.14	0.20	0.419	0.685	0.685	0.048	0.419	1.000
Back-calculation DMI (kg DM/ cow/ day)	17.17^{a}	16.43^{ab}	14.48^{c}	15.8^{b}	13.89^{c}	12.36^{d}	11.69^{d}	12.34^{d}	0.930	1.315	1.859	0.46	0.65	0.92	0.004	<.001	0.869	0.027	0.429	0.942

LSD = Least significant difference of means (5% level), SED = Standard error of the difference of means

$^{a-f}$ Means of the same variable in the same row with different subscripts differ for one factor LSD

[1] One factor LSD and SED

[2] Two-way interactions LSD and SED

[3] Three-way interactions LSD and SED

Figure 4.1. Milksolids (kg) according to week for high herbage allowance treatment groups (D = Dominant cows; S = subordinate cows; M = D and S cows mixed; A = D and S cows apart).

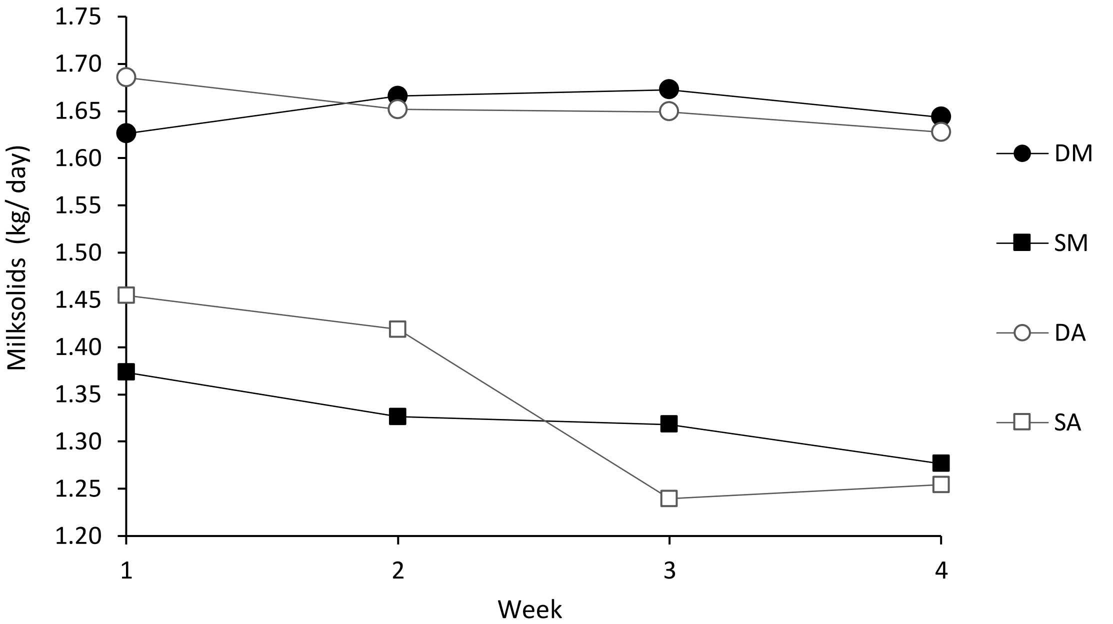
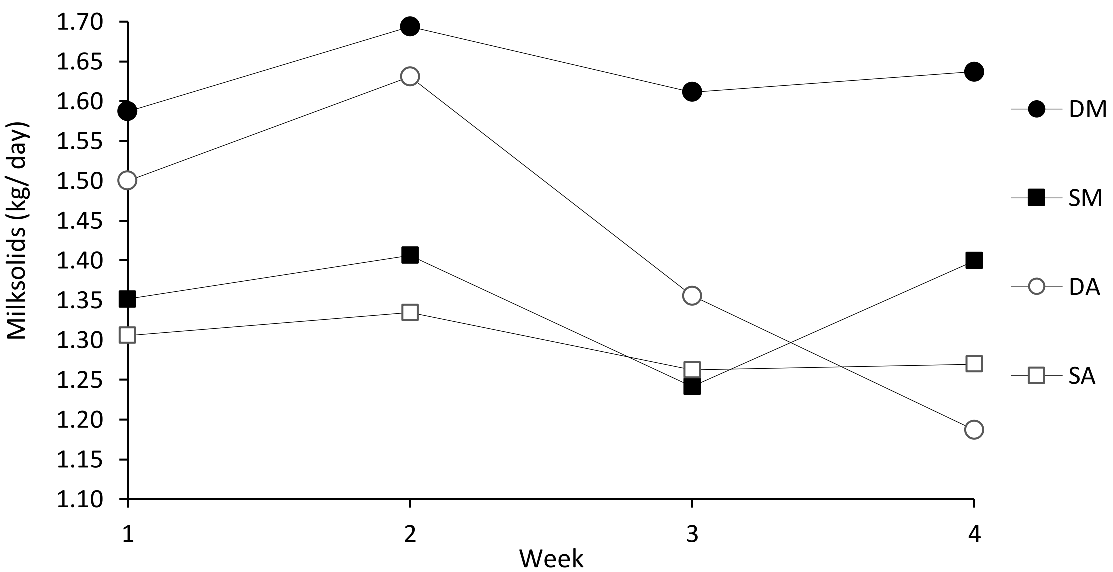


Figure 4.2 Milksolids (kg) according to week for low herbage allowance treatment groups (D = Dominant cows; S = subordinate cows; M = D and S cows mixed; A = D and S cows apart).



4.3.3 Grazing behaviour

Compared with S cows, D cows spent more time ruminating while standing (11.8 vs 7.9 minutes; P = 0.038) and lying down without ruminating (19.2 vs 9.7 minutes; P < 0.001, Table 4.5). Cows offered the LA spent more time grazing and idling while standing than cows offered the HA (250.1 vs 235.8 and 26.0 vs 18.0 minutes; P = 0.006 and P = 0.015, respectively). On the other hand, cows offered the HA spent more time ruminating and lying down than cows offered the LA (29.6 vs 10.9 minutes and 34.9 vs 14.6 minutes, respectively; P < 0.001). Cows offered HA also ruminated for longer while lying down than cows offered LA (18.6 vs 1.9 minutes; P < 0.001). Cows in separate grouping spent more time ruminating while standing compared to cows in the mixed groups (13.9 vs 5.8 minutes; P <0.001).

During the first grazing hour, S cows had a faster bite rate than D cows (56 vs 51 bites/ minute; P < 0.048). During the first and second grazing hour, bite rate for cows offered LA was faster than cows offered HA (57 vs 50 bites and 46 vs 53 bites/ minute; P < 0.004 and P < 0.011, respectively).

There were significant interactions between dominance and grouping (P < 0.001) for ruminating time, where D cows in the apart groups ruminated for longer while standing than D cows in the mixed groups (19.0 vs 4.0 minutes; P < 0.001). There were also significant interactions (P = 0.019) between herbage allowance and grouping for idling while lying down. When offered the LA, cows in the mixed groups idled while lying down for 9 minutes longer than cows in the apart groups. For total standing time, there was a significant three-way interaction between dominance, herbage allowance and grouping (P < 0.042). When offered the HA, S cows spent longer time standing in the mixed groups than S cows kept apart. However, when offered the LA, S cows that were kept apart spent longer time standing than S cows in the mixed groups. As for D cows, when offered the HA and kept apart, they spent longer time standing than D cows in the mixed groups.

There were no effects of individual factors of dominance and grouping on the bite rate during the second grazing hour. However, there were significant interactions (P = 0.048) between dominance and grouping on this behaviour, where D cows had faster bite rate when mixed with S cows than D cows kept apart (52 vs 45 bites/ minutes; P = 0.048). There were also significant interactions (P = 0.005) between herbage allowance and grouping on this behaviour. Cows in mixed group offered LA, had a faster bite rate than those offered the HA (58 vs 43 bites/ minute).

Table 4.5. The effects of dominance, grouping, herbage allowance and interactions of those factors on grazing behaviour (minutes/ 5 hours) and bite rate (bite/ minute) for each treatment (HA = high herbage allowance; LA = low herbage allowance; D = Dominant cows; S = subordinate cows; M = mixed group of D and S cows; A = D and S cows kept apart; DV = dominance value; PA = herbage allowance; G = grouping).

	Treatment								LSD			SED			*P Value*					
	HA				LA				[1]	[2]	[3]	[1]	[2]	[3]						
Items	D M	D A	S M	S A	D M	D A	S M	S A	DV PA G	DV × PA DV × G PA × G	DV × PA × G	DV PA G	DV × PA DV × G PA × G	DV × PA × G	DV	PA	G	DV × G	PA × G	DV × PA × G
Grazing	235.0^{cd}	230.6^{d}	232.2^{d}	245.6^{b}	244.4^{bc}	248.7^{ab}	257.2^{a}	250^{a}	9.92	14.02	19.83	4.90	6.93	9.81	0.187	0.006	0.766	0.748	0.548	0.144
Total ruminating^{+}	24.4^{bc}	28.9^{ab}	33.9^{a}	31.1^{a}	6.1^{d}	21.3^{c}	7.2^{d}	8.9^{d}	6.88	9.73	13.76	3.47	4.81	6.80	0.981	<.001	0.180	0.135	0.270	0.843
Total standing^	26.7^{b}	35.6^{a}	33.3^{a}	21.7^{b}	32.8^{ab}	36.7^{a}	27.2^{b}	44.4^{a}	8.15	11.53	16.30	4.03	5.70	8.06	0.758	0.146	0.262	0.657	0.146	0.026
Total lying^	38.3^{a}	33.9^{a}	34.4^{a}	32.8^{a}	22.8^{b}	14.7^{bc}	15.6^{b}	5.6^{c}	9.09	12.86	18.19	4.50	6.36	8.99	0.243	<.001	0.186	0.961	0.508	0.797
Ruminating, (while standing)	3.3^{e}	21.1^{a}	10.6^{c}	8.9^{c}	5.6^{de}	17.3^{b}	3.9^{e}	8.3^{cd}	3.69	5.21	7.37	1.82	2.58	3.65	0.038	0.236	<.001	<.001	0.988	0.105
Ruminating, (while lying)	21.1^{a}	7.8^{b}	23.3^{a}	22.2^{a}	0.6^{c}	3.3^{b}	3.3^{b}	0.6^{c}	5.71	8.08	11.42	2.82	3.99	5.65	0.148	<.001	0.208	0.558	0.208	0.123
Idling (while standing)	23.3^{c}	14.4^{e}	22.8^{c}	12.8^{e}	27.2^{b}	19.3^{d}	23.3^{c}	36.1^{a}	6.46	9.13	12.92	3.19	4.52	6.39	0.409	0.015	0.280	0.134	0.070	0.096
Idling (while lying)	17.2^{bc}	26.1^{a}	11.1^{d}	10.6^{d}	22.2^{a}	11.7^{cd}	12.2^{c}	5.0^{e}	5.48	7.75	10.96	2.71	3.83	5.42	<.001	0.197	0.720	0.597	0.019	0.234
Bite rate 1st hour	46.0^{c}	49.1^{c}	50.1^{c}	54.8^{b}	59.4^{a}	50.0^{c}	57.4^{ab}	59.9^{a}	4.40	6.23	8.81	2.18	3.08	4.35	0.048	0.004	0.917	0.127	0.098	0.246
Bite rate 2nd hour	44.5^{de}	48.0^{cd}	41.9^{e}	50.9^{bc}	58.7^{a}	41.5^{e}	57.2^{a}	55.7^{ab}	5.24	7.42	10.49	2.59	3.67	5.19	0.217	0.011	0.556	0.048	0.005	0.333

LSD = Least significant difference of means (5% level), SED = Standard error of the difference of means

$^{+}$during standing and lying, ^during ruminating and idling

$^{a\text{-}e}$ Means of the same variable in the same row with different subscripts differ for one factor LSD

[1] One factor LSD and SED

[2] Two-way interactions LSD and SED

[3] Three-way interactions LSD and SED

4.4 Discussion

4.4.1 Dry matter intake and production measures

4.4.1.1 Herbage allowance

There was no effect of herbage allowance on milk yield and milksolids production. Herbage allowance was reported to affect DMI and subsequent milk production of dairy cows (Cosgrove and Edwards, 2007), in which cows that grazed at high herbage allowance produce more milk compared with cows grazing at low herbage allowance. Auldist *et al*. (1998) reported a 44.5% increase in DMI for cows allocated to more than 45 kg DM of herbage than those offered 16 – 18 kg DM of herbage. In addition to greater DMI, this was due in part to high herbage allocation offering more opportunities for cows to select the most nutritious and digestible herbage. Despite apparent herbage allocation being lower than planned, herbage DMI was 2.2 kg DM/ cow/ day higher at HA than LA. However, this difference may not have been large enough to lead to an increase in milk production.

A further factor that may contribute to the limited effect of herbage allowance on milk production is the stage of lactation. The stage of lactation can modulate the partitioning of nutrients (Kirkland and Gordon, 2001). Lactating dairy cows partition more ME towards LW than milk production during the late stage of lactation (Thomson *et al.*, 2001). In this study, although there was no effect of herbage allowance on milk production, there was an effect on the cow LWG. The average LWG across D and S cows shows that LWG was greater at HA than LA by 0.9 kg/ day. The result is similar to a study done by Thomson *et al.*, (2001) who reported dairy cows in late-lactation (200+ days in milk), utilised a higher proportion of their herbage intake for LWG and less for milk production.

4.4.1.2 Dominance

Dominant cows produced 20% more milk than S cows. This result is consistent with the positive correlation between DV and milk yield shown in Chapter 3. This difference may reflect age structure of the cows whereby the average age of D cows was 2.1 years older than S cows, with D cows in the study predominantly being multiparous cows and S cows predominantly being primiparous cows. Multiparous cows produce more milk than primiparous cows (Johnson *et al.,* 2003). This is due to multiparous cows having a greater DMI than primiparous cows (Kertz *et al*., 1991; Johnson *et al.,* 2003). Furthermore, according to Wathes *et al.* (2007), between multiparous and primiparous cows, there are differences in the control of tissue mobilization that promotes the nutrient partitioning into growth and milk during lactation. The nutrient partitioning in primiparous cows is directed into growth and milk, whereas in multiparous cows, the nutrient partitioning is focused more on milk production (Wathes *et al.*, 2007). This result is similar to the study done by Sottysiak and Nogalski (2010) who found that higher-ranking cows are older and produce greater milk yield, with 20% difference in average milk production compared to the lower ranking cows. Phillips and Rind (2002) found D cows produced 13.6% more milk compared to S cows. Therefore, the greater milk yield found in D cows in this study suggests that D cows have a greater conversion of nutrient into milk compare to S cows, due to them being multiparous in lactation.

The differences in the age structure of the cows from this study were derived from the attempt to balance the blocking of cows for each treatment group according to their DV, which resulting in D cows selected to be predominantly older and multiparous and S cows predominantly being younger and primiparous in lactation number.

4.4.1.3 Grouping

Competition in feeding was created when both D and S cows were mixed in a group. Such competition can be the main driver for the D cows to exhibit their social dominance in having access to the best feed available (Albright and Arave, 1997). This may lead them to have a higher feed DMI. In this study however, the effect of grouping D and S cows together versus apart was small, even when the competition was enhanced by lower herbage allowance. Milk yield and milksolids were unaffected by grouping at both HA and LA. However, in this study D cows had a better LWG (0.17 kg/ day) when mixed with S cows. This was supported by the finding that D cows in the mixed group had higher DMI when back calculated from milk production, LW gain and herbage quality. This may be the result of competition which enhanced D cows to compete for more food due to the presence of S cows in the mixed group. The result also shows that keeping both ranks apart seems to have benefited the S cows in terms of LWG, with 0.36 kg/ day greater LWG in S cows when kept apart from D cows versus S cows mixed with D cows. This agrees with the previous study by Thompson *et al.* (1991) on wintering system involving mature mixed age dairy cows and 2 year old heifers. They reported that the heifers winter LWG was significantly higher ($P < 0.01$) when wintered separately from the mixed age group. Therefore, the different effect of grouping on D and S cows in this study suggests different management opportunities for each rank to achieve the desirable production performance related to weight gain.

One explanation for the lack of effect on milk production of mixing D and S cows together versus keeping them separate is that production changes could happen through time, whereby social dominance could change through new groupings imposed in experimental design. This was examined by considering the milksolids production over time in different groupings. This analyses found there was no significant effect of the time × grouping interaction. Phillips (2002) stated that social disorganisation occurs when cattle groups are mixed, and behavioural changes that follow may affect production (Brakel and Leis, 1976). Although cows re-rank themselves according to the new social environment, through frequent mixing, cows usually end up in a similar social rank (Brakel and Leis, 1976). Therefore, this frequent mixing could diminish the effect on milk production in cows (Sowerby and Polan, 1978). Since the cows in this study were used to frequent mixing according to the farm management prior to the study, this may explain why no production changes happened through time, associated with the grouping. A further explanation is that spatial competition may not have been achieved in this study. While herbage allowance was controlled, the lower pre-grazing herbage mass in the mixed groups led to greater space allocated/ cow compare to the animals in the separate groups. Therefore, it may have contributed to the lack of effect.

4.4.2 Grazing behaviour

4.4.2.1 Herbage allowance

When herbage allowance is high, the DMI increase may lead to greater rumination time (Ribeiro Filho *et al.*, 2005). Rumination in cattle is under voluntary control (Hancock 1950), and when the situation is desirable, cows prefers to ruminate while lying down (Phillips and Rind, 2002). Ruminating behaviour indicates the cow's resting time and is known to be the primary determinant in improving the cow's LWG (Phillips, 2002). This was evident in this study where cows in HA spent greater time ruminating and lying. On the other hand, when food is scarce, cows increase their grazing time to compensate for low DMI per bite (Pérez-Ramírez *et al.*, 2008). This is in agreement with the results of this study, where cows offered LA spent 14 minutes more in grazing time compared with cows offered HA. Similarly, Pérez-Prieto *et al.* (2011) reported 20 minutes greater grazing time between cows allocated to low herbage than medium and high herbage allowances. Also, cows offered LA were also found to idle (standing-without ruminating) longer than cows at HA. This is in agreement with Baker et al. (1981) who reported cows spent less time grazing when offered low herbage allowance. They also reported that herbage intake was reduced at the lower herbage allowance, and this was reflected in the reduced rumination time and increased time spent idling.

Furthermore, cows in this study at LA had a faster bite rate compared to cows at HA in both the first and second hour of the grazing session. This may be due to the low herbage mass that drives the cows to have a faster bite rate, to maximise DMI (Cosgrove and Edwards, 2007). The increase in bite rate of cows offered low herbage allowance in the first and second hour of the grazing session indicates the competition in getting enough feed between cows. This was also seen in the second hour of grazing when the bite rate was found to be consistently higher, especially for cows in the mixed groups. Due to the limited feed offered, cows tended to increase their bite rate to compete with other cows in gaining more feed as well as to increase DMI, especially when keeping both ranks together. Cosgrove and Edwards (2007) reported that low herbage mass drives cows to have a faster bite rate in order to maximise their DMI, which was evident in this study.

4.4.2.2 Dominance

The higher amount of time spent ruminating while standing by D cows than S cows in this study is in agreement with Ungerfeld et al. (2014) who reported that higher rank cows ruminated more frequently than lower rank cows. As previously discussed, D cows had higher DMI than S cows in this study, which could be the reason for the higher ruminating time of the D cows. Although there were no differences found in the grazing time between the two ranks, and that D cows bite rate was lower than S cows, their greater DMI may indicate that D cows harvest more pasture per bite (bite mass) and eat in preferential areas, fill faster and begin ruminating earlier and for longer (Ungerfeld et al., 2014). However, the was no bite mass data recorded in this study to support this suggestion. Furthermore, the fact that D cows spent more time ruminating while standing instead of lying down, could be related to the additional time and effort they need to maintain their social position (Le Du et al. 1981), which is easier to achieve while standing than when lying down.

The greater amount of time spent lying without ruminating by D cows in this study suggests that higher-ranking cows had the privilege of resting longer without being disturbed compared to S cows (Phillips, 2002). This may reflect that S cows prefer not to be displaced by D cows when lying down even when the resting place is available. In a study on social rank in a freestall system, Friend and Polan (1974) found that social position affects the use of lying space, where lower-ranking cows tend to avoid lying down in the free stalls previously occupied by higher-ranking cows, resulting in inefficient use of certain stalls at times. It was proposed that this was due to S cows being displaced by the D cows in gaining the desired place to lie down and rest. This study however, did not find any differences in the time budget for lying or standing between high and low ranking cows.

A complementary explanation for longer lying down time (without ruminating) in D cows could be related to high milk production. According to Phillips (2002), high-yielding cows need longer lying time, which was evident in this study. This is because blood circulation through the udder increases by up to 30% when cows lie down, which may enhance milk production in cows (Rulquin and Caudal, 1992). The higher amount of time spent lying without ruminating by D cows in this study may also suggest that higher-ranking cows had the privilege of resting longer without being disturbed compared to S cows (Phillips, 2002). In a cubicle system, social position affects the use of lying space as the D cows have usually displaced S cows. This is due to cows competing for the desired place to lie down and rest (Friend and Polan, 1974). Therefore, it is likely that the longer lying time spent by D cows indicates the superiority in them having undisturbed resting time as well as a contributing factor to the increase in milk production that was evident in this study.

In the Phillips and Rind (2002) study, D cows were reported to have a faster biting rate than the S cows, with 67 bites per minute. However, in this study, an opposite result occurred where, during the first hour of the grazing session, S cows had a faster biting rate than D cows with 56 bites. This result may suggest that S cows were more competitive and focused on grazing during the first hour of the grazing session while D cows were busy engaging in keeping their dominant position in the herd (Le Du et al., 1981). According to previous studies, (Friend and Polan, 1978; Phillips and Rind, 2002), animals spent time in an effort to maintain their social position at the expense of grazing. This suggests that cows that were involved more in social interactions spending less time eating. Phillips (2002) reported that cows bite rate is usually constant during most meals. However, as time spent in other activities increases, a reduction in bite rate at the beginning and end will occur. In the second hour of the grazing session, D cows in the mixed groups were found to have a faster bite rate with 52 bites per minute compared to D cows in the apart groups (45 bites/ minute). Other than the idea of needing to compensate the DMI in the second hour of the grazing session, this may also suggest that D cows become more competitive in the second hour of grazing period with the presence of S cows in the mix groups.

4.4.2.3 Grouping

Ruminating in cattle indicates the relaxed state of both ranks during the absence of social tension in the group (Ewbank, 1978). The higher total ruminating time while standing by cows in the apart groups as well as by D cows when kept apart from the S cows may indicate their relaxed state due to the absence of disturbance from the S cows. Furthermore, ruminating while standing can also indicate the need for the cows greater vigilance of their surroundings during grazing, especially when they were grouped in smaller groups (less than eight animals) (Rind and Phillips, 1999). On the other hand, when offered low herbage allowance, cows in the mixed groups were found to idle while lying down for longer compared to cows in the apart groups. This may indicate that cows in the mixed groups have higher shared vigilance towards the threat of predation due to the higher number of animals in the herd and were in a more relaxed state compared to cows in the apart group who had fewer animals per group. According to Penning et al. (1993), the possibilities for shared vigilance activities were reduced in small groups (e.g. less than 4-5 animals). Also, due to the small number of animals in the apart groups, the act of standing may serve as a better anti-predator strategy compared to when lying down.

In this study, there were significant three-way interactions between dominance, herbage allowance and grouping. When offered high herbage allowance, S cows in the mix groups spent more time standing than D cows, whereas D cows spent more time standing when kept apart from the S cows. This may be due to the competition between S and D cows in having a desired place to rest, where S cows usually are displaced by D cows, which may result in S cows having to stand from their lying place and thus be standing for longer periods. However, there was no data recorded on the displacement act of D cows on S cows to support this claim. On the other hand, the longer time spent on standing for D cows in the apart group may indicate a greater vigilance of predator compared to D cows in the mix groups.

4.5 Study limitation

Grouping animals and maintaining group size was an important consideration in the design of experiment, although it is hard to control both simultaneously within a single design without a further factor of group size. In the experimental design, total group size was increased in the mixed group compared to apart (e.g. 12 versus 6 animals), as a consequence of keeping the number D and S animals in each treatment group constant (e.g. 6 animals). Due to this design, there is a confounding of total group size and treatment (mixed versus apart), and as such, results must be considered with caution. Penning et al. (1993) noted that one of the major factors controlling DMI and behaviour was group size. For sheep, they showed that grazing time markedly declined when group size was lower than three sheep. In a study by Rind and Phillips (1999), grazing time was measured from 4, 8 to 16 cows. They found no significant effects of group size on grazing time, but that cows in small groups moved their head more frequently, and had higher rumination time. In this study, the effects of possible group size were minimised by having 6 animals as the minimum group size.

4.6 Conclusion

Overall, for cows rotationally grazed at pasture, high herbage allowance affected the cows DMI and grazing behaviour, especially the amount of time spent for ruminating and lying in both social ranks. The competition that exists within a mixed group of cows led to D cows have increased LWG in this study, compared to D cows grouped apart, due to having higher DMI when back calculated from milk production, LW gain and herbage quality. Dominant cows had a longer resting time without ruminating than the S cows, which may have contributed to their higher milk production. The reason for the lack of significant effect on milk production when grouping cows according to their social rank in this study is unclear. However, it is believed that the effect was more apparent for LWG than milk production due to the cows being at the late stage of lactation. Although grouping cows, according to the social rank, did not improve their milk production, it did lead to greater LWG in S cows. Keeping D cows apart from S cows also helped them to increase their rumination time. Therefore, grouping cows according to their social dominance affected S cows DMI and LWG, but there was no benefit to milk production of separating them based on dominance value even when low allowance enhanced competitive interactions.

Having identified this, restricting herbage allowance may not be enough to enhance the effects of dominance in production fully. This raises questions regarding whether the impact of social dominance on production and grazing behaviour may be accentuated more by manipulating space through supplement feeding, while separating S cows from D cows, may help to reduce competition. Therefore, this is addressed in the next experiment (Chapter 5) by manipulating feed and space as well. This was achieved by measuring milk production of dairy cows of low and high dominance rank, with S cows grazing either together with D cows in a mixed group or graze apart from D cows. Competition among cow groups was enhanced by supplement feeding of fodder beet to cows and grazing *in situ* in the paddock.

Chapter 5
Effects of social dominance on milk production and grazing behaviour dairy cows offered supplements

5.1 Introduction

Dairy cows establish a distinct hierarchy through social interactions to ascertain dominance and subordinance. Social interactions between animals often involve certain aggression and rank has a pronounced effect on the individual. Effects of the aggression can be seen in the distribution of basic resources such as feed, space, mating and resting places, where dominant animals have the supremacy in the priority of access to these resources (Potter and Broom, 1987, Barroso *et al.*, 2000), whereas subordinate animals may suffer from reduced access to these resources.

In the New Zealand pasture-based dairy system, supplement feeding of crops such as fodder beet (FB) *in situ* is increasing in current practice. This is because, it has been shown to be an effective feed option for dairy systems (Edwards *et al.*, 2014), especially during winter and in dry season in cows, or as supplement to pasture. However, the provision of feed supplement may enhance the aggression between cows as a result of feed competition (Clutton Brock *et al.*, 1976), which may affect the cows behaviour and production performance. In a study on the effect of two wintering systems on cow behaviour using block and paddock grazing offered silage as supplement by Judd *et al.* (1994), they reported that the method adopted for feeding supplement partly influence the behaviour of cows. They reported that feeding supplement (i.e. silage) increase competition between heifers and mature cows when grouped together, resulting in twice the number of the aggressive interactions compared to when the cows and heifers were grouped apart. The common New Zealand practice of feeding FB in paddocks and grazing *in situ* may accentuate competition in feeding between cows. This is accentuated by the common method of allocating the crop in a long narrow strip grazing pattern, and allocating high DM yield of the crop, so enhancing stocking densities.

According to European studies using high feed input systems on grazing dairy cows, social rankings are important determinants of feed intake and milk production. When competition for feed exists, it can result in the subordinate (S) cows receiving a lower allocation of feed compared to the dominant (D) cows (Arave and Albright, 1981). Such competition may result in D cows obtaining greater DMI compared to the S cows (Manson and Appleby (1990), due to the D cows greater intake rate (e.g. bite rate) (Phillips and Rind, 2002) and feeding at the desired feeding time (Ungerfeld *et al.*, 2014). Unless there are sufficient resources such as feed and space for all cows to eat at once, this leaves the S cows no choice but to feed on what is left by the D cows, denying those S cows the option of selecting a high-quality diet. As nutrient intake is the key driver for milk production, there may therefore be an opportunity to use grouping management, to minimise the negative impact of excessive competition on feed resources and hence intake (Grant and Albright, 2001) and milk production, especially for S cows.

The behaviour patterns of cows are influenced by environmental conditions, and feeding activity may be strongly influenced by feed composition and nutrient supply (Gregorini *et al.*, 2006), including social influences (Ungerfeld *et al.*, 2014). According to Olofsson (1990) and Phelps (1992), the effects of competition that exists between D and S cows, leads to D cows having a longer feeding time and greater DMI than S cows. Due to such conditions, S cows tended to increase their grazing time to compensate for the lower nutrient content of the feed left (Stobbs, 1978). In a study done by Ungerfeld *et al.* (2014), they found that high and low ranking cows had different time budgets when they grazed separately, with high ranking cows grazing and walking less, but ruminating more than low ranked cows. Furthermore, the differences found in the time budget between D and S cows could be due to responses to individual social interactions as well as to the coping mechanism that are directly related to the position of the individual in the social hierarchy.

Grouping cows according to their social dominance may reduce feeding competition, especially when involving feed supplementation. In studies with housed animals, cows were found to be less fearful and content when they were grouped according to their social rank leading to a greater dry matter intake (DMI) and productivity (Albright and Arave, 1997). Phillips and Rind (2002), reported that in a mixed group of D and S cows, S cows competed for more hay compared to the D cows, based on their longer feeding time and the increase in the number of ruminating bites/ day. Following that, the time spent grazing on pasture by S cows was reduced. Furthermore, when keeping both ranks apart, both ranks increased the amount of time lying down and reduced the hay eating rates, which indicates higher competition when they were kept together for hay feeding.

In chapter 4, the effects of grouping D and S cows together and apart were examined. There was no effect on milk production of grouping D and S cows together or apart. However, S cows gained more weight when they were grouped apart compared to when mixed with D cows. This occurred where the effect of treatment designed to increase competition (i.e. reduced herbage allowance) had a relatively small effect on production and parameter. Here, it was hypothesised that in an intense feeding situation, performance and behaviour of S cows would be improved by grazing apart from D cows. More information on competition and social stability was needed to explain the lack of milk yield response and sensitivity of subordinate cows to mixing in chapter 4. Therefore this study was carried out to determine the effect of separating subordinate cows on milk production and behaviour under restricted feeding of pasture and FB supplementation.

The objective of this study was to examine the effects of social dominance in a dairy cow herd on milk production from a New Zealand pasture-based dairy farm. This was achieved by measuring milk production of dairy cows of low and high dominance rank, with S cows grazing either together with D cows in a mixed group or grazing apart from D cows. Competition among cow groups was enhanced by supplement feeding of fodder beet to cows and grazing *in situ* in the paddock.

5.2 Materials and methods

5.2.1 Experimental site

The study was conducted in accordance with the approval of the Lincoln University Animal Ethics Committee (AEC; No. 2016-07). The experiment was done at the Lincoln University Research Dairy Farm, Canterbury, New Zealand (43°38S', 172°27E') for 19 days in mid-autumn, from 18 April till 6 May 2016. Prior to the actual experimental study, a pre-observational study was conducted between the 20 January and 17 March 2016 (58 days) to determine the dominance ranking of cows, for selection in the grazing experiment.

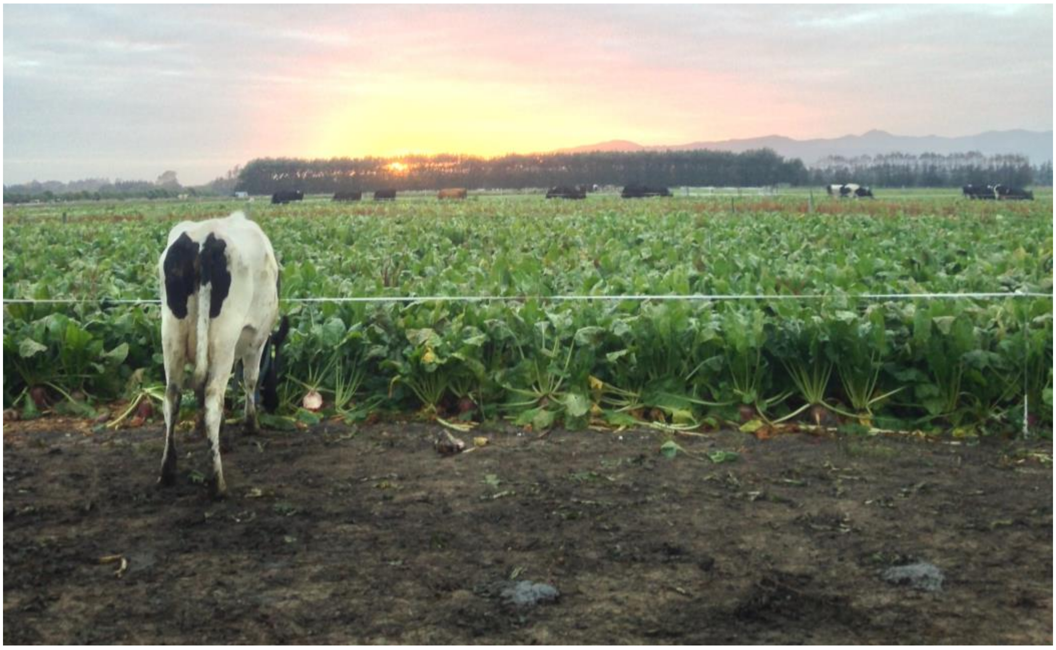
5.2.2 Experimental design and management

The experimental design was a completely randomised design with two treatments and three replicates. A total of 54 multiparous, late-lactating, pregnant, spring-calving, Friesian × Jersey dairy cows previously scored for DV were selected and used in this experimental study. These selected cows represented the highest (D cows, n = 18) and lowest (S cows, n = 36) ranking of cows. All cows were then allocated to three replicates of two treatments: the first was the control consisting of a high competition mixed (M) of 12 cows; six S cows combined with six D cows or an alternative separation of S cows only in apart (A) group; six S cows kept apart throughout the entire experiment. Within each dominance group, cows were blocked based on DV (D = 89.4 ± 0.6, S = 5.5 ± 1.7; mean ± SEM), milk production (D = 10.0 ± 0.5 L/ day, S = 8.8 ± 0.4 L/ day), liveweight (LW) (D = 507.4 ± 17.0 kg, S = 481.2 ± 11.7 kg), body condition score (BCS) (D = 3.8 ± 0.1, S = 3.9 ± 0.1) and age (D = 5.5 ± 0.7 years old, S = 4.0 ± 0.4 years old).

One week prior to the start of the experiment, all cows were adapted to a daily allocation of 3 kg DM of FB. The amount of FB offered was increased by 0.5 kg DM/ cow for every two days. During the experiment, all cows were offered a total of 3 kg DM of FB/ cow/ day, grazing *in situ* on a 4.2 ± 0.16 m strip of FB/

cow, in their respective group. Cows were allowed to graze on fodder for three hours after milking (0830 h to 1130 h), before being moved to graze on a new paddock of perennial ryegrass (*Lolium perenne* L.) and white clover pasture(*Trifolium repens* L.) throughout the day, in their respective group. FB bulb was extracted from the ground daily to ensure maximum consumption of the crop offered and also to ensure that there were no leftovers remaining on the break. Pasture allocation was given the same for all treatment groups at 12 kg DM/ cow/ day above 3.5 cm of herbage height. The ME requirement for these animals was approximately 150 MJ/ cow/ day (AFRC 1993) or approximately 13 kg DM/ cow/ day accounting for milk yield, gestation and BCS gain requirements.

Figure 5.1. Cows consuming fodder beet crop *in situ* in their respective groups before being moved to graze on a new paddock of pasture.



Daily pasture allocations during the experiment were estimated from a compressed height using an electronic rising plate meter (Kellaway *et al.*, 1993). At least 30 compressed herbage height measurements were taken using a calibrated rising plate meter (RPM, Jenquip, Feilding, New Zealand) to determine the amount of herbage availabilit in the area estimated for the herbage allocation, prior to the experiment. The plate meter was then calibrated by recording the compressed height of 61 quadrats (0.2 m^2 each), where all herbage within the quadrat was harvested to ground level. Cut herbage was later oven dried at 60°C for 48 hours for determination of DM yield (kg DM/ ha). A calibration equation was then derived by fitting a single line through all data points (n = 61). The calibration equation was then used for daily herbage allocation throughout the experiment:

Herbage mass $_{pre}$, kg DM/ ha = 149 (RPM) + 520, where a RPM is equal to 0.5 cm units, (R^2 = 0.59).

Daily allocated areas were calculated from estimates by controlling area allocated to groups of cows with electric fences, with the area (m^2) allocated determined by herbage mass estimate and the number of cows per group. Based on paddock size and pre-grazing herbage mass, the daily space allocated on pasture for D and S cows in the mixed group was 96.4 ± 4.16 m^2/ cow and for S cows in the apart group was 92.1 ± 4.27 m^2/ cow. Daily allocated areas were controlled by temporary electric fences to prevent back grazing with each group offered *ad libitum* access to water through a portable trough. All cows were milked once daily at 0600 h.

5.2.3 Herbage measurements and intake

At least 30 compressed herbage height measurements were taken daily pre- and post-grazing using a calibrated rising plate meter (RPM, Jenquip, Feilding, New Zealand). Pre-grazing measurements were taken in the area estimated to be allocated in the next herbage allocation. A total of 18 quadrats (each 0.2 m^2; 10 pre- and 8 post-grazing quadrats) were randomly collected for each group (n = 108) during the experiment to calibrate the height measurement of sward. By using an electronic rising plate meter, two compressed height reading were taken at the sites of the quadrat, and all herbage in the quadrate was cut to ground level. All cut samples were then oven dried at 60°C for 48 h before weighing, to determine the herbage DM content. Samples were taken in the morning prior to grazing, once every three days. A calibration equation was then derived from it to estimate the herbage DM (kg/ ha) in relation to the RPM measurements. The calibration equation derived from the pre- and post-herbage cuts was:

kg DM/ ha = 208.35 (RPM) – 312.4, where RPM is equal to 0.5 cm units (R^2 = 0.82).

By using the calibration equation derived from the data set and the grazing areas allocated, the herbage mass allocated was 14.4 and 13.7 kg of DM/ cow/ day for mixed and apart groups, respectively.

Apparent group DMI was determined by herbage disappearance difference between pre- and post-grazing calibrated RPM measurements and areas allocated using the equation below:

$$\frac{[(\text{pre mass-post mass}) \times \text{grazing area}]}{\text{Number of cows}} = \text{kg DM/ cow/ day}$$

A back calculated DMI was determined by calculating the cows energy requirement for production, maintenance, LW change, pregnancy, lactation and feed energy (ME) content (Nicol and Brookes, 2007), where data for each cow was averaged across sampling days. Data were then analysed using the same method as production measures and grazing behaviour.

Herbage samples (400 g) were collected by cutting herbage to grazing height (3.5 cm) once every five days pre- and post-grazing. Fresh samples were then mixed and split into three sub-samples. The first sub-sample (40 g of fresh weight; FW) was oven dried at 60°C for determination of dry matter (DM) percentage. A second sub-sample (150 g of FW) was sorted into perennial ryegrass, white clover, weed and dead material before oven dried at 60°C for 48 hours and weighed. The third sub-sample (150 g of FW) was frozen at -20°C, freeze-dried and later ground through a 1 mm sieve and scanned by near-infrared reflectance spectrophotometry (NIRS) (Feed and Forage Analyzer, FOSS Analytical, Hillerød, Denmark) to determine crude protein (CP), digestible organic matter (DOMD), acid detergent fibre (ADF), neutral detergent fibre (NDF) and water-soluble carbohydrates (WSC) (Lincoln University Analytical Laboratory).

Pre-grazing FB DM yield was determined prior to the study and at a weekly interval during the experiment. Pre-grazed FB was harvested to ground level in two to three randomly positioned 6 m^2 quadrats (2 rows × 3 m row length). The area sampled represented what the cows would graze the following week (Edwards *et al.*, 2014). The FW of each bulked sample was recorded in the field. A subsample of one plant of FB in each quadrat (total n = 15) was taken and separated into bulb, leaf and stem and weighed. The leaf and bulb were chopped into two smaller subsamples of approximately 100 – 300 g of FW. One of these subsamples was weighed and oven dried at 90°C for 48 h to determine DM% and DM yield. The other subsample was separated into leaf and bulb, freeze-dried and later ground through a 1 mm sieve to determine OM, DMD, CP, ADF, NDF, WSC and ash, by using wet chemistry and NIRS analysis. Metabolizable energy for both pasture and FB was calculated as:

$$\text{ME MJ/ kg DM} = 0.172 \times \text{DMD\%} - 1.707 \text{ (CSIRO, 2007)}$$

The mean DMI for FB whole leaf (leaf and stem) or bulb was derived from the proportion of whole leaf or bulb of the pre-grazing FB DM yield, where the whole leaf or bulb was divided by the whole plant weight, and the proportion was multiplied by whole plant weight to determine DMI of the whole leaf or bulb proportion:

$$\left(\frac{\text{Whole leaf or bulb weight}}{\text{Whole plant weight}}\right) \times \text{Whole plant weight} = \text{DMI (kg) of whole leaf or bulb proportion}$$

Figure 5.2. Fodder beet plants in the paddock

5.2.4 Milk yield and samples

Daily milk yield was recorded for each cow using an automatic system (DeLaval Alpro Herd Management System, DeLaval, Tumba, Sweden). To determine milk composition, milk samples were collected once every four days for each cow during milking. Milk composition was analysed by Livestock Improvement Corporation Ltd Laboratory (Christchurch, New Zealand) to determine milk fat, protein and lactose by MilkoScan^{TM} (Foss Electric, Hillerod, Denmark).

5.2.5 Liveweight and body condition score

Cow BCS was assessed based on a ten-point scale scoring system (Roche *et al.,* 2004), and LW was recorded manually using an electronic walk-over scale (TRU-Test XR3000, TRU-Test Corporation Limited) once every seven days after milking.

5.2.6 Behaviour observation

To determine cow perception of resource abundance and their need to compete, visual observations were made during the hours on supplement and the first two hours on pasture. On supplement, the resource was depleted rapidly, whereas on pasture the resource was depleted slowly. Visual observations on cow grazing behaviour were carried out on day 2, 9 and 16 of the experiment after morning milking. Observations were done for three hours during FB supplementation (0830h to 1130 h), followed by another two hours of observation on pasture after the cows been moved to a new herbage break (1130 h to 1330 h). Three trained observers were randomly assigned to observe two groups each. Inter-observer reliability was tested before the start of each observation and was found to be consistent across observers. Permanent plastic ear tags, with the cow identification number, were used to identify cows. Grazing behaviour observed in this study was grazing, ruminating, lying down and standing. The description of each of these grazing behaviour observed is further described in Table 5.1.

Table 5.1. Grazing behaviours definitions

Behaviour	Definition
Grazing	Actively prehending herbage with the head lowered
Ruminating	Rhythmic chewing of herbage accompanied by regular regurgitation of boli from the rumen
Standing	Maintaining an upright position on extended legs
Lying	Lying down in any resting position

Behavioural data were recorded through visual observations by one-zero sampling with a maximum of one recording per 10-minutes (min) interval (Mitlohner *et al.*, 2001) using an instantaneous-scan sampling method as described by Altman (1974). The duration spent on each grazing activity was calculated by multiplying the total frequency of each activity with 10 minutes. Total duration derived becomes the estimation of time spent on each activity over five hours of observation. Other than grazing behaviour, bite rate (number of bites in prehending herbage during grazing on pasture) were also recorded for 60 seconds for each cow by the same trained observers at 0 and 60 minutes after the observation session commenced (Bryant *et al.*, 2012).

Social interactions between cows throughout the observations were also recorded using an all-occurrences sampling method, as described by Altman (1974). The types of social behaviour observed were bunting (swinging their head, in the direction of the other animals), pushing (uses part of their body to displace another cow) and allogrooming (one cow licks the body region of another cow). All possible social interactions that occur between two or more animals were recorded on a win or loss basis (Schein and Fohrman, 1955). Behaviour that was initiated by a cow that shows a sign of social interaction, which causes another individual to react to the interaction by a characteristic of alarmed and retreat, is considered as one successful win and loss interaction.

5.2.7 Statistical analysis

Data were tested for normality using a W-test. All data were found to be normally distributed, and all data were analysed using parametric statistical methods using the statistical package GenStat (18^{th} Edition VSN International). Production and grazing behaviour measurements were averaged across cows in each replicate group and across sampling days. The mean value for each group was then analysed as a one-way ANOVA with group as replicate (6 degrees of freedom for error) and dominance as treatment. Means were separated by a prior contrasts test between D and S cows in mixed and S cows in mixed and apart groups. Apparent herbage DMI was analysed, using day as replicate.

A repeated measure ANOVA was used to compare the profile of each behaviour through five hours of observation, with dominance rank and time (30-minute interval) included as fixed effects and the group as replicate. A repeated measure ANOVA was used to compare the percentage type of behaviour (bunting, pushing and allogrooming) initiated by cows throughout three sampling days of observation, with dominance and time (week) included as fixed effects and the group as replicate.

5.3 Results

5.3.1 Dry matter intake

Herbage mass, apparent DMI and nutrient compositions for pasture and FB are presented in Table 5.2. Nutrient composition of pasture used in this study contained an average of 12.15 ME (MJ/ kg) DM with 196 g CP, 422 g NDF, 221 g ADF, 245 g WSC and 80.6% digestibility. The nutrient composition of FB bulb and whole leaf used in this study contained an average of 14.1 and 12.5 ME (MJ/ kg) DM with 104 and 216.9 g CP, 93 and 209 g NDF, 61 and 129.7 g ADF, 524 and 131 g WSC, and 92% and 83% digestibility for bulb and stem, respectively. On average, the herbage offered in this study consisted of 87% ryegrass, 3% white clover and 10% of weeds and dead materials. The 3 kg DM of FB offered in all treatment groups consisted of 41% bulb and 59% whole leaf. There was no significant difference in the utilisation of FB or pasture between all groups. The mean apparent DMI between all treatment groups was found to be similar (3.0 and 10.45 kg of DM/ cow/ day for FB bulb and whole leaf and pasture, respectively).

5.3.2 Milk production

There was no significant difference found on the average milk yield (9.20 vs 8.29 L/ cow/ day) and milksolids (1.06 vs 1.01 kg/ cow/ day) for S cows in the mixed and apart groups. However, the average milk yield of D cows was found to be greater than both S cows in mixed and apart group(10.7 vs 9.2 and 8.29 L/ cow/ day; P = 0.016) with no differences in milksolids production between S cows (Table 5.3). There was no significant effect of treatments on the cows liveweight gain (LWG) and BCS.

Table 5.2. Mean and standard error of mean (SEM) for grazing herbage mass, apparent dry matter intake (DMI), nutritive value and the composition of feed offered in the experiment (D = dominant; S = subordinate; Mixed = D and S cows group together; Apart = S cows kept apart; FB = fodder beet).

	Mixed			Apart			SEM**
	Pasture	FB Bulb	FB leaf and stem	Pasture	FB Bulb	FB leaf and stem	
Pre-grazing herbage mass (kg DM/ ha)	2871	8720⁺	3682^	2967	8720⁺	3682^	35.90
Post-grazing herbage mass (kg DM/ ha)	1651	-	-	1689	-	-	25.90
Apparent DMI (kg DM/ cow/ day)*	10.6	1.2	1.8	10.3	1.3	1.7	0.19
Perennial ryegrass (%)	86.8	-	-	86	-	-	1.16
White clover (%)	2.5	-	-	3.3	-	-	0.29
Weed (%)	1.2	-	-	0.6	-	-	0.34
Dead material (%)	9.5	-	-	10.2	-	-	1.10
Dry matter (g/kg)	195.4	14.1	7.6	198.7	14	7.2	0.41
Ash (g/kg)	108	66.4	193.5	110.1	62.9	205.6	1.71
Crude protein (g/kg)	195.7	107	215.1	195.3	101.3	218.6	1.62
Water-soluble carbohydrates (g/kg)	246.7	510.1	135.4	243.7	537.7	126.4	4.10
Neutral detergent fibre (g/kg)	421.3	97.7	211.5	423.3	87.5	205.6	4.20
Acid detergent fibre (g/kg)	220.7	62.3	132.3	221.7	59.1	127.1	1.70
Digestibility of DM (%)	80.6	91.2	82.7	80.6	92	83	0.30
Metabolisable energy (MJ/ kg DM)	12.2	14.0	12.5	12.1	14.1	12.6	0.05

*P value = 0.276, **values are for pasture only, ⁺SEM = 373.55, ^SEM = 166.64

Table 5.3. Mean and standard error of mean (SEM) of milk parameters, liveweight gain, body condition score and back-calculation on dry matter intake (DMI; kg DM/ cow/ day) according to group (D = dominant; S = subordinate, Mixed = D and S cows group together; Apart = S cows kept apart; 1 = between D and S cows in mixed group; 2 = between S cows in mixed group and S cows kept apart).

	Treatment									
	Mixed				Apart		SEM*	Contrast		*P Value*
	D	SEM	S	SEM	S	SEM		1	2	
Milk yield (L/ day)	10.67	0.53	9.20	0.49	8.29	0.89	0.66	0.042	0.161	0.016
Fat (kg/ day)	0.66	0.03	0.61	0.05	0.57	0.05	0.05	0.666	0.564	0.593
Protein (kg/ day)	0.49	0.02	0.44	0.03	0.44	0.04	0.03	0.265	0.821	0.355
Lactose (kg/ day)	0.44	0.02	0.43	0.04	0.39	0.04	0.03	0.853	0.432	0.575
Milksolids (kg MS/ day)	1.13	0.05	1.06	0.08	1.01	0.09	0 .08	0.486	0.646	0.507
Somatic cell count	438	132.60	394	187.00	413	113.20	147.60	0.844	0.932	0.979
Liveweight gain (kg/ day)	0.56	0.10	0.44	0.11	0.55	0.13	0.11	0.664	0.679	0.879
End body condition score	4.4	0.09	4.5	0.07	4.7	0.10	0.09	0.591	0.300	0.296
Back-calculation DMI (pasture + FB)	12.31	0.20	11.35	0.62	10.91	0.65	0.757	0.250	0.579	0.243

*SEM = Standard error of means between two treatments

5.3.3 Grazing behaviour

Grazing behaviour is presented in Table 5.4 and 5.5 for FB and pasture, respectively. On FB, cows spent on average 54% of the time feeding and 46% idling (45% standing and 1% lying; both without ruminating), with no effect of treatment. On pasture, cows spent on average 96% of the time grazing and 4% ruminating and idling, also with no treatment effects.

A repeated measure of ANOVA on grazing behaviour over time was analysed. There was no significant interaction between treatment and time on any grazing behaviour (average percentage out of 6 cows; Figure 5.3). However, there was a time effect on cows grazing, idling, standing and walking on FB (Figure 5.3; A, C, D and F, respectively). In three hours of being offered a fresh allocation of FB, the average percentage of cows grazing declined significantly from 84% to 44% ($P < 0.001$; Figure 5.3, A), the average percentage of cows idling (standing or lying down) increased significantly from 5% to 37% ($P < 0.001$; Figure 5.3, C), the average percentage of cows standing (with or without ruminating) increased significantly from 33% to 47% ($P = 0.019$; Figure 5.3, D), and the average percentage of cows walking decrease significantly from 66% to 45% ($P = 0.016$; Figure 5.3, F) .

On pasture, there was a time effect on all of grazing behaviour variables (Figure 5.3; A, B, C, D, E and F, respectively). In two hours of being offered a fresh break of pasture, the average percentage of cows grazing decline significantly from 100% to 78% ($P < 0.001$; Figure 5.3, A). The average percentage of cows ruminating increased significantly from 0 to 12% ($P = 0.017$; Figure 5.3, B). The average percentage of cows idling (standing or lying down) increase significantly from 0 to 10% ($P = 0.004$; Figure 5.3, C). The average percentage of cows standing (with or without ruminating) increase significantly from 2% to 33% ($P < 0.001$; Figure 5.3, D). The average percentage of cows lying time increased significantly from 0 to 15% ($P = 0.023$; Figure 5.3, E), and the average percentage of cows walking decreased significantly from 98% to 51% (Figure 5.3, F).

Table 5.4. Mean and standard error of mean (SEM) of grazing behaviour (min/ three hours) on fodder beet according to group (D = dominant; S = subordinate, Mixed = D and S cows group together; Apart = S cows kept apart; 1 = Between D and S cows in mixed group; 2 = between S cows in mixed group and S cows kept apart; FB = fodder beet).

Behaviour	Treatment						SEM*	Contrast		*P Value*
	Mixed				Apart					
	D	SEM	S	SEM	S	SEM		1	2	
Feeding FB bulb and leaf	108	8.09	89	7.60	97	6.42	7.40	0.230	0.597	0.455
Feeding FB bulb	83	8.59	55	8.10	51	5.68	7.56	0.091	0.806	0.120
Feeding FB leaf	25	3.44	34	4.31	46	3.97	3.92	0.228	0.167	0.071
Ruminating	6	2.63	9	2.38	11	2.71	2.57	0.528	0.727	0.602
Ruminating (while standing)	6	2.63	9	2.38	10	2.71	2.57	0.550	0.912	0.734
Ruminating while lying	0	0.00	0	0.00	1	1.11	0.64	1.000	0.267	0.422
Standing	72	8.06	91	7.60	79	6.07	7.29	0.249	0.441	0.478
Standing, not ruminating	66	6.59	82	6.41	69	4.19	5.83	0.203	0.293	0.379
Lying	0	0.28	0	0.00	4	3.28	1.90	0.903	0.087	0.152
Lying, not ruminating	0	0.28	0	0.00	3	2.32	1.35	0.853	0.059	0.107

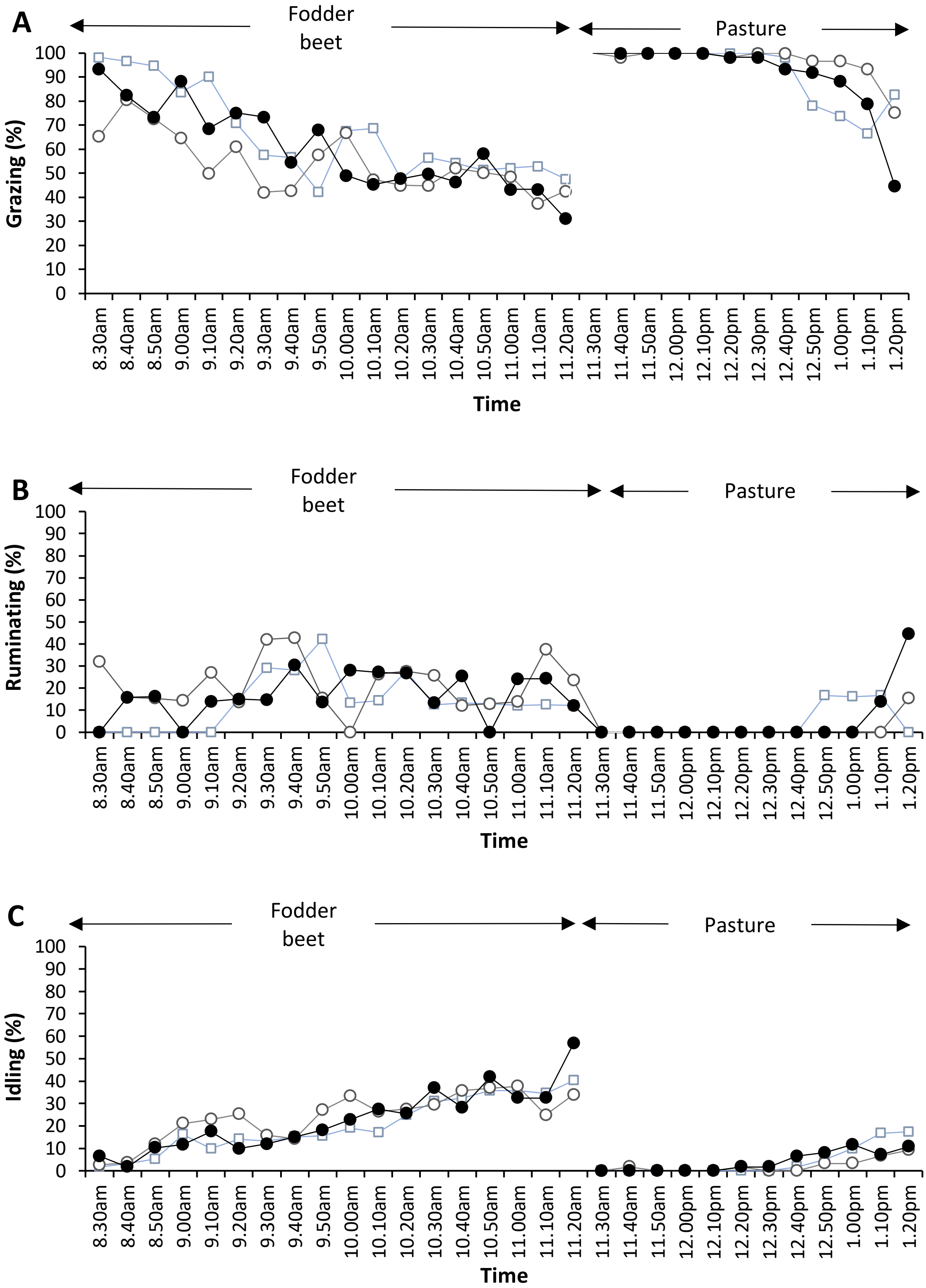
*SEM = Standard error of means between two treatments

Table 5.5. Mean and standard error of mean (SEM) of grazing behaviour (min/ two hours) on pasture according to group (D = dominant; S = subordinate, Mixed = D and S cows group together; Apart = S cows kept apart; 1 = Between D and S cows in mixed group; 2 = between S cows in mixed group and S cows kept apart).

Behaviour	Treatment						SEM*	Contrast		*P Value*
	Mixed				Apart					
	D	SEM	S	SEM	S	SEM		1	2	
Grazing	114	2.00	119	0.504	111	2.80	2.01	0.256	0.109	0.239
Total ruminating	1	0.38	0	0.00	2	0.70	0.46	0.267	0.010	0.027
Ruminating while standing	0	0.28	0	0.00	1	0.68	0.42	0.680	0.074	0.152
Ruminating while lying	0	0.28	0	0.00	0	0.28	0.23	0.420	0.420	0.630
Total standing (with & without ruminating)	5	1.96	1	0.504	4	1.91	1.61	0.108	0.216	0.229
Standing, not ruminating (idling)	5	1.81	1	0.504	3	1.47	1.38	0.088	0.417	0.205
Total lying (with & without ruminating)	1	0.83	0	0.00	4	2.28	1.40	0.676	0.058	0.119
Lying, not ruminating (idling)	1	0.56	0	0.00	4	2.30	1.36	0.792	0.084	0.161
Bite rate 1st hour (rate/ min)	59	1.25	59	1.37	57	1.58	1.41	0.902	0.403	0.566
Bite rate 2nd hour (rate/ min)	56	1.99	58	1.122	56	1.55	1.59	0.157	0.200	0.283

*SEM = Standard error of means between two treatments

Figure 5.3. The average percentage of all dominant (D) cows (—□—), subordinate (S) cows in mixed group (—○—) and S cows kept apart (—●—) observed A, grazing, B, ruminating, C, idling (while standing or lying without ruminating), D, standing (with or without ruminating), E, lying (with or without ruminating) or F, walking (including while grazing), according to time.



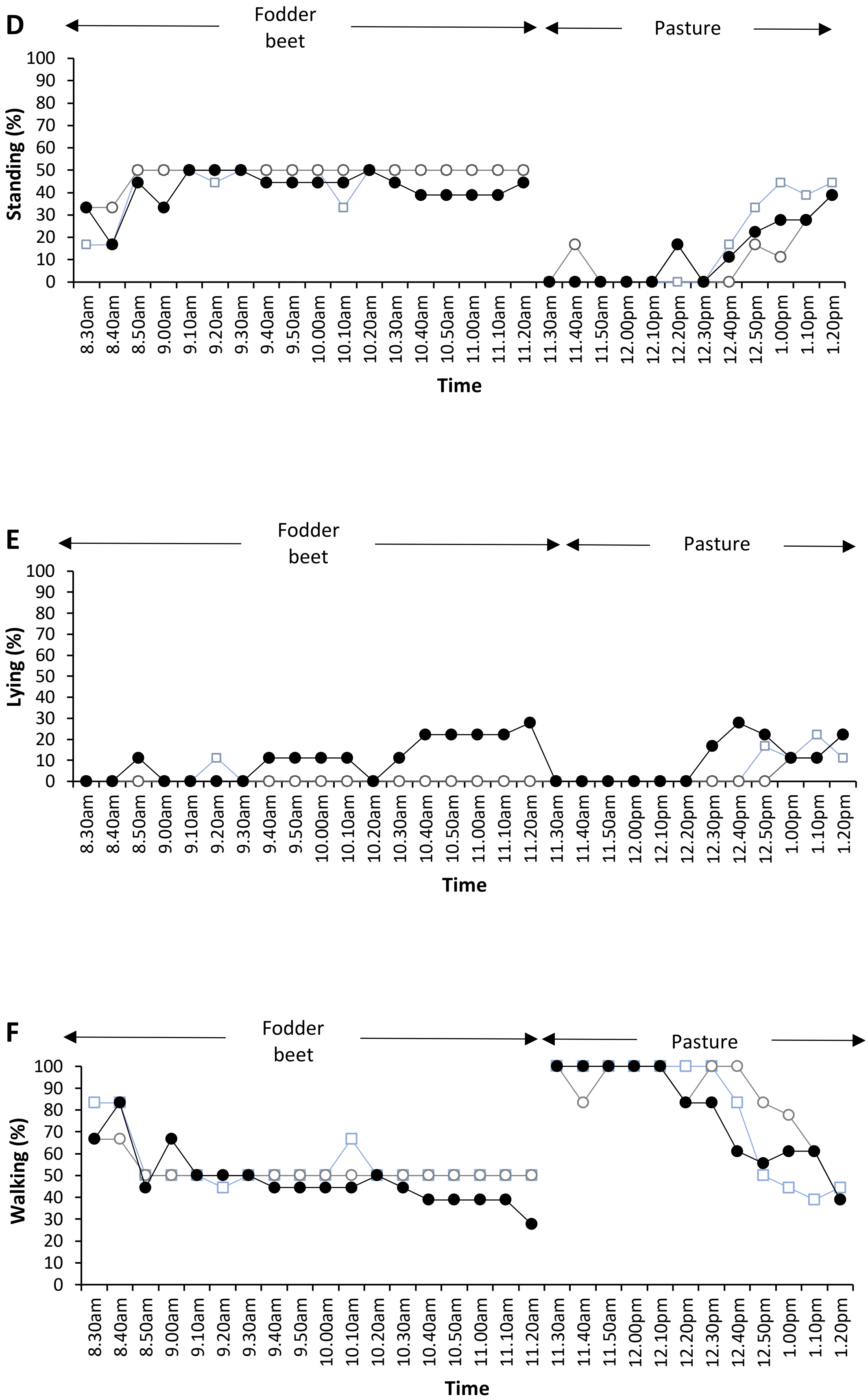
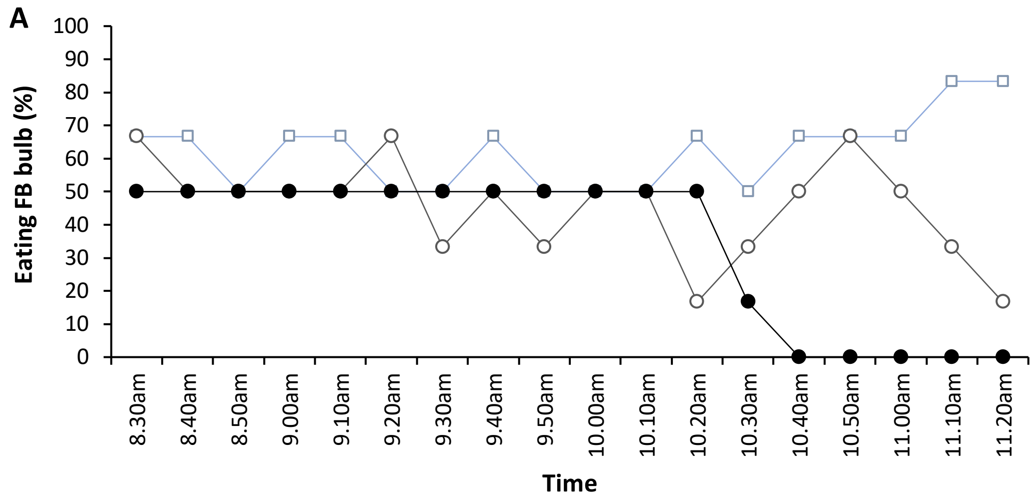
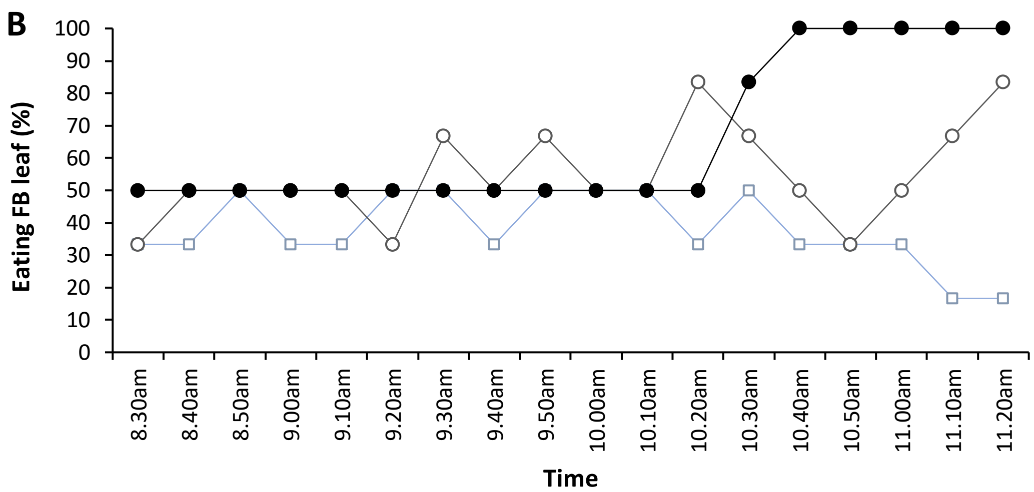

D
Fodder beet
Pasture
Standing (%)
Time
E
Fodder beet
Pasture
Lying (%)
Time
F
Fodder beet
Pasture
Walking (%)
Time
8.30am 8.40am 8.50am 9.00am 9.10am 9.20am 9.30am 9.40am 9.50am 10.00am 10.10am 10.20am 10.30am 10.40am 10.50am 11.00am 11.10am 11.20am 11.30am 11.40am 11.50am 12.00pm 12.10pm 12.20pm 12.30pm 12.40pm 12.50pm 1.00pm 1.10pm 1.20pm

Figure 5.4. The average percentage of all dominant (D) cows (—□—), subordinate (S) cows in mixed group (—○—) and S cows kept apart (—●—) observed eating fodder beet (FB) A, bulb or B, leaf, according to time.





5.3.4 Social interaction

The total number of agonistic interactions was higher on FB than on pasture (428 vs 16 interactions, respectively; Figure 5.5). During FB feeding, cows in the mixed group had triple the total number of aggressive interactions than S cows in the apart group (325 vs 103 interactions, respectively). On FB, the total number of interactions initiated by D cows was higher than both S cows in the mixed and apart group (233 vs 92 and 103 interactions, respectively). On pasture, although few in total, there were few interactions occurred in week 2 (Figure 5.5). In week 2, the total number of interactions initiated by D cows on pasture double compared to both S cows in the mixed and apart group (8 vs 4 and 4 interactions, respectively; Figure 5.5).

There was no significant interaction between dominance and time (wee) on bunting, in both FB and pasture. However, there was a time effect on bunting. Most bunting were performed in week 2 with 51.5% of bunting was performed when on FB and 87.5% of bunting was performed when on pasture (Figure 5.6; A and B, respectively). The time effect on allogrooming on FB was observed only in week 2 (Figure 5.6; A). When on pasture, there was significant interaction between time and dominance on allogrooming with the highest percentage of allogrooming performed by D cows in week 2 (Figure 5.6; B).

Figure 5.5. The total number of social interactions performed by dominant (D) cows, subordinate (S) cows in the mixed group (MS) and S cows kept apart on fodder beet and pasture according to weeks.

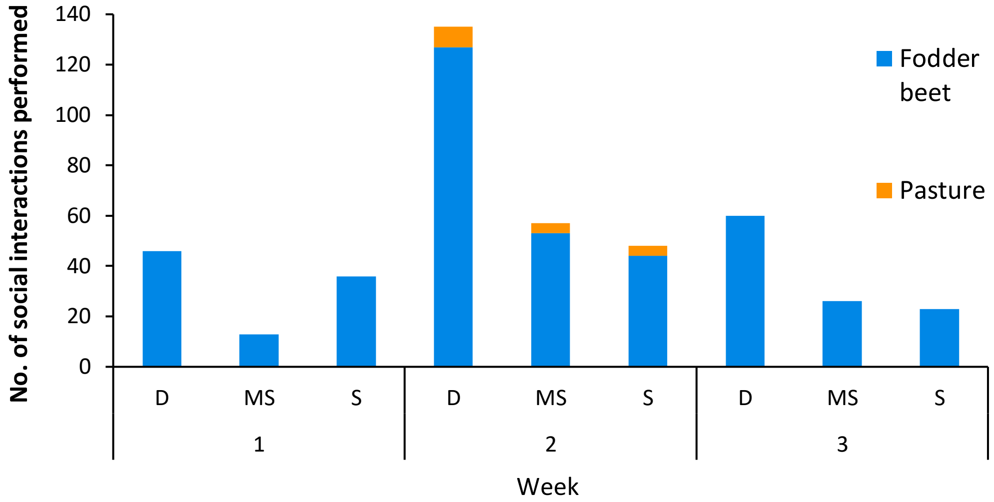
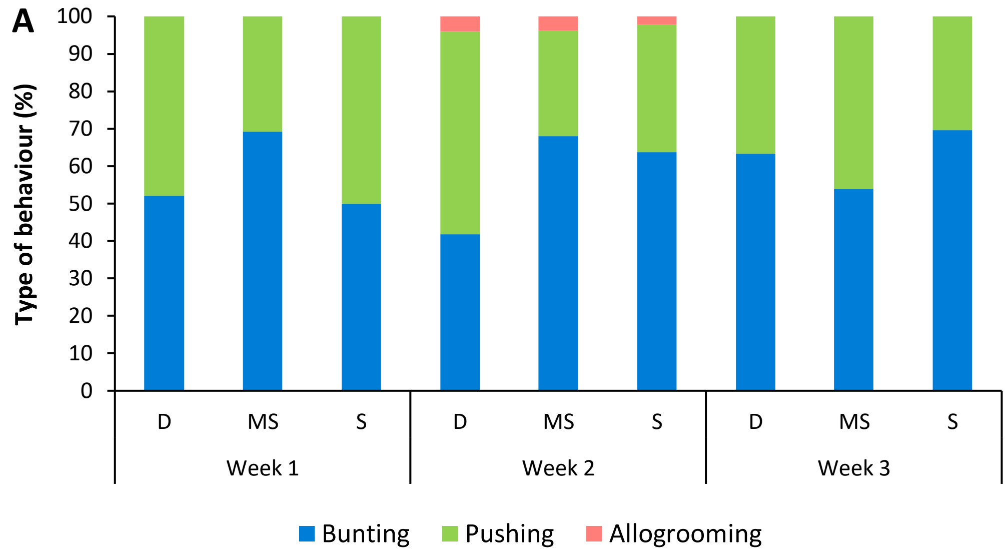
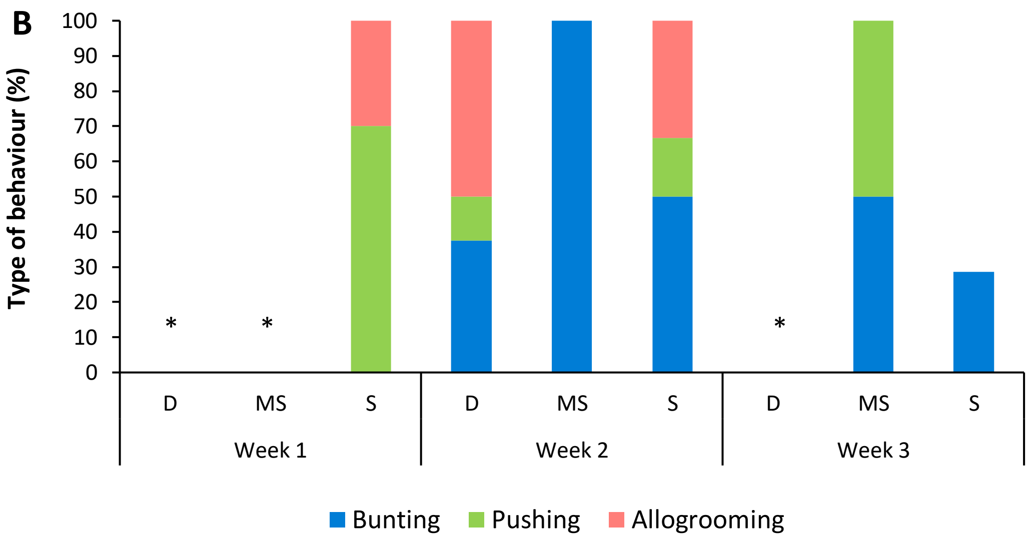


Figure 5.6. The total percentage of bunting, pushing and allogrooming performed by dominant (D) cows, subordinate (S) cows in the mixed group (MS) and S cows kept apart on A; fodder beet and B; pasture according to weeks.





*No social interaction data collected for dominant and subordinate cows in the mixed group in week 1, and no social interaction data collected for dominant cows in week 3.

5.4 Discussion

5.4.1 Dry matter intake (DMI), milk production and liveweight gain

The hypothesis was that separating the S cows from D cows would improve the DMI and productivity of S cows compared to when they were being mixed with the D cows. It was proposed that this would be accentuated when feeding a supplementary high DM yield crop, thus positively affect their production. In the group where S and D cows were mixed, it was expected that D cows would consume more of the allocation, thus reducing the feed available to S cows. By removing the D cows, it was anticipated that the S cows would improve their average milk production by increasing DMI. However, in this study, there was no evidence to support this. Although many more interactions occurred on fodder beet than on pasture (428 vs 16 interactions, respectively; Figure 5.5), dry matter intake, milk production and LWG of S cows were similar when kept together with D cows (Phillips and Rind, 2002), or apart.

During blocking of cows into the treatment group, it was apparent that D cows had a higher milk yield, heavier LW, higher BCS and were older than S cows. The 21.9% greater average milk yield found in D cows than both S cows in the mixed or apart group could be due to D cows being older than the S cows. According to Johnson et al. (2003), older cows (e.g. multiparous) have greater DMI, produce more milk, as well as having a greater conversion of nutrient into milk (Wathes *et al.*, 2007) compared to younger cows (e.g. primiparous). In this study, the average age of D cows was 1.5 years older than S cows. Therefore, the greater milk yield found in D cows in this study could be attributed to the older age of D cows.

5.4.2 Grazing behaviour

In a study done by Phillips and Rind (2002), they observed that when keeping D and S cows apart, the cows lay down for longer compared to when mixed. Although numerically, on FB, S cows kept apart were observed to have slightly longer feeding time (in minutes) compared to S cows in the mixed group, this effect was not significant. They also had fewer aggressive interactions in the group and were able to have some short lying down time. Furthermore, the standing time of S cows in the mixed groups was 12 minutes longer than S cows kept apart, which suggest that the presence of D cows may have prevented them from lying down. Therefore, it is suggested further research should be done on having a longer feeding time on FB while separating them according to their social dominance, which may or may not show any significant differences on their grazing behaviour.

There was no time by treatment interaction on grazing behaviour found in this study. However, there was a time effect on the average percentage of grazing, idling, standing and walking on FB (Figure 5.3; A, C and D respectively), and all cow behaviour parameters when on pasture (Figure 5.3; A, B, C, D, E and F, respectively). Over time, the percentage of cows grazing gradually declined from 84% to 44% when on FB. When on pasture, cows spent nearly all of their time grazing, with a gradual decline from 100% to 78% of cows all grazing during the last 30 minutes of observation time. When on FB, most cows spent more than half of their time feeding (54%) with 45% idling and 1% lying down and ruminating. This finding is similar with a study done by Jenkinson et al. (2014) on pregnant, non-lactating cows offered 8 kg DM/ cow/ day of FB supplemented with 6 kg DM/ cow/ day ryegrass baleage grazing in situ. Jenkinson (2014) reported that during the six hours observation after being offered a fresh allocation of FB, cows spent half of their time (49%) feeding on FB with 33% of their time idling and 7% ruminating. Jenkinson (2014) also found that within six hours of being offered a fresh break, cows consume 90% of the 8 kg DM of FB offered. This corresponds to the total DM intakes of 3 kg of DM of FB within 3 hours found in this study. This shows that cows used half of their feeding time to consumed 90 to 100% of offered feed before engaging in another behaviour. In a study done by Thompson and Stevens (2012), cows were reported to consume 4.8 kg of DM of swede, a bulb-forming plant similar to FB, in over five hours.

5.4.3 Social interaction

In a study done by Judd *et al*., (1994) on the effect of two wintering treatments (confined and paddock) with or without supplement on cow behaviour, they found that feeding silage can result in increased competition between animals. The study reported that, when silage was not made available, the aggressive interactions between cows ranged from 4 to 16 interactions. However, when silage was offered at 6 kg DM/ cow/ day, the number of aggressive interactions between cows increased to almost twice the number, especially for cows in the paddock treatment. This shows that feed supplement created competition for feed, thus leading to an increase in aggressive interactions between cows. However, feed availability and space allowance given during the feeding session also play a major role in creating competition for feed. In this study, cows had more aggressive interactions on FB than on pasture, with 428 vs 16 interactions, respectively (Figure 5.5). The higher number of interactions that occurred on FB may be due to the space allocated to cows during supplement feeding being more constricted compared to the much bigger space allocated when grazing on pasture (4.2 m of feeding row/ cow, assuming each row of FB is 0.5 m apart, the FB allocation equals to 2.1 m^2/ cow/ day vs 92 m^2 of space/ cow, respectively). This is consistent with the hypothesis and the study by Judd *et al.* (1994) that feeding a high yield crop should accentuate more competition and interaction between cows, due to the limited space available during feeding. The higher agonistic interactions found between cows in the mixed group (325 interactions) provided evidence of competition between S and D cows when they were kept together for supplement feeding (Phillips and Rind, 2002). Besides, Kondo *et al.* (1989) found that agonistic interactions between cows increased as the group size increased. Therefore, more animals in the mixed group are believed to have also contributed to the increase in the agonistic interactions, compared to the smaller number of cows in the apart group.

Overall, observations on FB found that D cows initiated more aggressive interactions than both S cows in the mixed and apart group (233 vs 92 and 103 interactions, respectively). The fact that D cows in this study were on average 1.5 years older than S cows, is in agreement with Judd et al., (1994) who reported more aggressive interactions were initiated by mature cows than heifers. As age was found to be a good indicator of dominance in dairy cows (Schein and Fohrman, 1955; Guhl and Atkeson, 1959), this can be explained by the older cows being more experienced in having interactions with other cows compared to younger cows (Guhl and Atkeson, 1959).

5.5 Conclusion

Although fodder beet feeding enhanced more aggressive social interactions between cows, this study found no significant effects of grouping on the DMI, milk production or grazing behaviour of S cows. Therefore, the original hypothesis of grouping cows according to their social rank when feeding them supplement to help increase feed accessibility as well as increase the production of the S cows was not supported in this study. Future research is required to test these grouping and supplement feeding effects using early or mid-lactation cows with longer hours of observation during the grazing period, which may lead to a better indication of the effect of grouping cows according to social rank with supplement feeding.

Chapter 6

General discussion

6.1 Factors determining dominance

In the current study dominance was most strongly correlated with the age of the cow, followed closely by her liveweight (Chapter 3). Across a range of animal species, social dominance has been related to sex, age and physical attributes of the animals, such as liveweight (LW), body condition score (BCS), girth width, height at the withers and presence of horns (Schein and Fohrman, 1955; Sottysiak and Nogalski 2010; Phillips and Rind 2002). In cattle, the seniority in the herd and the early experience of having encounters with other animals are also factors that can influence the establishment of dominance in cattle (Schein and Fohrman, 1955). Overall, the primary determinants for social dominance have been found to be age and LW in beef cattle (Šárová *et al.*, 2013), sheep (Hurnik *et al.*, 1994; Fisher and Matthew, 2001), horses (Keiper and Sambraus, 1986; Giles *et al.*, 2015) and deer (Veiberg *et al.*, 2004). In swine, social dominance is related to LW and sex (Beilharz and Cox, 1967), whereas, in poultry, dominance is related to sex and age (Hurnik *et al.*, 1994). Generally, factors determining dominance in livestock animals are age and LW. This is consistent with dairy cattle, where age and LW were found to be highly correlated with dominance value (DV) in many studies (Schein and Fohrman, 1955; Guhl and Atkeson 1959; Dickson *et al.*, 1970; Arave *et al.*, 1973, Phillips and Rind, 2002, Sottysiak and Nogalski, 2010). Therefore, it can be concluded that age and LW can be used as the primary determinant for social dominance in livestock animals.

The relationship between cattle milk production and DV in previous studies has been shown to be inconsistent, with significant positive (Sambraus *et al.*, 1979; Sottysiak and Nogalski, 2010; Schein and Fohrman, 1955; Beilharz *et al.*, 1966) and negative (Collis *et al.*, 1979; Phillips and Rind 2002) relationships recorded.

In Chapter 3, a significant positive correlation was found between the cow's dominance value and milk production. Although for all three herds studied, dominance was found to be consistently related to age and liveweight, a significant positive correlation between DV and milk production was found only in two herds. This is similar to a study done by Sambraus (1970), where a significant correlation between rank and milk production was found in some but not in all herds. This finding indicates that each herd establishes a different type of hierarchy, where each hierarchy has a different relationship between dominance and production (Stricklin and Kautz-Scanavy, 1983).

In the observational study (Chapter 3), the group offered the least supplement had the strongest correlation between DV and milk yield, indicating perhaps a competitive advantage compared with cows that get supplemented individually in the shed. Social hierarchy in domesticated cattle is developed mainly to determine priorities over resources such as feed and space. The establishment of this social organisation mainly involves agonistic interactions between herd members, where social dominance is determined. This dominance establishment process causes social stress (Tesfa, 2013) that reduces the cow's ability to reach its normal production performance. Through many agonistic interactions, animals who win the most fights will end up being the dominant (D), thus having the advantages in exploiting resources. An animal who loses from the competition will exhibit submission behaviour, thus allowing the winning individual to claim over the resources. Many studies report negative effects of aggressive behaviour on cow's production performance (Schein and Fohrman, 1955; Brantas, 1968; Moberg, 1991), especially on the subordinate (S) cows, which may explain why D cows tended in to be higher milk producers than their S peers.

In all studies (Chapter 3, 4 and 5), the D cow's average milk yield was found to be significantly greater by almost 2 litres per day than the S cows (Table 6.1). In other domestic animals such as pullets, high-ranking birds had significantly better egg production compare to low ranking birds (Tindell and Craig, 1959).

Table 6.1. The average in milk yield, liveweight, body condition score and age of dominant and subordinate cows according to chapters and the percentage difference between dominant and subordinate cow average productions (3a = LSR group; 3b = MSR group; 3c = HSR group).

Chapter+	Social rank	Milk yield (L/ day)	Liveweight (kg)	Body condition score	Age (years old)
3a	Dominant	28.7	545.9	4.2	6.1
	Subordinate	26	520.8	4.1	4.0
	% difference	10.4	4.8	2.4	52.5
3b	Dominant	23.7	488	4.1	5.4
	Subordinate	20.7	465	4.1	4.0
	% difference	14.5*	4.9	0	35
3c	Dominant	27.2	520.7	4.3	5.8
	Subordinate	24.9	500.2	4.3	4.0
	% difference	9.2	4.1	0	36.3
4	Dominant	16.55	516	4.2	5.8
	Subordinate	13.72	475	4.1	3.7
	% difference	20.6*	8.6	2.4	56.8
5	Dominant	10.67	511	4.4	5.5
	Subordinate	8.75	490	4.6	4.0
	% difference	21.9**	4.3	4.5	37.5

+Chapter 3. September – December 2014; Chapter 4. March 2015; Chapter 5. April – May 2016. *P < 0.001. **P < 0.05.

In dairy cattle, effects of social dominance have been associated with milk production, where D cows sometimes produce higher milk yields. The LW of D cows was also 20 to 40 kg heavier than the S cows. Furthermore, the average age of D cows is 0.6 to 2.1 years older than their S peers. In short, the findings in this study agree with previous studies, suggesting that the higher-ranking cows are much older, heavier and they produce greater milk yield than the S cows, who are much younger, lighter in weight, and produce lesser milk. Through time, however, S cows can develop better experience in having successful encounters and challenge their way up the rank, thus, taking over the D cow position.

In this study, there was no effect of dominance, herbage allowance and grouping on milk composition such as fat and protein percentage between D and S cows. One hypothesis is that D cows produce more milk simply because they are bigger. However, on the basis of milk yield per kilogram of liveweight, both D and S cows are very similar at 20:1 (kg LW/kg MY) suggesting that S cows are no less efficient than D cows.

In a study using cows in an intensive system, a positive correlation between the animal's dominance value (DV) and the number of winning fights was found, where D animals had more winning interactions than S animals in the herd (Wierenga, 1990). The fights were derived from competition for space in the cubicle, resulting in D cows having a longer lying time than S cows (Wierenga, 1990). The gesture of lying demonstrates the cow's resting behaviour. In Chapter 4, D cows had a longer lying time and produced more milk than the S cows. This indicates that higher ranking and high yielding cows have the privilege of having a longer lying and resting time (Phillips, 2002).

In Chapter 5, there were no differences found in any measures of grazing behaviour (e.g. grazing, ruminating, standing and lying down) between D and S cows, yet D cows still produced a higher milk yield than the S cows. The reason to support this finding is unclear. In grazing systems, priority to the best grazing spot may be the factor driving social dominance in cattle. Furthermore, a D cows may be a better producer because of its faster bite rate during grazing (Phillips and Rind, 2002) that makes them an efficient grazer compare to their S peers (Lovari and Rosto, 1985; Thoules 1990). However, none of the parameters mentioned by previous studies was found to be significant.

On the other hand, this may be due to the fact that behaviour observation was done only for a short period of time (i.e. 5 hours), which may not be sufficient to show any significant difference in the cows grazing behaviour. In a study done by Ungerfeld *et al.* (2014) on grazing dairy cows, over the observations of 24 hours, different time budgets were reported between high and low-rank cows grazed separately, with high ranking cows grazing and walking less but ruminating more than low-rank cows. Whereas low-rank cows increased the grazing frequency between morning and afternoon grazing bouts, mainly to continue grazing from mid-morning, when the high ranking cows stopped grazing. This suggested that, a longer observations hours (e.g. 24 hours) may provide a better result on grazing behaviour of D and S cows.

Another hypothesis as to why D cows produced more milk may be that D cows has better genetic merit that might have influenced their production performance, or perhaps dominance is related to the D cow's dam. In experiment 1 (Chapter 3), the mean breeding worth for D, mid-ranking and S cows in the LSR (147, 164 and 154 ± 4.8; mean ± SEM), MSR (126, 122 and 137 ± 3.2; mean ± SEM) and HSR (137, 142 and 173 ± 3.9; mean ± SEM) groups were checked and showed otherwise. Therefore, this rejects the hypothesis. Furthermore, according to Stricklin and Kautz-Scanavy, (1984), the heritability of social dominance in cattle happens to be mainly related to an outcome of correlated traits, which mainly relate to animal size. In a study done by Dickson *et al.* (1970) on Holstein cow's social dominance and milk production, the heritability approximation based on paternal-half siblings' correlation for social dominance was calculated. They found that the estimated heritability (h^2) for unadjusted DV ranged from 0.15 to 0.29. However, when DV was adjusted for age, weight and height, the range fell from 0 to 0.07. In another study on social dominance and milk production of Holstein cow twins, the heritability of the cow's DV was estimated to be 0.40 (Beilharz *et al.*, 1966). However, heritability was believed to be immoderate due to the non-additive genetic effects as well as the probability of standard environmental factors of twin pairs (Stricklin and Kautz-Scanavy, 1984). There is controversy on the effects of genetics of social dominance. According to Moore (2013), this is mainly because two individuals are required for the expression of the behavioural trait. Hence, it is difficult to measure heritability. Since two animals are needed to be involved for a social dominance to be exerted, each one acts as an environment for the other animal. The genetic effect is not exerted on the main animal alone but also on the receiving social partner. Therefore, it leads to direct additive genetic influence on the focal animal and indirect genetic influence on the receiving animals. Furthermore, a genetic correlation of -1 is predicted by Moore (2013) between the direct and indirect genetic effect, which means that one animal becomes more dominant, the other becomes less dominant. Overall, it is believed that crucial point to dominance in animal is related to the aggressive behaviour in combination with age and size which are advantageous in competition for resources, and also found to be the primary determiners of dominance in cows, which may have influenced their production performance.

6.2 Grouping according to social dominance

Intensified animal production system such as those characterised by high stocking rate, limited space allocation, and provision of high yielding supplements may contribute to the increase in aggression between cattle in grazing systems (Clutton Brock *et al.,* 1976). The behaviour of cattle such as feeding and resting may be disturbed due to the competition for resources where the S cattle will experience social stress the most. This either affects D cows, due to the need to continue to maintain dominance rank or S cows by not allowing access to sufficient resources such as feed and desired space for resting. Negative effects of social stress on performance have been reported in many previous studies, which leads to the reasonable assumption that reducing such stress would benefit animal production (Judd *et al.,* 1994). Moreover, this serves as a practical reason for the need for separate grouping (Grant and Albright, 2001), which may improve the performance for both social ranks.

In Chapter 4 of this study, high and low herbage allowance was designed to create competition between the two social ranks in the grazing situation. In Chapter 5, fodder beet feeding was used and played the same role. As hypothesized by Phillips and Rind (2002), keeping D and S cows apart should increase DMI. The same hypothesis was adapted in this study in Chapter 4 and 5. However, in the Phillips and Rind (2002) study, the DMI between the two ranks was found to be the same, and the benefits of the separate grouping were found only on the D cows; D cows produce more milk and gained more weight. This is in contrast with the findings in Chapter 4, where instead of D cows, S cows were the rank that benefited from the separate grouping treatment by having a greater LWG. However, the grouping effects on intake and milk production were absent, where D cows maintained greater milk yield than the S cows. In Chapter 5, although supplement feeding increased aggression between the two ranks in the mixed group, the production performance of S cows in the mixed and apart groups was found to be the similar.

The lack of social dominance effect of the cow's milk production is believed to be due to the impact of the competition designed in both studies not being sufficient to enhance competition between the cows that could result in different DMI. In Chapter 5, although fodder beet feeding increased interactions between animals, perhaps it is not sufficient enough to affect the animal's DMI. Further, although feeding space was made more constricted with fodder beet feeding, the study found no effect on milk production of cow.

Another insight that could contribute to the lack of significant effect of grouping treatment on the S cows production could due to that cows were in their late lactation phase. The partitioning of energy in late-lactating cows may have contributed to the cow body condition instead of milk production, to replenish the adipose tissue lost during the early lactation. This was supported with the result shown in Chapter 4 where the effects of grouping cows based on social dominance increased the S cows LWG, instead of milk production.

Overall, although low herbage allowance and feed supplement was used to drive competition and thus enhanced social interactions in cows, studies in this thesis found that there was limited benefit in separating grazing dairy cows on pasture according to their social rank, especially to improve their milk production and intake.

6.3 Practical implications of studies results

Regrouping cows is a common management practice in both commercial and non-commercial dairy farms. Cows often are grouped based on their production (milk yield, milksolids, LW, BCS), physiological status (lactating or dry), age, lactation number or days in milk. In Chapter 3, there was a correlation between DV and milk production. Therefore, in Chapter 4 and Chapter 5 studies, cows were blocked primarily based on their DV. However, there was no grouping by dominance effects on milk production found in both studies. Although social hierarchy does exist in the herd, there was no clear evidence to show the benefits of separating cows based on their social dominance. Therefore, the practical message that can be concluded is that there is no benefit of separating cows according to their social dominance on their production or grazing behaviour. However, welfare considerations are an important part of consideration by consumers, and this study shows that despite no production benefits, cows do have fewer adverse interactions when being grouped according to social dominance. Thus, as the dairy industry moves to greater recognition of animal welfare concerns, separation according to the cows social dominance may be of greater relevance. This is an indirect benefit of separating cows according to their social dominance.

6.3.1 Experimental design

In this study, different approaches to experimental design and animal replication were used. In experiment 2 (Chapter 4), the individual cow was used as replicate, following approaches of Phillips and Rind (2002). In experiment 3 (Chapter 5), a group of cows was used as replicate, with the group mean used for statistical analysis. These two approaches reflected a compromise between the number of treatments (six and two in experiment 2 and 3, respectively), availability of cows and resources available to manage multiple groups of cows. There has been considerable debate on experimental design, in particular, whether behaviour measurements can be considered independent (Rook and Penning, 1991; Rook and Huckle, 1995). The basis of this is that because the behaviour of animals is synchronized, they are not independent of each other (Rook and Huckle, 1995). Therefore, individual animals should not be treated as replicates in the experimental design. However, Phillips (1998; 2000) and Iason and Elston (2002) indicated the relevance of the discussion is not just on animal behaviour responses, but because of the relationships between behavioural responses and animal production, reproduction and nutrition, to the entire range of animal production research. Phillips (2000), suggested that, if researchers accept that animals should not be used as replicates, a form of doubt is cast upon most of the farm animals research studies. Furthermore, if the basis of analysis were wrong, research studies on animal responses to management, reproductive, nutritional and other treatments, would not have made any progress or evolved. Using groups removes the question of independence between animals, and in part, in experiment 3 (Chapter 5) was made possible by the reduced number of treatments.

6.4 Recommendations for future work

To have a better understanding of the nature and mechanism of social dominance and its effects on the production performances and grazing behaviour of grazing dairy cows in the New Zealand pasture-based system, further research needs to be carried out in the following areas:

1. The effects of social dominance on production and grazing behaviour using early-lactation cows. This could give a better indication of social dominance effects on the milk production and their grazing behaviour when cows are competing for resources to compensate with the requirement of greater energy intake to cope with the increased milk production after calving.

2. Examination of the effects of social dominance on the same age group (primiparous cows) instead of multiparous cows, or using cows of similar LW, to eliminate the age and weight factor in determining dominance.

3. Testing the effect of social dominance on a larger group of cattle that are not familiar with regrouping much throughout their entire lifetime.

4. To extend the behaviour observation period up to 12 or 24 hours, to give a better indication of the effects of social dominance on the cow's grazing behaviour.

6.5 Conclusions

The research presented in this thesis has provided an assessment of the social dominance of grazing dairy cows in the New Zealand pasture-based system. Specific conclusions were:

1. The factors determining dominance in grazing dairy cows were significantly related to age, LW and sometimes milk production of cows, where D cows were older, heavier, and produce greater milk yield than S cows. However, the reason behind such factors that relate to dominance was found to be unclear.

2. Separating multiparous, late-lactation grazing dairy cows according to social dominance when herbage allowance was low, benefited S cows by increasing their LWG, but not their milk production.

3. There was no benefit of separating multiparous, late-lactation grazing dairy cows according to social dominance on their milk production, even when fodder beet was offered as supplement to enhance competition.

Appendix A

Chapter 3 dominance value of the three groups

Table A.1. Average dominance value (DV)) of 29 cows in low-stocking-rate (LSR) group based on social group of dominant (D), mid-ranking (M) and subordinate (S) according to the first three weeks and the last three weeks of the study and overall DV throughout 12 weeks of study; n/i = no interactions observed.

Cow ID (LSR)	Social group	Week		
		1 to 3	10 to 12	Overall (1 to 12)
1	D	75.6	30.0	73.3
2	D	60.5	n/i	66.4
3	D	56.7	n/i	65.2
4	D	56.2	90.0	62.4
5	D	59.3	90.0	59.4
6	D	n/i	57.7	55.8
7	D	51.6	33.2	53.6
8	D	58.9	0.0	53.3
9	D	40.9	90.0	48.9
10	D	30.7	90.0	46.1
11	M	38.9	n/i	46.1
12	M	56.3	n/i	45.4
13	M	43.8	n/i	43.1
14	M	39.5	90.0	41.0
15	M	52.6	0.0	40.9
16	M	46.2	0.0	40.5
17	M	n/i	25.7	40.4
18	M	45.0	n/i	39.6
19	M	26.6	n/i	35.3
20	M	32.8	90.0	33.6
21	S	27.4	0.0	31.7
22	S	49.1	n/i	30.0
23	S	0.0	n/i	29.0
24	S	30.7	n/i	24.5
25	S	9.6	n/i	20.9
26	S	25.2	n/i	18.9
27	S	17.3	n/i	13.9
28	S	16.1	n/i	12.9
29	S	0.0	n/i	12.2

Table A.2. Average dominance value (DV)) of 34 cows in high-stocking-rate (HSR) group based on social group of dominant (D), mid-ranking (M) and subordinate (S) according to the first three weeks and the last three weeks of the study and overall DV throughout 12 weeks of study; n/i = no interactions observed.

Cow ID (HSR)	Social group	Week		
		1 to 3	10 to 12	Overall (1 to 12)
1	D	80.3	63.4	67.9
2	D	90.0	56.3	67.3
3	D	76.7	45.0	62.0
4	D	55.3	39.2	59.3
5	D	41.8	90.0	57.5
6	D	n/i	90.0	57.4
7	D	56.1	70.5	53.0
8	D	n/i	34.3	52.8
9	D	50.8	45.0	52.2
10	D	n/i	90.0	52.0
11	D	60.0	51.7	49.1
12	M	90.0	55.7	48.0
13	M	51.7	73.2	45.8
14	M	58.5	90.0	45.8
15	M	n/i	37.8	45.0
16	M	35.3	66.9	44.5
17	M	19.5	46.9	44.3
18	M	52.5	50.2	44.0
19	M	58.1	n/i	42.9
20	M	0.0	40.9	42.4
21	M	37.8	47.9	42.4
22	M	n/i	40.9	42.3
23	S	38.3	0.0	42.1
24	S	50.8	37.1	39.0
25	S	57.2	0.0	38.3
26	S	22.8	48.2	38.3
27	S	34.8	40.6	34.4
28	S	69.3	0.0	32.7
29	S	22.6	25.9	29.4
30	S	35.9	0.0	28.9
31	S	57.7	0.0	28.7
32	S	20.2	31.7	26.2
33	S	19.5	0.0	20.1
34	S	33.7	0.0	18.0

Table A.3. Average dominance value (DV)) of 189 cows in medium-stocking-rate (MSR) group based on social group of dominant (D), mid-ranking (M) and subordinate (S) according to the first three weeks and the last three weeks of the study and overall DV throughout 12 weeks of study; n/i = no interactions observed.

Cow ID (MSR)	Social group	Week		
		1 to 3	10 to 12	Overall (1 to 12)
1	D	n/i	n/i	90.0
2	D	90.0	n/i	90.0
3	D	n/i	n/i	90.0
4	D	n/i	n/i	90.0
5	D	n/i	n/i	90.0
6	D	n/i	n/i	90.0
7	D	n/i	90.0	90.0
8	D	n/i	90.0	90.0
9	D	n/i	90.0	90.0
10	D	n/i	90.0	90.0
11	D	90.0	n/i	90.0
12	D	n/i	n/i	90.0
13	D	90.0	n/i	90.0
14	D	n/i	n/i	90.0
15	D	90.0	n/i	90.0
16	D	n/i	90.0	90.0
17	D	n/i	90.0	90.0
18	D	90.0	n/i	90.0
19	D	90.0	90.0	90.0
20	D	90.0	63.4	79.1
21	D	n/i	66.6	71.9
22	D	68.8	90.0	71.6
23	D	67.8	n/i	70.9
24	D	n/i	n/i	70.5
25	D	90.0	90.0	68.9
26	D	90.0	90.0	65.9
27	D	57.4	90.0	64.6
28	D	60.0	n/i	64.3
29	D	90.0	n/i	62.8
30	D	90.0	90.0	61.3
31	D	69.7	0.0	60.6
32	D	0.0	90.0	60.0

33	D	54.7	n/i	60.0
34	D	n/i	n/i	60.0
35	D	90.0	n/i	60.0
36	D	54.7	90.0	60.0
37	D	69.3	40.9	59.7
38	D	90.0	90.0	58.7
39	D	47.2	72.5	58.3
40	D	90.0	0.0	58.1
41	D	n/i	n/i	57.7
42	D	n/i	40.9	57.7
43	D	90.0	35.3	57.2
44	D	60.0	90.0	57.0
45	D	90.0	0.0	56.8
46	D	90.0	n/i	56.3
47	D	60.0	49.1	56.1
48	D	53.8	90.0	55.5
49	D	0.0	n/i	54.7
50	D	n/i	90.0	54.7
51	D	90.0	26.6	54.7
52	D	45.0	n/i	54.7
53	D	49.1	n/i	54.0
54	D	50.2	30.0	53.6
55	D	50.8	90.0	53.4
56	D	22.2	63.4	53.0
57	D	90.0	90.0	52.9
58	D	n/i	n/i	52.9
59	D	90.0	45.0	52.5
60	D	48.6	90.0	52.4
61	D	52.2	n/i	52.2
62	D	90.0	0.0	51.9
63	D	n/i	0.0	51.7
64	M	90.0	n/i	51.4
65	M	50.8	70.5	51.2
66	M	0.0	n/i	51.1
67	M	65.2	n/i	50.5
68	M	37.8	90.0	50.1
69	M	0.0	n/i	50.1
70	M	50.1	n/i	50.1
71	M	n/i	40.9	49.5
72	M	n/i	30.0	49.1
73	M	45.0	n/i	49.1
74	M	39.2	90.0	49.1
75	M	57.2	n/i	49.1

76	M	0.0	60.0	48.8
77	M	42.8	n/i	48.6
78	M	n/i	n/i	48.2
79	M	49.1	90.0	47.6
80	M	45.0	n/i	47.6
81	M	n/i	90.0	47.0
82	M	49.1	n/i	47.0
83	M	n/i	n/i	46.9
84	M	45.0	90.0	46.5
85	M	35.3	0.0	46.1
86	M	45.0	0.0	45.7
87	M	48.8	0.0	45.5
88	M	n/i	n/i	45.0
89	M	32.3	n/i	45.0
90	M	n/i	n/i	45.0
91	M	37.8	n/i	45.0
92	M	0.0	40.9	45.0
93	M	45.0	n/i	45.0
94	M	45.0	n/i	45.0
95	M	45.0	0.0	45.0
96	M	n/i	n/i	45.0
97	M	n/i	n/i	45.0
98	M	0.0	n/i	44.3
99	M	52.6	0.0	44.1
100	M	0.0	0.0	44.1
101	M	45.0	n/i	43.9
102	M	35.3	n/i	43.5
103	M	n/i	90.0	42.8
104	M	0.0	90.0	42.8
105	M	53.6	n/i	42.4
106	M	40.9	90.0	42.1
107	M	0.0	0.0	42.0
108	M	49.1	0.0	41.9
109	M	0.0	0.0	40.9
110	M	n/i	n/i	40.9
111	M	n/i	40.9	40.9
112	M	n/i	n/i	40.6
113	M	30.0	n/i	39.8
114	M	39.2	0.0	39.6
115	M	41.4	45.0	38.3
116	M	38.9	n/i	38.3
117	M	90.0	16.1	37.4
118	M	n/i	n/i	37.4

119	M	40.5	32.3	37.1
120	M	31.0	0.0	37.0
121	M	n/i	0.0	36.9
122	M	0.0	n/i	36.6
123	M	40.2	0.0	36.3
124	M	30.0	0.0	36.0
125	M	0.0	0.0	35.3
126	M	39.2	n/i	34.3
127	S	50.8	40.9	34.2
128	S	0.0	0.0	33.7
129	S	90.0	n/i	33.2
130	S	0.0	n/i	32.3
131	S	49.1	0.0	31.7
132	S	90.0	n/i	31.5
133	S	0.0	0.0	31.1
134	S	0.0	n/i	31.1
135	S	35.3	n/i	30.7
136	S	0.0	n/i	29.3
137	S	n/i	n/i	29.0
138	S	22.2	n/i	29.0
139	S	n/i	n/i	28.6
140	S	n/i	28.1	28.1
141	S	45.0	n/i	28.1
142	S	40.9	n/i	27.6
143	S	0.0	n/i	27.6
144	S	0.0	n/i	27.3
145	S	0.0	0.0	26.1
146	S	0.0	n/i	26.0
147	S	33.7	n/i	25.9
148	S	90.0	0.0	24.5
149	S	0.0	n/i	24.1
150	S	26.6	0.0	23.4
151	S	90.0	0.0	23.4
152	S	27.6	n/i	22.2
153	S	26.6	n/i	20.7
154	S	n/i	n/i	19.9
155	S	n/i	0.0	19.5
156	S	0.0	n/i	15.5
157	S	0.0	0.0	0.0
158	S	n/i	n/i	0.0
159	S	n/i	n/i	0.0
160	S	n/i	n/i	0.0
161	S	n/i	n/i	0.0

162	S	n/i	0.0	0.0
163	S	0.0	0.0	0.0
164	S	0.0	n/i	0.0
165	S	0.0	n/i	0.0
166	S	0.0	0.0	0.0
167	S	0.0	n/i	0.0
168	S	n/i	0.0	0.0
169	S	0.0	0.0	0.0
170	S	0.0	n/i	0.0
171	S	n/i	n/i	0.0
172	S	0.0	n/i	0.0
173	S	0.0	n/i	0.0
174	S	0.0	n/i	0.0
175	S	0.0	0.0	0.0
176	S	n/i	0.0	0.0
177	S	n/i	n/i	0.0
178	S	n/i	n/i	0.0
179	S	n/i	n/i	0.0
180	S	n/i	n/i	0.0
181	S	n/i	n/i	0.0
182	S	n/i	n/i	0.0
183	S	n/i	n/i	0.0
184	S	n/i	n/i	0.0
185	S	n/i	n/i	0.0
186	S	n/i	n/i	0.0
187	S	n/i	n/i	0.0
188	S	n/i	n/i	0.0
189	S	n/i	n/i	0.0

Appendix B

Published paper

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