Birth weight and growth of New Zealand Thoroughbred foals

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Abstract

The success of the New Zealand Thoroughbred horse industry is highly dependant on the production of good foals. The birth weight of the foal, and its weaning weight, is closely associated with maternal factors, such as age, parity, size, and nutrition. Age is associated with endometrosis and limited placentation, which leads to a reduction in foal birth weight. Multiparous mares tend to produce larger foals than primiparous mares because of the priming effect that a first pregnancy has on the uterus.

Nutrition affects the size of the mare, which is positively correlated with foal birth weight. The size of the mare is positively correlated with birth size of the foal, and the birth weight of the foal is positively correlated with the mass, gross area and volume of the allantochorion, and the total area of foetomaternal contact. The information available on the maternal effects on foal birth weight is limited. This study attempts to improve our understanding of this relationship by examining data collected from New Zealand Thoroughbred mares, which are held on pasture throughout the year and may receive little supplementary feed during pregnancy.

Data were collected from 49 New Zealand Thoroughbred mares and their foals during the 2004 foaling season. Analyses were conducted to determine whether the age, parity, body condition score, weight pre- and post-partum, and height of the mare, the length of gestation and the allantochorion weight and volume were associated with foal sex ratio (n = 49), foal wet birth weight (n = 27), day 1 weight (n = 49), and foal height (n = 49). The daily growth of a subgroup of 15 foals in their first two weeks of life was monitored. In addition, age and parity data was collected via the online Thoroughbred Studbook from 492 mares that were bred to one of the Waikato Stud stallions in the 2001 breeding season.

The mean age of mares was 10.8 ± 0.8 years for the Newmarket Lodge population and 11.0 ± 0.2 years for the Waikato Stud population; the mean parity of mares was 4.5 ± 0.4 for the Newmarket Lodge population and 5.9 ± 0.2 years for the Waikato Stud population; and the mean length of gestation was 355.67 ± 1.26 days. The age and parity of the mare and the sex of the foetus had no significant effect on the length of

gestation. Primiparous mares had significantly lighter and lower foals than multiparous mares, independently of the age of the mare. The mean wet birth weight of foals was 54.6 ± 1.1 kg and the mean day 1 weight was 55.7 ± 0.8 kg. The range of foal birth weights was from 41.0 to 66.5 kg. The sex of the foal did not significantly affect its wet birth weight and day 1 weight. The mean wet birth weight was 54.1 ± 2.1 for a filly, and 55.0 ± 1.3 for a colt. The mean day 1 weight was 55.2 ± 1.4 for a filly and 56.2 ± 1.1 for a colt. The relationship between the wet weight of the foal and its day 1 weight was highly significant.

Mare age and parity affected the weight and volume of the allantochorion. The allantochorions of primiparous and multiparous mares aged 16 years and over were lighter and had lower volumes than those of multiparous mares aged five to 15 years. There was no difference in the weight and volume of the allantochorions of primiparous mares and multiparous mares aged 16 years and over. The mean weight of the allantochorion was 3.68 ± 0.09 kg, and the mean volume was 2.86 ± 0.07 litres. The weight and volume of the allantochorion were significantly associated with the wet birth weight and day 1 weight of the foal. Moreover, the weight of the mare pre- and post-partum significantly affected the wet birth weight, the day 1 weight, and the height of the foal. Mares lost an average of 80.9 kg liveweight with the foaling process.

Foals lost on average 1.17 ± 0.94 kg between the wet birth weight and day 1 weight measurements. Seventy percent of foals lost weight between these measurements. The average daily weight gain of foals from day 2 to day 14 of life was 1.71 ± 0.11 kg. The average weight gain of foals was 25.05 ± 1.02 kg in the first 14 days of life. The mean height of foals at birth was 1.028 ± 0.008 m and they grew on average 0.062 ± 0.005 m to reach a mean height of 1.087 ± 0.005 m at two weeks of age. The average daily height increase from day 1 to day 14 was 0.004 ± 0.002 m. There was no significant influence of the sex of the foal on the weight gain and height increase from day 1 to day 14, although the mean wet birth weight, day 1 weight and day 14 weight of colts is slightly higher than that of fillies.

Maternal factors influence the birth size of the NZTB foal born to mares kept on pasture. The weight of the mare is closely associated with the size of the allantochorion, which is significantly associated with the birth weight of the foal. Primiparous and older

mares ($\geq$ 16 years) produce smaller foals than multiparous mares younger than 16 years. Foals lose weight in the first 24 hours after birth. This early neonatal weight loss probably occurs because of drying off. The sex of the foal did not affect the length of gestation, and it did not influence the birth weight of the foal and its daily growth in the first two weeks post-partum. The information in this study has not been previously reported for horses in New Zealand.

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ABBREVIATIONS

AC	Allantochorion
cm^2	centimeter square
cm^2/cm^3	centimeter square per centimeter cubed (unit of area per unit volume)
CP	Crude protein
DE	Digestible energy
Foal day 1 weight	Foal weight on the morning after birth (within 8 to 12 hours of birth)
g/kg DM	gram of protein per kilogram of dry matter
IgG	Immunoglobulin G
IUGR	Intrauterine growth retardation
Kcal	kilocalorie
Kg	Kilogram
Kg/d	Kilogram per day
l	litre
MJ	Megajoule
MJ DE/day	Megajoule of digestible energy per day
μm^{-1}	micrometer to the power of negative one (or $\mu m^2/\mu m^3$, unit of microcotyledon surface density)
NRC	National Research Council
NZTB	New Zealand Thoroughbred
NZTR	New Zealand Thoroughbred Racing
P	pony
SEM	Standard error of the mean
TB	Thoroughbred

Wet birth weight Foal birth weight immediately after birth

Chapter 1

Introduction

1.1 Introduction

The New Zealand Thoroughbred (NZTB) horse breeding industry is the fifth largest in the world, behind the United States of America, Australia, Japan, and Ireland (Perkins, 2005). It generates annually over NZ$110 million in revenue from exports (Anonymous, 2006b). The goal of the NZTB horse breeding industry is to produce foals that are capable of achieving athletic success. According to statistics obtained from the New Zealand Thoroughbred Studbook, over the eleven-year period from 1994-2005, the mean annual number of live NZTB foals was 4,980 (Anonymous, 2006c; 2006d).

The economic success of the Thoroughbred (TB) breeding industry depends on the production of horses that can generate profit both through racing and (for stallions) through cover fees that are charged when they sire foals. Breeding management is used to match dam and sire pedigrees and physical characteristics to produce athletically successful horses. TB horses are usually marketed as yearlings. Therefore, it is important that they appear suitable for athletic performance at this age. The birth weight and growth of the foal are important factors to consider as previous research has demonstrated a positive correlation between the weight of the TB foal at birth and its weaning weight (Brown-Douglas, 2003). Furthermore, the maternal environment is important in determining the birth weight of the foal (Allen et al., 2002b). Foals that were deprived in utero – TB foal gestated in pony mare – had smaller birth weights than control foals, and foals that were privileged in utero – pony foal gestated in TB mare.

Maternal factors, such as age, parity, size, and nutrition, are closely associated with the birth weight of the foal, and therefore, its weaning weight (Allen *et al.*, 2002b, 2004). Understanding these maternal factors, and how they interact with foal birth weight, could be used to develop strategies to improve the production of foals that become successful equine athletes. Older mares are more likely to experience endometrosis (Kenney, 1993) and have limited placentation, which leads to smaller foals at birth (Wilsher and Allen, 2003). Primiparous mares tend to produce smaller foals than multiparous mares because to reach its full potential in terms of placental development and foetal growth, the uterus must be primed by a pregnancy. The size of the mare is positively correlated with placenta size, and the birth weight of the foal is positively correlated with the mass, gross area, and volume of the allantochorion, and the total area of foetomaternal contact (Allen *et al.,* 2002b).

The data available on foal birth weight and growth, and how it is affected by maternal factors is limited, particularly for foals born to mares managed under New Zealand grass fed conditions. In addition, most published birth weight data are not 'true' birth weights, but rather the weight measured on the day following birth. The most significant study on the effects of maternal factors on the birth weight and growth of the foal used between-breed pregnancies in the Northern Hemisphere (Allen *et al.*, 2002b). Less comprehensive studies, also from the Northern Hemisphere, include an investigation into the effect of parity on the birth weight of the foal by implanting one foal into a primiparous mare and its full-sibling on a multiparous mare (Pool-Anderson, 1994). In addition, a study by Tischner (1985) investigated the effect of mare size on the birth weight of the foal by implanting Polish-pony embryos into larger mares.

The objective of this study is to observe, under typical New Zealand conditions, how the natural variation in the characteristics of NZTB mares influences foal birth weight, and postnatal foal growth in the first two weeks of life. This study will provide data that has not been previously obtained on NZTB horses, and that can be used to maximise the growth of the NZTB foal.

Chapter 2

Literature Review

2.1 The New Zealand Thoroughbred Breeding Industry

The NZTB horse breeding industry is concentrated in six main regions. The major studs are located in the Waikato and South Auckland (Anonymous, 2006a), but a significant proportion of the breeding industry is located in: the Hawke's Bay and Central Districts in the North Island, and Canterbury and Southland in the South Island.

The NZTB horse breeding industry is diverse; the size of the breeding enterprise varies from horse breeders with one or two mares to large commercial stud farms that stand stallions and breed 100 to 200 foals each year (Anonymous, 2006a). The NZTB horse is bred specifically for the racing industry. Typically, they are sold as yearlings and usually starts racing as two-year olds.

Karaka, in South Auckland, hosts the elite NZTB yearling sale every year at the end of January. The aggregate earnings of the New Zealand national yearling sales was NZ$65.7 million in 2006, and has averaged $51.75 million annually from 1994 to 2006 (Anonymous, 2006c). Karaka also hosts a sale of two-year-old NZTB horses ready to begin racing. These horses are videotaped and timed, galloping over 200 metres, prior to the sale. The videos can be viewed online by potential buyers. The Ready-to-Run sale does not generate as much income as the yearling sale (Anonymous, 2006b), but the average price of a horse in the sale was NZ$50,085 in 2006 (Anonymous, 2006e), and the total gross earning of the sale was around NZ$9.8 million in 2006 (Anonymous, 2006e).

The NZTB horse industry exports horses to Australia and Asia (Malaysia, Singapore, Macau and Hong Kong), and these were valued at an average of NZ$115 million per season, from the 1999/00 to the 2004/05 seasons (Anonymous, 2006b). In addition, an increasing number of horses are being sold to the Middle East, Korea, and mainland China (Anonymous, 2004b). The TB racing and breeding industries represent approximately 1.3% of Total Gross Domestic Product of New Zealand, and 73% of this is generated by NZTB racing (Anonymous, 2004b).

2.1.1 Importance of reproductive performance to the New Zealand Thoroughbred Industry

Reproductive performance is an important component of the NZTB industry and a good reproductive performance is essential to maximise profits. For example, mares that conceive late in the breeding season will often foal progressively later in each successive foaling season, and may eventually not be pregnant for a year.

In the TB industry, most fillies retire to stud at three or four years of age, and are expected thereafter to produce a foal annually. In New Zealand, there are 9,288 TB mares kept on pasture (Anonymous, 2006c). The mean age of NZTB mares is about 11 years of age, and ranges from three to 26 (Anonymous, 2004b). It is estimated that 4,985 NZTB foals are born annually (Anonymous, 2004b, 2006c) and 2,000 of these foals are exported as yearlings (Anonymous, 2006b).

Horses are seasonal breeders. In the Southern Hemisphere, mares reach their peak fertility in the summer months (November, December and January), when 90% of mares ovulate. In winter (July, August and September) only 20% of mare ovulate (Pickett & Voss, 1998). The New Zealand TB breeding season runs from September 1 to December 31, and requires mares to be bred in September to October when they are not at their peak fertility. In the Southern Hemisphere, the official birthday of TB horses is August 1 and as the length of gestation in mares is approximately 11 months, breeders try to breed mares so they will foal as close to August 1 as possible to have the advantages of relative maturity and strength when competing with other horses of the same official age.

Many factors affect the reproductive performance of NZTB horses. These include factors relating to the environment, nutrition, the mare, the stallion, the stud and economic factors. The age, parity, size and nutrition of the mare contribute significantly to the overall reproductive efficiency of the entire TB horse population (Morris & Allen, 2002).

2.2 Maternal influences on foal birth weight

2.2.1 Age

Foetal development *in utero* is closely associated with the number and development of the microcotyledons (Wilsher & Allen, 2003). As the mare ages, the endometrium degenerates, leading to endometrosis and limited placentation. The degenerative lesions in the endometrium of older mares interfere with placental morphology and efficiency (Bracher *et al.*, 1996). Endometrosis include accumulations of mononuclear cells in the endometrial stroma, degeneration and dysfunction of the endometrial glands, degeneration and occlusion of endometrial blood vessels and formation of lymph-filled endometrial cysts that protrude into the uterine lumen (Figure 2.1) (Allen and Stewart, 2001).

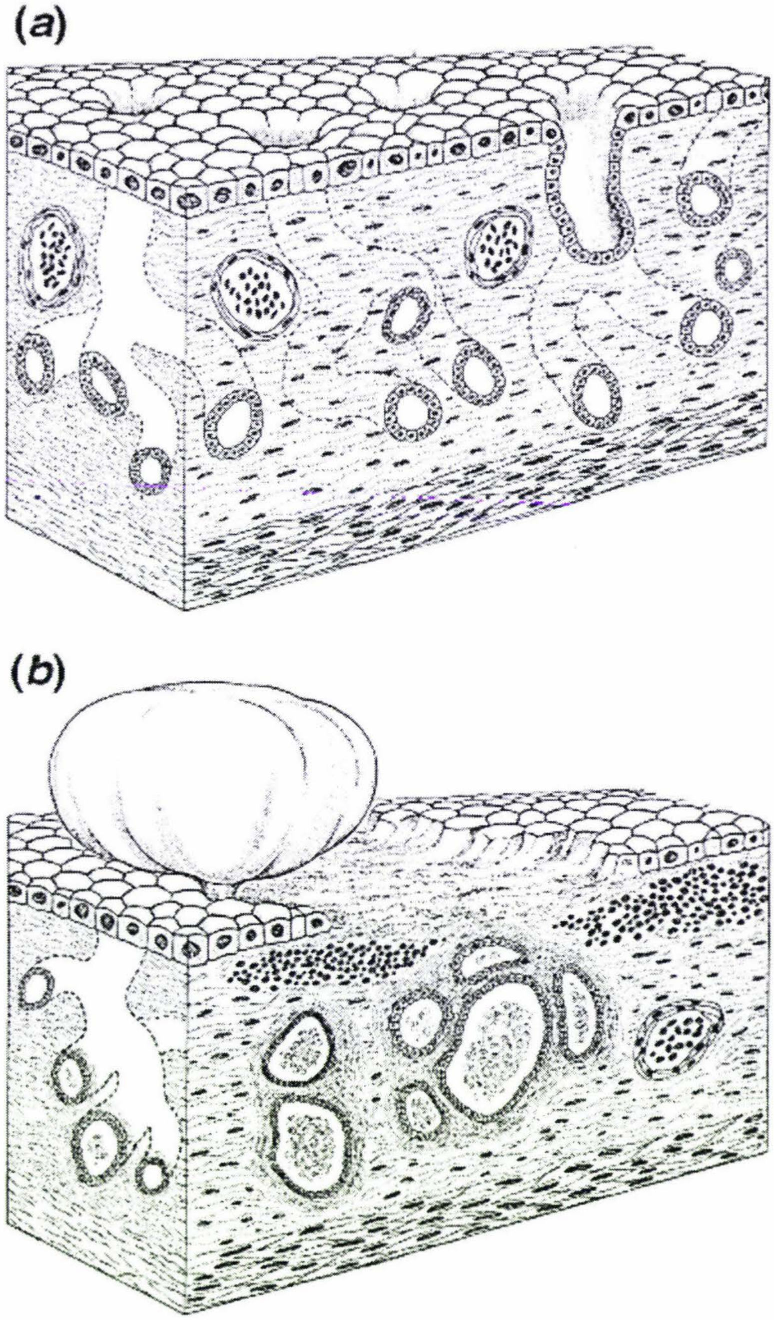

Figure 2.1: *Diagrammatic representation of the essential architecture of the endometrium of the mare in (a) a healthy, fertile young animal and (b) an aged mare exhibiting the degenerative changes of endometrosis (from Allen and Stewart, 2001)*

The areas of allantochorion connected to degenerated areas of the endometrium have fewer and shorter chorionic villi, which causes delayed and abnormal development of microcotyledons (Bracher *et al.*, 1996). Wilsher and Allen (2003) demonstrated that the development of the microcotyledon and microcotyledon surface density were lowest in aged multiparous mares. Consequently, the birth weights of foals born to mares aged 16 years and older were significantly lower than the birth weights of foals born to mares aged up to 15 years.

2.2.2 Parity

Parity has been associated with altered foetal growth *in utero* (Wilsher & Allen, 2003). Studies in sheep (McDonald *et al.*, 1989) and women (Pivalizza *et al.*, 1990) have shown that the altered foetal growth in primiparous animals occurs because of impairment of the transfer potential of the placenta (Wilsher & Allen, 2003). There is some evidence that primiparous mares produce smaller foals than secondiparous and multiparous mares (Wilsher & Allen, 2003) because the microcotyledon surface density is lower in the first pregnancy in comparison to subsequent pregnancies.

As previously mentioned, in the TB industry the majority of fillies retire to stud when they are about three or four years old. Therefore, age and parity are closely associated. There is a widely held view that mares will produce smaller foals in their first parity than in subsequent pregnancies. Hintz *et al.* (1979) hypothesized that younger mares were unable to provide sufficient nutrients to the foetus; therefore, they produced smaller foals. Nevertheless, the data correlating low birth weights in foals born to primiparous mares to a reduction in placental size are still limited. The foetal genotype interacts with the uterus to modulate the development of the placenta to some extent (Wilsher & Allen, 2003). However, the most cited reason for the lower birth weight of the first foal is the limited intrauterine space for the growing foetus, due to a limited ability of the uterus to stretch (Wilsher & Allen, 2003).

It has been suggested that the uterus has to be 'primed' by a first pregnancy before it can reach its full potential in terms of placental and foetal development (Wilsher & Allen, 2003). The priming effect has been demonstrated in a study by Wilsher and Allen (2003), in which they followed eleven maiden mares in two successive pregnancies (Table 2.1). These mares showed significant increases in microcotyledon surface density values in the second parity, with equivalent improvements in foal birth weight (Wilsher & Allen, 2003).

Table 2.1: *Mean ± SEM maternal, foetal and placental parameters measured in 11 mares at the end of their first and second parities (adapted from Wilsher and Allen, 2003)*

	First parity (n = 11)	**Second parity (n = 11)**
Maternal weight (kg)	503.7 ± 12.0	506.7 ± 11.3
Foal birth weight (kg)	46.9 ± 1.0^{a}	54.8 ± 1.7^{b}
Mass of allantochorion (kg)	3.7 ± 0.2	4.1 ± 0.2
Gross area of allantochorion ($cm^2 \times 10^{-3}$)	12.1 ± 3.6	13.1 ± 6.2
Volume of allantochorion (l)	3.5 ± 0.1	3.9 ± 0.2
Microcotyledon surface density (μm^{-1})	0.034 ± 0.001^{a}	0.041 ± 0.001^{b}

Different superscripts in the same row indicate significant differences ($p<0.05$).

2.2.3 Size

The maternal environment interacts with the genotype of the foetus to modulate foetal growth (Allen *et al.*, 2002b). The size of the mare can influence the size of the placenta, by affecting the gross area of the allantochorion, and the density, complexity and depth of the microcotyledons.

Studies conducted by Allen *et al.* (2002a), Allen *et al.* (2002b) and Allen *et al.* (2004) investigated the effect of the maternal environment on the birth weight of the foal. In this study, conventional within-breed TB and pony (P) control pregnancies were compared to between-breed trial pregnancies established by embryo transfer. The TB embryos that were implanted into pony mares had a 'restricted' condition *in utero*, while P embryos that were implanted into TB mares had a 'luxurious' condition *in utero*. Their results showed that foals gestated in a restricted environment (TB-in-P) had lower birth weights than the control TB foals (born to a TB dam), while foals that were gestated in a 'luxurious' environment (P-in-TB) had higher birth weights than the control P foals (P-in-P) (Allen *et al.*, 2002b).

At birth, the size increase or reduction in the between-breed (P-in-TB and TB-in-P) foals was approximately 15%, respectively, compared with their controls. The size difference associated with between-breed foals and the control foals continues after three years of postnatal growth. However, the genotype of the foals starts to exert more control postnatally, and the foals exhibit compensatory growth in the first six months after birth. The foals that suffer growth retardation in the uterine environment show enhanced growth, while the foals that experienced a 'luxurious' uterine environment show restricted growth compared with their respective controls (Allen *et al.*, 2004). By 3 years of age, the difference in size observed between control foals and between-breed foals has decreased to 5%, and that difference persists throughout life. These results support the findings by Walton and Hammond, in 1938. They reported that the restricted or enhanced growth *in utero* resulted in a restricted or enhanced foal birth size, respectively, and that the difference persisted through to 18 months of age. Moreover, Tischner and Klimczak (1989) observed that 'luxurious' foals grew more rapidly than 'restricted' foals until weaning. They noted, however, that the differences in foal size became less evident following weaning.

The enhanced or restricted growth during the first 6 months after birth occurred mainly through skeletal changes (Allen *et al.*, 2004). Bone is the first of the three major tissues (bone, fat, and muscle) to reach maturity. 'Luxurious' foals showed a growth spurt of the radius bone between 30 and 80 weeks (10 weeks longer than their control group), while the cannon bone suffered a growth spurt between 70 and 90 weeks of age (Allen *et al.*, 2004). As the foal depends almost entirely upon its dam for nutrients in the first weeks of life (Koterba, 1990), and milk yield (kg/day) is greater in TB than in P mares

(Doreau & Boulot, 1989) it could be expected that the 'restricted' foals would show a reduced weight gain in comparison to their controls and that the 'luxurious' foals would show a greater weight gain than their controls. However, Allen *et al.* (2004) stated that no significant differences were found between the four groups when their weight gain was expressed as either kg/week or percentage increase in bodyweight, suggesting that the milk supply adjusted to the demands of the foal.

Nutrition influences mare size, and plays a vital role in the reproductive performance of horses by influencing its hormonal output which regulates the oestrous cycle (Mackay, 2003). The conception rate is influenced by the body condition of mares at breeding (Henneke *et al.*, 1984). Body condition scoring is used instead of body weight because it is more informative to refer to the appearance of the animal, as it does not depend on individual size, than weight, which is not always easy to obtain (McMeniman, 1996). There are two condition scoring systems generally used: (1) described by Carroll and Huntington (1988), condition scores range from 0 (very thin) to 5 (very fat); and (2) described by Henneke *et al.* (1983), condition scores range from 1 (very thin) to 9 (very fat).

Changes in the body condition score of a mare have been linked with the birth sex ratio of foals, as well as with changes in fertility. Cameron *et al.* (1999) reported that feral mares in better condition at the time of conception were more likely to produce a male foal. In addition, mares that had foals of different sexes in different years were in poorer condition when they conceived the female foal. This trend could not be explained by differential foetal loss as the pregnancy progressed and therefore, indicated that, in wild horses, sex ratio modification occurs at conception (Cameron *et al.*, 1999).

Obese and thin mares have lower conception rates compared to mares in good body condition (Cuddeford, 2003). The conception rate can be improved by increasing the feed intake a few weeks prior to breeding, in a process called flushing. Thin mares gaining weight during the breeding period have been reported as being twice as likely to conceive as thin mares maintaining weight (Henneke *et al.*, 1984). McMeniman (1996) stated that obese pregnant mares are infertile in the subsequent breeding period, contradicting a previous report by Kubiak *et al.* (1989). However, Kohnke (1999) stated that an overweight mare will cycle and conceive successfully as long as any loss in body weight is avoided during the pre-breeding and breeding periods. In addition, the overweight mare should not lose any weight during the last trimester of pregnancy (Frape, 2004).

Overweight mares fed a low-energy diet during the breeding season have lower follicular activity and ovulate less than overweight mares on a high-energy diet (McMeniman, 1996). Although Kubiak *et al.* (1988) have found no adverse effects of obesity on the incidence of foaling difficulties, foal size, and subsequent rebreeding efficiency, overfeeding could lead to metabolic conditions, such as founder, and hyperlipidaemia (Frape, 2004; Hintz, 1993). Therefore, obesity should be minimised. Furthermore, deficiencies in protein, phosphorus, selenium, iodine, or vitamin A can reduce fertility (Cuddeford, 2003; Frape, 2004; Lewis, 1996).

Few studies have investigated the influences that mare size exerts on the birth weight of the foal. Furthermore, there is limited information on the effects of maternal size within a breed. TB mares can vary greatly in weight and height. However, there is currently very little information about the significance of this variation in mare size in relation to the birth weight of the TB foal. In TB horses, measurements taken from yearlings can be used to predict mature dimensions with reasonable accuracy (Anderson & McIlwraith, 2004; Staniar *et al.*, 2004b). The wither height of mature horses has been correlated with racing performance (Dolvik and Klemetsdal, 1999). Galisteo *et al.* (1998) reported a positive correlation between wither height and stride length, which, in turn, has been correlated with win percentage in Thoroughbreds (Smith *et al.*, 2006). Hip height, body length and heart girth have also been correlated with win percentage and Standard starts index that measures earnings per each start, taking into account the sex of the horse and its year of birth.

2.3 Nutrition of the mare and foal

Nutrition is an important component of a breeding programme to help regulate the body condition of mares to ensure optimum conception rates (Cuddeford, 2003). When feeding mares, there are several important factors to consider: these include the nutrient requirements of the particular class of mare, the physiological events involved in pregnancy, the physiological limitations of certain feeds, and the nutrient content of feeds (Anonymous, 1998). The concentrations of the major nutrients obtained from pasture vary significantly between countries because of the different pasture species that are predominant in different locations. In addition, soil fertility and climate will influence which pasture species will grow better at a specific location (McMeniman, 1996). Furthermore, nutrient concentrations change as pastures mature, and therefore, pastures that may meet the nutritional requirements of mares in spring, may not meet these requirements during winter.

2.3.1 Nutrient requirements

The horse evolved as a non-ruminant herbivore that uses hindgut fermentation to obtain energy from low quality forage (Argenzio, 1993). In the wild, horses will spend 60% of their time grazing (Duncan, 1980). Under New Zealand conditions, mares and foals are kept on pasture, and rely on it to provide the majority of their nutritional requirements (Goold *et al.*, 1988; Hoskin & Gee, 2004).

Horses that have access to good pasture rarely suffer the digestive or behavioural problems that can affect stabled horses because of restricted activity, feeding time, increased exposure to stress, and specific highly concentrated starchy cereals, proteins and dried forages in the diet (Avery, 1997; Frape, 2004). Feeding pasture to horses also has the advantage of lower overall feeding costs (Kohnke *et al.*, 1999) compared to supplementary feeding (Avery, 1997). However, pastures must be properly managed;

otherwise, the amount of feed provided by pasture may decrease significantly because of factors such as overgrazing, and improper irrigation or fertilizer use (Lewis, 1996).

Poor nutrition is one of the factors that cause a reduction of reproductive efficiency of mares. It impacts on fertility, conception, and foaling rates (Kohnke, 1999). This influence occurs despite good breeding management and veterinary care, and therefore, a well balanced diet is needed if breeding success is to be achieved.

Throughout the breeding season, the mare should be in a positive plane of nutrition. During the first eight months of gestation, the mare should be fed for maintenance, but as the pregnancy progresses, the digestible energy (DE) requirements increase to 1.11, 1.13, and 1.20 times that of maintenance for months 9, 10, and 11 of gestation, respectively (Anonymous, 1989). During the last three months of gestation, 67% of foetal growth and 90% of foetal bone development occurs (Anonymous, 1998); therefore, energy, protein, calcium and phosphorus requirements increase significantly.

Throughout gestation, the weight of the mare should increase by about 9-12% of her weight to maintain body condition. Two-thirds of the weight gain occurs in the last trimester (Lewis, 1996). Another factor that must be taken into account is that, while the nutrient requirements increase, the capacity of the digestive tract of the mare to hold bulky feed decreases. This occurs because the developing foal will occupy an increasing proportion of the abdominal cavity of the mare. Consequently, the need for improved feed quality over quantity increases (Cuddeford, 2003).

The effect of nutrition on the birth weight of the foal has received the most research attention out of the maternal factors that influence foal birth weight. However, few studies have attempted to link mare fatness with the weight of the foal at birth. Kubiak *et al.* (1988) reported that foal birth weights and placenta weight did not differ between mares with a moderate body condition and obese mares.

2.3.2 Nutrients from pasture

Horses are selective grazers, choosing to graze younger, faster-growing forages (Hunt, 1994). Horses have different preferences of pasture species depending on the time of year (Hunt, 1994). In autumn, horses showed preference for legumes (such as white clover), while in winter and spring, the preference was for prairie grass, Italian ryegrass, chicory, and sheep's burnet, in addition to white clover. Nevertheless, perennial ryegrass, short-lived ryegrass, tall fescue, prairie grass, and timothy are all acceptable for horses (Table 2.2) (Avery, 1997). However, they show preference for a pasture mix of perennial grasses and white clover over pure swards (Archer, 1973).

Table 2.2: *Mean energy and protein contents of pastures for horses in New Zealand (Hoskin & Gee, 2004)*

Pasture	**Content**	
	Energy (MJ DE/day)	**Crude protein (g/kg DM)**
Ryegrass + white clover		
Autumn[a]	10.8	250 – 254
Winter[ab]	11.4 – 11.2	222 – 268
Spring[cd]	10.8 – 11.8	148 – 220
Spring (leafy)[a]	12.0	220 – 236
Summer (leafy)[a]	10.3	150 – 219
Summer (stalky)[a]	8.0	100
Red clover[a]		
Pre-bloom	11.0	230
Full-bloom	10.0	180
Lucerne[a]		
Pre-bloom	11.5	220
Full-bloom	10.5	160

[a] Hunt (1994); [b] Grace *et al.*(2003); [c] Grace *et al.*(2002a); [d] Grace *et al.* (2002b)

In New Zealand, the predominant pasture species is a blend of ryegrass (80-95%) and white clover (5-20%) (Goold *et al.*, 1988; Hoskin & Gee, 2004). Ryegrass-based pastures appear to have a high DE and crude protein (CP) content (Hoskin & Gee, 2004), based on the data presented by the National Research Council (NRC) (Anonymous, 1989). These are widely accepted although they are sourced from horses fed conserved forage and grain-based diets. Ryegrass-based pastures grow well under New Zealand conditions when managed correctly.

Nutrient concentrations change significantly as pastures mature (Grace *et al.*, 2002b). Immature plants are more nutritious and palatable than mature plants (Lewis, 1996). The digestible energy and protein content of grasses decreases by over half from mid-vegetative stage (two to four weeks of growth and two-thirds mature height) to seed-forming maturity (12 weeks of growth) (Lewis, 1996). However, immature plants are smaller and therefore, provide less feed. Goold (1990, 1991) reported high nutrient contents for pastures grazed by horses in the Waikato region of New Zealand, with CP contents rarely dropping below 200 grams per kilogram dry matter. However, the concentration of calcium and phosphorus in pasture was marginal for rapidly growing horses during winter. Grace et al. (2003) stated that increasing the dietary calcium intake of weanlings 3.5-fold for three months had an insignificant impact on bone growth and development.

The selective grazing behaviour of the horse eventually reduces the nutritive value of pasture as the uneaten mature plants become dominant in the sward (Grace *et al.*, 2002b). Regular paddock rotations with sheep and/or cattle can be used to ensure that the grass species that are unpalatable to horses do not become predominant (Grace *et al.*, 2002b). In addition, New Zealand soil is deficient in copper, cobalt, selenium, iodine and zinc, and therefore, it needs regular applications of fertilizers to maintain soil fertility (Grace *et al.*, 2002b).

In terms of pregnant and lactating mares and young growing horses, Hoskin & Gee (2004) affirmed that the feeding value of ryegrass-based pastures in New Zealand appears high. Therefore, provided the quality and quantity of pasture is adequate, ryegrass-based pastures should meet the nutrient requirements of New Zealand mares.

Grace *et al.* (2002b) explained that good quality ryegrass (*Lolium* spp) - white clover (*Trifolium repens*) pasture could provide an adequate dry matter intake (DMI), and digestible energy intake (DEI), provided that the pasture had a digestible energy (DE) content of 10.8 MJ/kg DM for lactating mares to ensure adequate milk yield. In addition, the macroelement composition of pasture to ensure sufficient macroelement intake for lactating mares was Ca 3.33 g/kg, P 3.0 g/kg, Mg 1.67 g/kg, Na 1.67 g/kg, and K 24.2 g/kg (Grace *et al.*, 2002b). For weanlings and yearlings, the DE content of pasture needed to ensure superior growth is 11.4 MJ/kg DM and 11.3 MJ/kg DM, respectively (Grace *et al.*, 2002a; 2003).

The recommended daily calcium and phosphorous requirements for rapidly growing weanling horses (gaining 0.85 kg/day) are 6.1 g/kg DM and 3.4 g/kg DM, respectively (Anonymous, 1989). It has been suggested that the calcium content of New Zealand pastures is not adequate to meet the requirements and ensure good bone development in growing horses (Grace et al., 2003). However, in deficient pastures, increasing calcium intake from 19.3 to 67.3 g/day had no effect on the apparent absorption of calcium and no significant effects on bone parameters (Grace *et al.*, 2003).

The growth rates for TB horses in New Zealand are similar to Northern Hemisphere data from stud farms feeding grain in addition to pasture (Hoskin & Gee, 2004). Although, the information available on the utilisation of digested nutrients from pasture by horses, such as the partitioning of metabolisable energy in different physiological states, is limited (Hoskin & Gee, 2004), energy and protein intake are the most critical factors that can influence breeding success (Kohnke, 1999).

2.3.3 Lactation

A 500 kg mare will produce 15-18 kg of milk per day, during the first 40 days of lactation (Doreau *et al.*, 1993; Martin, 1993), and although it is of relatively poor quality, it effectively doubles the energy requirements of the mare compared to maintenance levels (Cuddeford, 2003). The DE intake required to produce one kilogram of milk is estimated to be 3.3 MJ (Anonymous, 1989), while in the first and second months of lactation the DE intake requirements are even higher: 4.3 and 4.0 MJ DE per kg milk, respectively (Doreau *et al.*, 1988). Peak milk yield occurs from days 30 to 70 of lactation (McMeniman, 1996), after which milk production gradually decreases.

The lactating mare has an increased requirement for energy, protein, calcium, phosphorus, potassium, magnesium, and vitamins A, D and E. Lactation can be supported by pasture alone if the availability and nutrient content of the pasture are adequate (McMeniman, 1996). Both Martin (1993) and Doreau *et al.* (1988) have shown that lactating mares can achieve the nutritional requirements from pasture alone. With the exception of calcium levels for early lactation, perennial ryegrass-based pastures in New Zealand have been reported to meet the nutritional requirements of lactating TB mares (Grace *et al.*, 2002b) when compared to NRC requirements (Anonymous, 1989). In early lactation (birth to 12 weeks), the high demand for calcium is likely to be met from bone calcium stores, which are replenished when lactational demand for calcium decreases (Grace *et al.*, 2002b). Nevertheless, most authors support the use of supplements during lactation, especially if pasture quality is not adequate. The recommended quantity of supplements for lactating mares is 30 to 40% concentrate in addition to pasture or conserved forages (McMeniman, 1996). It is also important to understand the preferences of horses for particular concentrates, and whether supplement intake will have a depressing effect on pasture intake (McMeniman, 1996).

In the first three months after foaling, significant weight loss in mares should be prevented as this may cause a reduction in milk production, and therefore, a retardation in the growth of the foal (Kohnke, 1999). Conversely, there is no advantage in overfeeding a lactating mare to increase milk production, except for increased fertility. In fact, Kohnke (1999) stated that excess energy intakes during lactation slightly decrease the fat or protein content of milk in the mare.

During late lactation (three months to weaning) milk production decreases to two-thirds of the level produced during early lactation. Consequently, nutrient needs decrease. Although the protein content of mature ryegrass-based pastures in summer is not adequate for lactating mares (Hoskin & Gee, 2004), this effect occurs after peak lactation, when the nutrient requirements of the mare are decreasing. In addition, pasture management generally reduces the impact of the maturing pasture on the nutrition of the mare (Hoskin & Gee, 2004).

2.3.4 Foal nutrition

During gestation, the foetus is continuously fed through the placenta. However, after birth it must adapt to an intermittent supply of milk as the major source of nutrients. The ability of the digestive system of the foal to adapt to milk and pasture will influence its growth, development, and health (Cuddeford, 2003). Milk composition reflects the nutritional needs of the foal at different stages of development. Colostrum contains a lot of protein and its consumption by the foal confers it immunity (immunoglobulins, such as IgG) against a number of disease agents. The serum IgG concentration in foals is dependant on the colostral IgG concentration (Morris *et al.*, 1985). Mares with low pre-suck colostral IgG concentration and specific gravity lower than 1.060 are more likely to have foals with partial or complete failure of passive transfer (Tyler-McGowan *et al.*, 1997). In addition, as the colostral IgG concentration and specific gravity decrease, the proportion of mares that pre-lactate (i.e. start dripping milk before parturition) significantly increase ($P < 0.01$) (Morris *et al.*, 1985).

Intestinal absorption of immunoglobulins rapidly decreases at 24 hours after birth, coinciding with a decrease in the colostral immunoglobulin concentration (Galan *et al.*, 1986). Nevertheless, milk continues to have a moderate concentration of immunoglobulins, mostly synthesized in the mammary gland, throughout lactation (McGuire *et al.*, 1977). The protein content of mares' milk decreases with time, and the normal composition of the milk of the mare is high in carbohydrates, and low in protein and fat (Cuddeford, 2003). The decline in protein content in milk is accompanied by an increase in the volume of milk produced, to ensure the foal receives a high energy intake. Young foals suck for small periods of time and more frequently than older foals (Kohnke, 1999), coinciding with the increase in milk production by the mare in the first two months of life.

French saddle foals need 9, 13, and 15 kg of milk to gain one kilogram of body weight at 1, 4, and 8 weeks of lactation, respectively (Doreau *et al.*, 1988). Subsequently, Martin (1993) found similar data for Australian stock horses kept on pasture. The intake of energy and protein are the factors most likely to affect the growth of the foal (Hoskin & Gee, 2004), and therefore, the requirements are variable depending on the stage of growth. Oftedal *et al.* (1983) reported that at 11 days of age, foals ingested 0.37 g protein and 8.3 kcal for a one-gram increase in body weight, while at 25 days this intake was reduced to 0.26 g protein and 6.7 kcal, and 0.30 g protein and 7.8 kcal at 39 days.

2.4 Development of the placenta

2.4.1 Placenta structure and physiology

The equine placenta is diffuse, epitheliochorial and microcotyledonary. It has three membranes – chorion, allantois, and amnion – that are usually referred to as the allantochorion and the amnion. The chorionic surface of the allantochorion is covered in microvilli that attach to the endometrial epithelium of the uterus of the mare to form microcotyledons (Wilsher & Allen, 2003). The microcotyledon is the basis for nutrient exchange between the mare and foetus through the placenta. They cover the entire surface of the allantochorion and increase the surface area available for haemotrophic exchange across the placental tissues (Wilsher & Allen, 2003). The development of the placenta has been associated with the size of the foal at birth (Allen *et al.*, 2002b).

The microvillous attachment between the allantochorion and the endometrium occurs after day 40 of the pregnancy, as simple undulations in the two epithelial surfaces (Wilsher & Allen, 2003). Fully differentiated microcotyledons (Figure 2.2) become present by day 150 of pregnancy (Samuel *et al.*, 1974, 1975; Wilsher & Allen, 2003), after the elongation, folding and sub-branching of the primary microvilli. In the second half of gestation, the microvilli continue to divide and lengthen (Macdonald *et al.*, 2000). In addition, the foetal and maternal epithelia within the microcotyledons become reduced in height and are actively indented by capillaries on each side to allow for the closest proximity possible between the foetal and maternal circulations (Samuel *et al.*, 1976). This design facilitates the exchange of blood, gases, and small molecules without breaking down epithelial barriers (Steven, 1982).

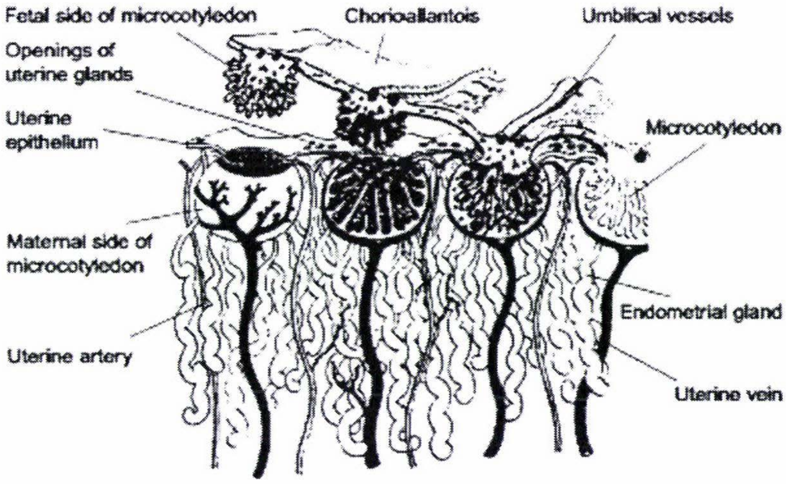

Figure 2.2: *Diagrammatic representation of the structure and vascularization of the mature microcotyledons in the equine placenta (reproduced from Steven and Samuel, 1975)*

The oxygen exchange system of the mare is significantly more efficient than other farm species (Ginther, 1992), as seen by the smaller oxygen gradient between the maternal and foetal sides than in ruminant species. The placental exchange system in the mare possesses a counter-current vascular flow that greatly increases the efficiency of nutrient exchange. The horse is five to seven times more efficient in transfer per unit area than cows or sheep (Wooding and Fowden, 2006), even though the horse has a much smaller area per unit volume (of the foetus plus foetal placenta) (4.4 cm^2/cm^3) than either species (27 cm^2/cm^3 for cows versus 20-23 cm^2/cm^3 for sheep).

The microcotyledons gradually increase in size with the progress of pregnancy, to reach widths of around 0.66 mm in mid-gestation and 1-2 mm at term (Abd-Elnaeim *et al.*, 2003). However, in older subfertile mares, microcotyledon development appeared to be reduced (according to Bracher *et al.*, 1996). In addition, both macrovilli and microvilli were shorter and blunter in older mares than in young fertile mares of the same gestational age (Bracher *et al.*, 1996). Given that foetomaternal exchange is compromised, foetal development is impaired leading to intrauterine growth retardation (IUGR) (Kenney, 1993). A study by Ousey et al. (2004) showed the effects of IUGR on the neonatal foal. Embryos from large TB mares were transferred to smaller P mares, and *vice-versa.* From 34 foals, four were stillborn; three of these were TB-in-P foals. The 'deprived' TB-in-P foals took longer to first stand and suck, some had fetlock hyperextension and low (< 4 g/l) plasma immunoglobulin G concentrations.

In the diffuse equine placenta there is less 'spare' capacity than in the compact placenta (e.g. ewe) (Wooding and Fowden, 2006). Therefore, the horse is more sensitive to deficiencies in the size of the placenta, and the total area of foeto-maternal contact than the sheep. Impaired growth *in utero* is associated with dysmaturity, maladaptation and poor viability of foals at birth, and may have consequences for the health and athletic performance of the mature horse (Rossdale and Ousey, 2002).

The data available on the relationship between the placenta and the birth weight of the foal are limited. Very few studies have compared the development and growth of foals from mares of the same breed, investigating the differences in placenta parameters. Allen *et al.* (2002b) observed that foal birth weight was positively correlated with the mass, gross area, and volume of the allantochorion. Different parts of the uterus show a variation in the size of the microcotyledons (Cottrill *et al.*, 1991), and mares may show varied rates of microcotyledon development throughout gestation. Consequently, it can be expected that the total microscopic area of foetomaternal contact at the placental interface is positively correlated with foal birth weight (Allen *et al.*, 2002b).

2.4.2 Placenta maturation and release of membranes

The separation of the placenta from the endometrium cannot be completed until the foetus is capable of its own oxygenation. The microvilli are probably squeezed apart by uterine contractions during the third stage of labour (Asbury & LeBlanc, 1993). During parturition, the allantochorion is ruptured at the cervical star, allowing the foetus to pass through the birth canal with the amnion intact around it. At this stage, the exchange of nutrient and gases between mare and foetus is minimal. The umbilical cord remains intact during the delivery, and its length enables the foetus to be delivered while the allantochorion is still attached to the endometrium. After delivery, blood flows from the placenta to the foal via the umbilical vein for a few minutes; however, the blood is not highly oxygenated and if the amnion has not been ruptured, the foal will experience hypoxia (Asbury & LeBlanc, 1993).

After foaling, the tension on the allantochorion, caused by the passage of the amnion and umbilical cord through the birth canal, initiates third stage labour (the expulsion of the placenta from the uterine system of the mare). Two complications of the normal process of placental expulsion result in hypoxia (a decreased amount of oxygen in the blood). When the allantochorion fails to rupture at the cervical star, the placenta separates from the endometrium prematurely. Consequently, the mare attempts to deliver the entire foetoplacental unit with the chorion intact. The premature separation of the microcotyledons from the endometrium cause a severe reduction in oxygen to the foetus, and may result in acidosis, hypoglycaemia, as well as renal, intestinal and endocrinologic dysfunction, depending on the length of the insult (Drummond & Koterba, 1990).

The other mechanical complication occurs when the umbilical cord is compressed against the maternal pelvis during parturition. This problem is only significant when the animal is in breach (posterior presentation) because the foaling process is delayed (Asbury & LeBlanc, 1993). Nevertheless, any hypoxia experienced by the foal will potentially affect its development and growth.

2.5 Foetal and neonatal growth and development

2.5.1 Growth

Growth can be defined in the simplest terms as a quantitative increase in the size or mass of an animal in time (Batt, 1980; Bogin, 1988). However, "it is a complex biological phenomenon with no adequately defined direct measure" (Santos *et al.*, 1999). Animal growth is an integration of all aspects of animal science, including nutrition, animal breeding, physiology and meat science (Santos *et al.*, 1999). It also includes the changes in the conformation and shape of an animal that result from the distinct relative growth rates of the different parts of the body (Fowler, 1968). Rapid growth can be detrimental to the horse, as it has been associated with developmental orthopaedic disease, such as osteochondrosis, and epiphysitis (Cymbaluk & Smart, 1993; Staniar *et al.*, 2004a).

To obtain accurate measurements of animal growth rate, there needs to be accurate measures of animal size. The majority of studies of horse growth utilize the measurement of weight, height, chest girth, and the length of the cannon bone (Green, 1976; Hintz *et al.*, 1979). However, the most practical way to measure the size of an animal is to weigh it.

Foetal growth is the result of a variety of genetic, foetal, maternal, and placental factors. The dynamic interaction between these factors, beginning prior to conception, ultimately determines how the foetus develops (Sacks, 2004). In the equine foetus, foetal weight gain increases linearly from day 200 of gestation until parturition (Pantaleon *et al.*, 2003).

Intrauterine growth is a very important factor in the normal development of foals; if it is impaired, it can lead to IUGR. The disturbances that lead to IUGR are infection (placentitis), hypoxia (placental insufficiency), malnutrition, and endocrine dysfunction. In addition, the limiting effect that increasing age has on placentation leads to IUGR of the foetus. Furthermore, primiparous mares produce smaller foals (Wilsher and Allen, 2003). Consequently, we would expect the foals of primiparous and aged mares to have lower birth weights, and therefore, have a greater probability of becoming smaller horses.

The birth weight of the foal is directly proportional to both the weight and area of foeto-maternal contact – the surface across which all the nutrient transfer occurs – of the term placenta (Wooding and Fowden, 2006). The area of foeto-maternal contact is controlled by the interaction of mare age, parity and size, and foetal genotype (Allen et al., 2002b; Wilsher and Allen, 2003).

2.5.2 Factors affecting foetal development

2.5.2.1 Twins

Equine twin embryos that do not undergo reduction during the implantation phase enter the foetal phase intact. However, when twin embryos are allowed to develop both foetuses are likely to die before parturition, or one or both are born weak and undersized (Ginther, 1998). As stated by Rossdale (2004), "the diffuse nature of the equine placenta causes competition to the endometrial surface after about 60 days of gestation". Pascoe (1983) reported that from 130 mares with twins on day 42, only seven foals (13%) were born alive. In addition, in a sample of 15 mares with a conceptus in each horn on day 40, ten mares lost both foetuses, the majority in the second month of gestation, and only one mare (7%) had both foetuses survive until parturition (Ginther & Griffin, 1994).

In order to breed a fully developed foal, one of the embryos in the twin set is killed. Embryo reduction occurs after day 11 of pregnancy (Ginther & Bergfelt, 1988), or after the embryo mobility phase when the embryo attaches to the uterine wall (Ginther, 1984). Occasionally, embryo reduction occurs naturally, and the remaining foal seems normal when the reduction occurs early in the pregnancy (month 2); however, when the reduction occurs late in the pregnancy (month 11), the remaining foal in undersized (Ginther & Griffin, 1994). In the NZTB industry, twin pregnancies are usually reduced - one conceptus is eliminated early in the pregnancy - so that the remaining foal develops fully.

The incidence of multiple ovulations (MO) increases as the mare ages ($p<0.01$) (Morel & O'Sullivan, 2001). Their study was comprised of 828 mares grouped into six age groups: A (2-5 years), B (6-8 years), C (9-11 years), D (12-14 years), E (15-18 years), and F (19-22 years). The proportion of cycles that resulted in MO for each age group were: A 15%, B 19.4%, C 24.6%, D 25.8%, E 28.6% and F35.1%. Therefore, there may be a link between the age of the mare and the incidence of twin pregnancies.

2.5.2.2 Placentitis

Foetal growth and development sometimes occur under abnormal intrauterine conditions. Placentitis is caused by bacterial or fungal agents, and manifests as "proliferative and exudative changes" on the surface of the allantochorion (Asbury & LeBlanc, 1993). Chronic placentitis may interfere with nutrient transport across the placenta, thus leading to placental insufficiency, which means that the placenta fails as a respiratory, nutritive, and endocrine organ. Consequently, the growth and development of the foetus is compromised, resulting in asymmetric IUGR: the head and brain of the foetus develops relatively normal, but its body weight and somatic organs are seriously affected (Pantaleon *et al.*, 2003).

Placentitis has been associated with foetal death or low birth weight live foals (Rossdale, 2004; Whitwell & Jeffcott, 1975). In a study by Rossdale *et al.* (1991 cited in Rossdale, 2004), a small area of the placenta of seven pony mares were separated manually from the endometrium at the cervical pole at 250 days of gestation. Within four to eleven days, plasma progestagen concentrations increased in four of the mares. Pathological changes could be observed in the placentas of three of these mares, and one of them aborted at 287 days of gestation. The other two mares also aborted, at 240 and 271 days; however, they did not show any increase in progestagens in the placenta.

2.6 Thesis objectives

The economic success of the NZTB industry is dependent on the growth of the foal. The maternal factors of age, parity, mare size, and placenta size have been associated with the birth weight of the foal. In addition, mare nutrition has been hypothesized to influence foal birth weight by its effect on mare size.

There is a dearth of data on the interactions of maternal factors with foal birth weight and post-natal growth, and the data available are from Northern Hemisphere horses fed concentrate foodstuffs. The NZTB horse is usually kept at pasture. A study of NZTB horses observed that the birth weight of the foal significantly influences its weight gain until after weaning (Brown-Douglas, 2003). The study showed that both spring-born and autumn born foals exhibited identical growth rate curves for the first six months of life, despite the seasonal influences. A better understanding of how maternal factors influence the birth weight and growth of the foal, under New Zealand pasture conditions, can help improve management practises in the NZTB industry.

The data on the weight of the foal at the time of birth (true birth weight) and before its first sucking is very limited because most studs that weigh their foals, do so on the morning after the foal was born. Since most mares foal at night, the foals are weighed within 12 hours after birth. There is limited scientific data on the true birth weight of the foal and its relationship with the weight on the morning after birth. Furthermore, there is a lack of scientific data on the daily growth of the foal in the first two weeks of life. Most scientific studies only weigh foals in fortnightly intervals from the morning after birth. The daily growth of the foal in those first two weeks is estimated and the growth rate of foals is assumed to be constant.

The main objectives of this study are: (1) to observe the effects of maternal factors (age, parity, weight and height, length of gestation, placenta weight and volume) on the birth weight of the NZTB foal born to mares kept on pasture; (2) to observe the daily growth of the NZTB foal from birth to two weeks of life. Furthermore, the study aims to examine the age and parity distribution within the NZTB mare population, and investigate the role of the sex of the foal on the length of gestation, and foal birth weight.

Chapter 3

Materials and Methods

3.1 Waikato Stud Population

3.1.1 Distribution of mare age and parity, and foal sex ratio

An electronic research was conducted on the New Zealand (Anonymous, 2004b) and Australian (Anonymous, 2004a) TB studbooks. The Australian TB studbook was included because NZTB mares are often sent to Australia to breed for differing amounts of time, and their breeding information during this period is only found in the Australian TB studbook. The electronic research was originally intended to be part of the study, but the records of foal birth weight were lost in a fire, and so the data were used to obtain a significant sample of the age and parity of the mare, and the foal sex ratio in the NZTB population. Data was obtained from 492 mares and their foals born in the 2002 season and sired by the Waikato Stud stallions (Danasinga, O'Reilly, Pins and Centaine).

3.2 Newmarket Lodge Population

3.2.1 Experimental site

3.2.1.1 Location and climate

The study was carried out at Newmarket Lodge Stud & Agistment, a stud farm situated on the outskirts of Palmerston North, in the North Island of New Zealand. Palmerston North is situated about 140 km north of Wellington, in the centre of the Manawatu Plains. Its coordinates are 40.35491°S 175.60951°E.

The climate is temperate, and the average daily maximum temperatures range from 12°C in winter to 22°C in summer. The average annual rainfall is 960mm (Statistics New Zealand, 2006).

3.2.1.2 Pasture

The predominant pasture species in New Zealand, and at Newmarket Lodge, are perennial ryegrass (80-95%) and white clover (5-20%) (Goold *et al.*, 1988; Hoskin & Gee, 2004). This ryegrass-based pasture grows well under New Zealand conditions and provides adequate nutrition to mares during the last trimester of pregnancy and lactation.

3.2.2 Experimental animals

Newmarket Lodge operates as a stud and agistment facility. It has two stallions, and a number of mares are housed at the stud for the foaling season and are served by one of the two stallions after foaling. They return to their owners after they have foaled and conceived again. In the 2004 foaling season, the farm had around 58 New Zealand Thoroughbred mares in foal. Data was collected from 49 of these mares. While some mares were permanently kept at Newmarket Lodge, others were brought to the stud close to the time of foaling. The mares were kept in paddocks and were fed pasture. Management decisions regarding the mares were made by the head groom at the stud, as well as by the stud owner and veterinarian.

The use of animals in this study was approved by the Massey University Animal Ethics Committee, Palmerston North, New Zealand.

3.2.3 Weighing scales

3.2.3.1 Description of the mare and foal platforms

In the field study, two types of platform scales were used to weigh mares and foals. The mare platform consisted of two load cells (Tru-test MP600, Auckland, NZ) underneath a platform and connected to a large display unit (Tru-test AG 500 series, Auckland, NZ) that recorded weights to the nearest 0.5 kg. The portable foal platform had the same load cells (Tru-test MP600, Auckland, NZ), attached to a plywood platform and connected to a smaller display unit (Tru-test Ezy Weight 2, Auckland, NZ) that recorded weights to the nearest 0.1 kg (Figure 3.1).

The accuracy of the foal and mare platforms was checked daily, in the first two months of experimentation, by placing a sealed 21 kg water container on the scales and noting any deviations from the true weight. In the last month of the trial, the 21 kg water container was replaced by 15 kg test weights. The foal and mare weight data was adjusted individually based on the weight of the 21 kg water container or the 15 kg test weight to counteract the inaccuracies with the weighing.

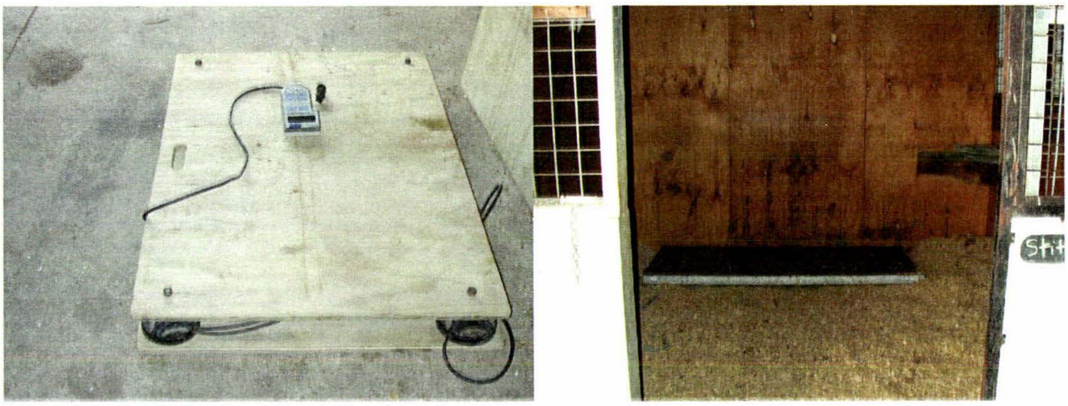

Figure 3.1: *Foal platform (left) and mare platform (right) used in the experiment.*

3.2.3.2 Description of the placenta weighing scales

In this study, counter beam (balance) scales (figure 3.2) were used to weigh the placentas.

Figure 3.2: *Counter beam (balance) scale (Anonymous, 2006f)*

3.2.3.3 Validation of the foal platform

At the beginning of the experimental period, a series of measurements were taken to ensure the scales were weighing correctly. The repeatability of the 21 kg water container was determined for the foal platform in the paddock by obtaining three consecutive measurements. All measurements produced the same value of 20.7 kg. In addition, the 21 kg water container was weighed again on the foal platform, in the paddock, two days later and it weighed 20.8 kg.

3.2.3.4 Validation of the mare platform

The repeatability of the mare platform was measured by obtaining three consecutive measurements of the 21 kg water container. All measurements recorded the same value of 21 kg.

As the foal platform obtained weight values to the nearest 0.1 kg while the mare platform obtained weight values to the nearest 0.5 kg, the reproducibility of the data for the standard weight is high. Therefore, the reliability of the data is high.

3.2.3.5 Validation of the placenta weighing scales

Throughout the experimental period, a series of measurements were taken to ensure all the protocol was accurate and valid. Taking into consideration that the counter beam scales obtained weight values to the nearest 0.001 kg, the reliability of the data is high.

3.2.4 Data collection procedures

3.2.4.1 Age and parity of the mare

The age and breeding information of the mares used in this study were obtained from the online New Zealand Thoroughbred Studbook (Anonymous, 2004b) and the online Australian Studbook (Anonymous, 2004a). Individual mare breeding information is available to the public. The mares were divided in four groups according to their age and parity: primiparous, multiparous (5 to 10 years), multiparous (11 to 15 years), and multiparous (16 years and over).The data collected was used to build an MS Excel (Microsoft Corporation, USA) spreadsheet that would later be analysed in conjunction with the other parameters measured.

The age and parity groups were used to test the age and parity effect on length of gestation (n = 45), foal sex (n = 46), wet weight of the foal (n = 25), day 1 weight of the foal (n = 46), foal height (n = 45), allantochorion weight (n = 46), and allantochorion volume (n = 32). Although the original sample size was 49 mares and foals, there were not 49 observations available for every parameter. In the analysis of the effect of mare age and parity on the length of gestation, only 45 observations were available, as four mares did not have a record of their breeding date, and therefore, the length of gestation of those mares could not be calculated.

One mare did not have a record of her age and parity, while two others did not have a record of their parities. Because of this, the analysis of the effect of mare age and parity on the sex of the foal, day 1 weight of the foal and allantochorion weight only had 46 observations. The height of the first foal to be born during the experimental period was not measured as we did not have a height stick available, and as a result, there are only 45 observations in this analysis. The wet weight of the foal was only obtained from 27 foals because of problems with the foal platform. In addition, two of the dams did not have parity records, and therefore, there are only 25 observations for this analysis. Moreover, the volume of the allantochorion was only available for analysis from 32 placentas because of extensive decay of the tissue at the time of the measurement.

3.2.4.2 Body condition score

The body condition score (C.S.) of mares was recorded in five different days – 09/09/04, 19/09/04, 30/09/04, 07/10/04, and 16/10/04; roughly ten days apart. Although it was planned to record the C.S. every ten days, the dates were adjusted depending on the number of mares present at the Stud, as well as the weather. On those five dates, the C.S. was recorded from pregnant mares that were in the foaling paddock and the paddocks along the driveway to the stable block. The C.S. of each mare was recorded once during the experimental period. The C.S. was measured by condition scoring the neck, withers, rump and tail of mares, using the scale from 1 (very thin) to 5 (very fat)

(Carroll & Huntington, 1988). The average of the four condition scores was calculated and added to the MS Excel (Microsoft Corporation, USA) spreadsheet.

The condition score of 40 mares were recorded, and its relationship with mare pre-foaling weight, post-partum weight, foal day 1 weight and foal sex were analysed. The relationship of the CS of the mare with the wet weight of the foal was also analysed. There were only 23 observations for this analysis since four mares of the 27 whose foals had wet weight measurements did not have their CS measured.

3.2.4.3 Pre-foaling weight of the mare

Prior to foaling, the weights of the mares in the study were recorded with the date of weighing. The time interval between the pre-foaling and the post-partum weight were determined.

The mare platform was set up in a stable box. The date and the name of the mare were spoken into a Dictaphone before the mare was lead into the box and onto the weighing platform. The weight of the mare and the exact time the measurement was taken were recorded on the Dictaphone. The data recorded on the Dictaphone was later transcribed into a notebook and added to the MS Excel (Microsoft Corporation, USA) spreadsheet.

Pre-foaling weight of the mare was measured in 40 mares. It was not available for all 49 mares because some mares arrived at the stud on the same day that they foaled. The effect of the pre-foaling weight on the wet weight (n = 24), day 1 weight (n = 40) and height (n = 40) of the foal was analysed. There were only 24 wet weight observations for this analysis because three mares whose foals had their wet weight measured arrived at stud on the day of foaling, and therefore, did not have their pre-foaling weight recorded.

3.2.4.4 Post-partum weight and height of the mare

Prior to weighing the mare, the scales were tested using a known weight. The mare was then led onto the scales, and her name, weight and the time were then recorded on the Dictaphone. The mare was then led onto a flat concrete surface and her height at the withers was measured with a height stick. The measurement was recorded on the Dictaphone and later transferred to the MS Excel (Microsoft Corporation, USA) spreadsheet.

The post-partum weight and height of the mare was only available for 46 mares. The first two mares to foal during the foaling season at the stud could not be measured as the equipment was not fully set up, and one other mare did not have a record because of technical problems with the recording device. The post-partum weight of the mare was analysed in terms of its relationship with the wet weight (n = 26), day 1 weight (n = 46), and height (n = 46) of the foal, as well as the weight (n = 45) and volume (n = 31) of the allantochorion.

Due to technical problems with the recording device that resulted in the absence of the post-partum weight record for one mare, the corresponding wet weight and allantochorion volume observations could not be used in the analysis. In the analysis with the weight of the allantochorion, two observations could not be included since there were no records of the post-partum weight of the mare for the reasons explained previously.

3.2.4.5 Foal birth weight data

3.2.4.5.1 Foaling procedure

The mares showing signs of foaling (pacing, anti-social behaviour, and waxing udder) were equipped with a foaling alarm on their halters, and were taken to a foaling paddock. When the alarm went off, it was switched off and switched back on again to ensure that it was not a false alarm. If the alarm was still sounding when switched back on, the date and time were recorded on the Dictaphone. The mare was then spotted with a flashlight and the veterinarian was called. A foaling kit, containing ropes, anti-tetanus injection and iodine spray, was taken into the foaling paddock, and the mare was assisted with foaling. As soon as the foal hit the ground, the name of the mare, time and sex of the foal were recorded on the Dictaphone. Subsequently, the mare and foal were given post-partum and post-natal care, respectively.

After foaling, the mare was checked every hour to determine if the placenta had been passed and if the foal was feeding. Once the placenta was passed, it was collected and sealed in a bucket labelled with the name of the mare, and then taken to the washing bay for measurements.

3.2.4.5.2 Day 0 birth weight data collection (Wet weight)

Within 30 minutes of birth, the foal weighing platform was brought into the foaling paddock and placed beside the foal, on the flattest surface possible. The scales were turned on and zeroed before the experimenter stepped onto the scales and recorded her own weight to the nearest 0.1 kg. With the help of the veterinarian, the foal was then lifted onto the scales and its weight and the time were recorded. After that, the foal was slipped back onto grass and the foal platform was taken back into the stable block and placed on concrete. The scales were turned on and zeroed before the experimenter recorded her own weight on concrete to be able to compare with her weight in the paddock. In addition, the standard weight was subsequently weighed on the foal platform on a concrete surface.

3.2.4.5.3 Day 1 birth weight and height data collection (Day 1 weight)

On the morning following foaling, the load cells were transferred to the mare weighing platform. After the scales were turned on and zeroed, they were calibrated by placing the standard weight in the middle of the platform and recording any inaccuracies with the measurement. The foal was subsequently lead onto the mare platform, ensuring all four limbs were entirely on the platform, and weighed to the nearest 0.5 kg. The time of the weighing was recorded. The height at the withers of the foal was then measured by leading the mare and foal onto a flat concrete surface, standing the foal squarely, and using a height stick to obtain the measurement.

In the analysis of the difference between the wet birth weight and day 1 weight of the foal (Figure 4.24 on page 68), two values (A and B) were excluded from the data set because the weight gains in 24 hours were not plausible for a 50 to 66 kg foal. Mare A foaled on a stormy night and the foal had difficulty standing and feeding. However, they were only moved into a box in the morning and, with assistance, the foal consumed a large quantity of milk just before weighing. In addition, the foal was still very wet when it was weighed. Mare B, foaled early in the morning (4.26 am) on a rainy day, therefore, the two weight measurements of the foal were only five hours apart. The foaled sucked well but did not pass faeces before the weighing. In addition, it was still wet at the time of weighing.

3.2.4.6 Length of gestation data

The length of gestation was calculated from the last breeding date and the foaling date. The results were added to the MS Excel (Microsoft Corporation, USA) spreadsheet.

The relationship of the length of gestation with the wet weight (n = 26) and the day 1 weight (n = 45) of the foal, and foal sex (n = 45) was analysed. The length of gestation could not be calculated for four mares because there was no record of their breeding date. That is why there were only 26 observations in the analysis for the wet weight of the foal and 45 observations for the sex and day 1 weight of the foal.

3.2.4.7 Placenta size data

The size of the placentas from 47 mares was recorded. To obtain an accurate assessment of the size of the placenta, more than one parameter must be measured. Therefore, in this study, the weight, and volume of the allantochorion were measured.
The reason why only 47 placentas were measured was that two of the placentas were missing pieces as they had been retained by the mare.

3.2.4.7.1 Day 0 weight

The placenta was weighed within one hour of it being expelled. Subsequently, the amnion and the umbilical cord were separated from the allantochorion and the allantochorion was weighed. The allantochorion was placed in the weighing bucket, and put on the scales. The weight of the allantochorion and time the measurement was taken was recorded on the data collection sheet. The allantochorion was then placed in the tagged bucket and the process was repeated two more times. After weighing the allantochorion, the amnion and umbilical cord were weighed together. The weight and the time the measurement was taken were recorded. Lastly, the allantochorion was returned to the tagged bucket, which was sealed with an airtight lid. The amnion and umbilical cord were discarded.

The relationship between the weight of the allantochorion and the wet weight (n = 27) and day 1 weight (n = 47) of the foal was analysed.

3.2.4.7.2 Volume

3.2.4.7.2.1 Method 1 – Weight of water displaced method

A large plastic tray was placed on top of the scales and its weight was recorded. Subsequently, a five litre polypropylene jug was placed inside the tray (Figure 3.3). The jug was then filled with water until it was about to overflow. Slowly and carefully, both pieces of the allantochorion were placed inside the jug, making sure no air pockets were formed, the allantochorion was completely submerged, and that all the water coming down was going into the tray. After waiting a few minutes for the water to stop dripping into the tray, the jug was taken away without spilling any more water into the container. The weight of the water displaced into the tray was recorded, and the volume was calculated following the assumption that one kilogram equals one litre. The allantochorion was then returned to the bucket, and the water in the tray was discarded. After the tray was dried off, the process was repeated four more times.

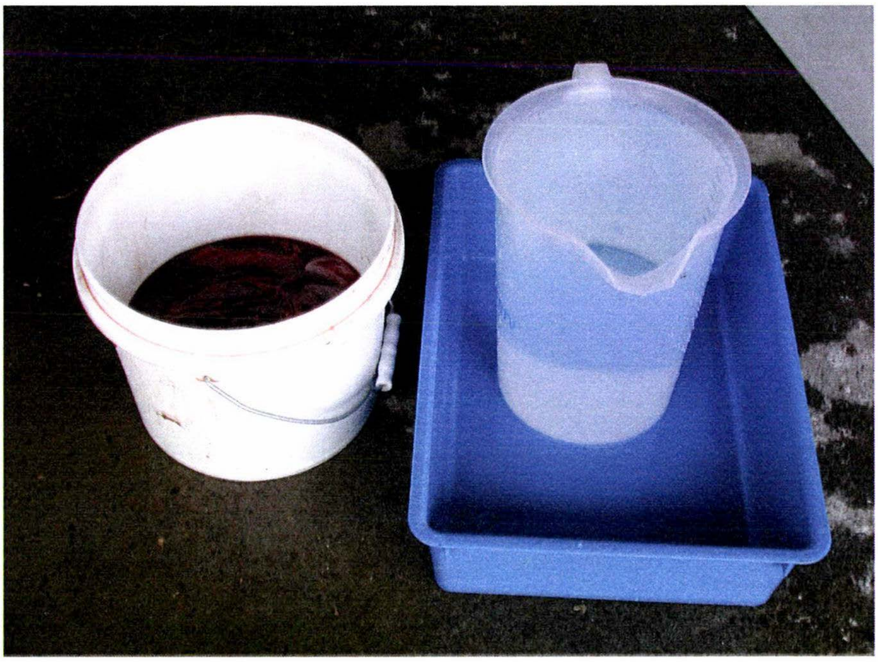

Figure 3.3: *Set up of method 1 to measure the volume of the allantochorion*

3.2.4.7.2.2 Method 2 – Water displacement method

The five-litre jug was half-filled with water before being placed on the scales. The weight of the jug and water was recorded on the data collection sheet. The left half of the allantochorion was immersed into the jug, slowly and carefully, to avoid air spaces being formed underneath the allantochorionic tissue. Subsequently, when the allantochorion was completely submerged, the water displacement was read on the side of the jug, and the weight of the jug, water and allantochorion was recorded. The allantochorion was then removed from the jug, which was refilled to the 2.5 litre mark before the right half of the allantochorion was placed in the jug, slowly and carefully, to avoid air pockets being formed underneath the allantochorionic tissue. The water displacement was measured when the allantochorion was completely submerged. In addition, the weight of the jug, water, and allantochorion was recorded. The allantochorion was then removed from the jug and returned to its bucket. The whole process was repeated four more times to ensure repeatability.

As previously mentioned, the volume of the allantochorion was only available for analysis from 32 placentas because of extensive decay of the tissue at the time of the measurement. This included some of the placentas of the foals who had wet weight records, and therefore, only 22 observations were available for this analysis. In addition, 32 records were available for the analysis with the day 1 weight of the foal.

3.2.4.8 Longitudinal study – foal growth

In addition to the birth weight data, a longitudinal study was carried out to investigate the rate of growth of foals in the first fourteen days after parturition. The population of the study comprised 15 mares and their foals. The first mare foaled on the 14/10/04, while the last mare foaled on 14/11/04; therefore, the study continued until the 27/11/04.

After the day 1 weight of foals was recorded, most of the mares and foals were turned onto pasture and were no longer a part of the study. However, for these 15 mares and foals, the weighing continued for another two weeks. The mares and foals were weighed as on day 1 after birth. Weighing occurred at a similar time of the day. The height of the foal was also measured everyday. The mares were weighed, as in the protocol for post-partum weight to determine whether their weight varied.

3.3 Statistical analysis

Regression models were fitted to describe the relationships between maternal parameters (age, parity, size, placenta size, and length of gestation) and foal parameters (foal sex, birth weight, height, and daily growth from birth to 14 days of age). Correlations between mare age and parity, mare weight and foal size, and CS and mare weight were analysed. Linear regression was used to calculate the ADG of foals from the relationship of age and liveweight of each foal. Statistical analyses were performed using SAS (SAS Institute, Inc., Cary, NC, USA). Means ± SEM are presented throughout, and the level of significance was set at $p=0.05$.

Chapter 4

Results

4.1 Limitations in weight measurements

It is important to note that throughout the length of the experiment, the weight recorded for the standard weight (21 kg water container) – used in both foal and mare platforms – gradually decreased (Figure 4.1) until the container was accidentally emptied. Subsequently, a 15 kg test weight was used to calibrate the scales. To counteract the inaccuracies with the weighing, the weight data for mares and foals was adjusted individually, based on the weight of the 21 kg water container or the 15 kg test weight on the day of the measurement.

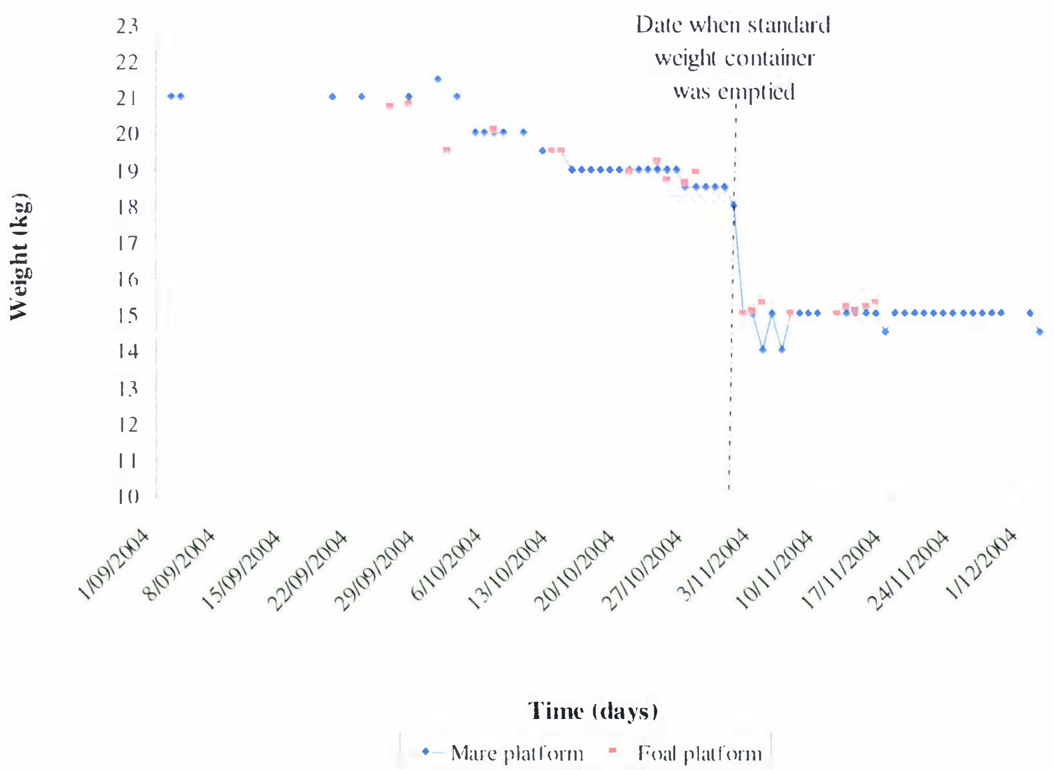

Figure 4.1: Change in weight recorded daily for the standard weights used during the experiment in both the mare platform and the foal platform.

4.2 Distribution of mare age and parity, and foal sex ratio

4.2.1 Waikato Stud sample population

The range of NZTB mare ages in the Waikato Stud sample population ranged from three to 26 years, and the distribution was skewered to younger mares (Figure 4.2). The mean age was 11.00 ± 0.20 years (mean ± S.E.M.).

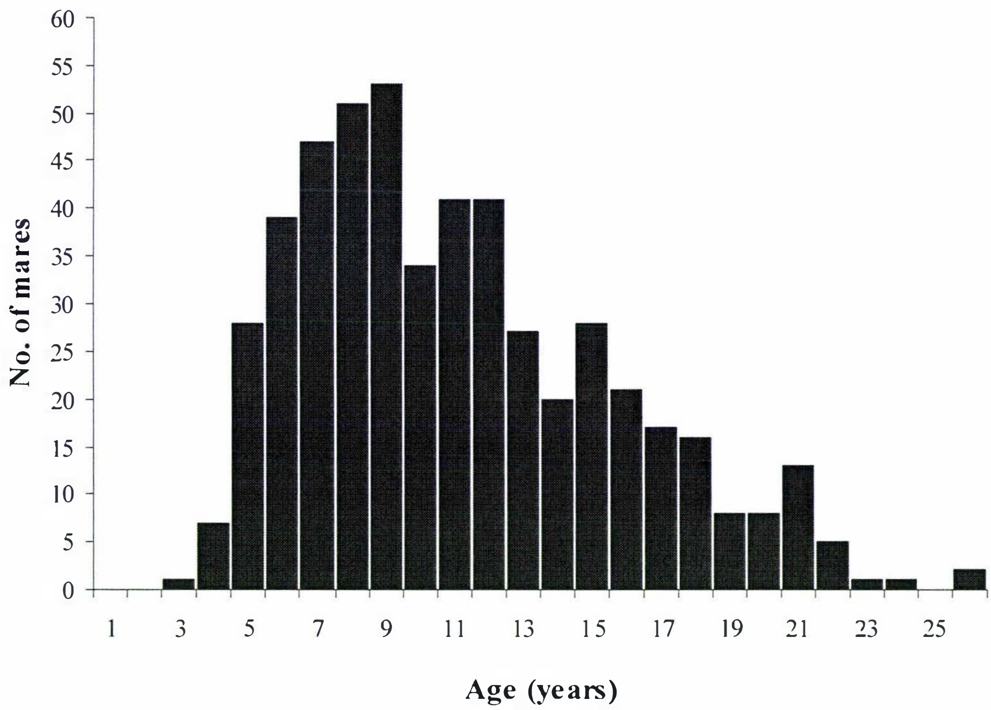

***Figure 4.2**: The age distribution of Waikato Stud sample population mares (data obtained from some mares bred to Waikato Stud sires – Centaine, Danasinga, Pins, and O'Reilly – in the 2002 breeding season)*

The mean parity of mares in the Waikato Stud sample population was 5.90 ± 0.18 (mean ± S.E.M), and the median was five. The parity in this population ranged from one to 22, and the distribution was skewered to lower parities (Figure 4.3).

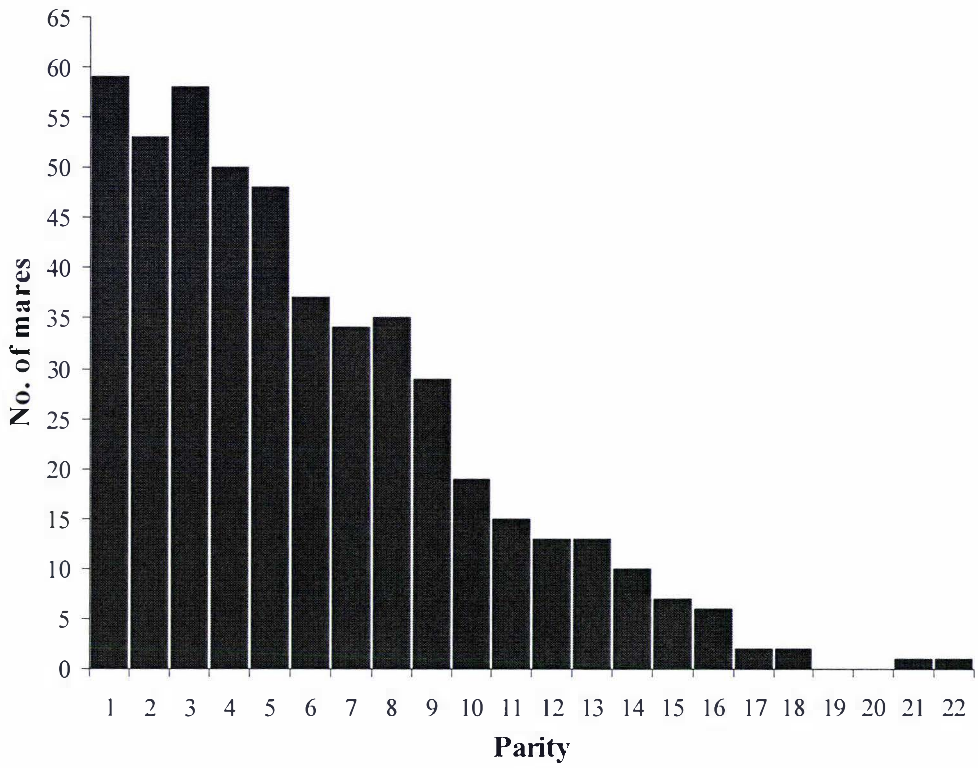

Figure 4.3: *Parity distribution of Waikato Stud sample population mares (data obtained from some mares bred to Waikato Stud sires – Centaine, Danasinga, Pins, and O'Reilly – in the 2002 breeding season)*

Mare age and parity in the Waikato Stud sample population were highly correlated (correlation coefficient = 0.88; Figure 4.4). In addition, the proportion of fillies and colts in the Waikato Stud sample population was 50.3% and 49.7%, respectively.

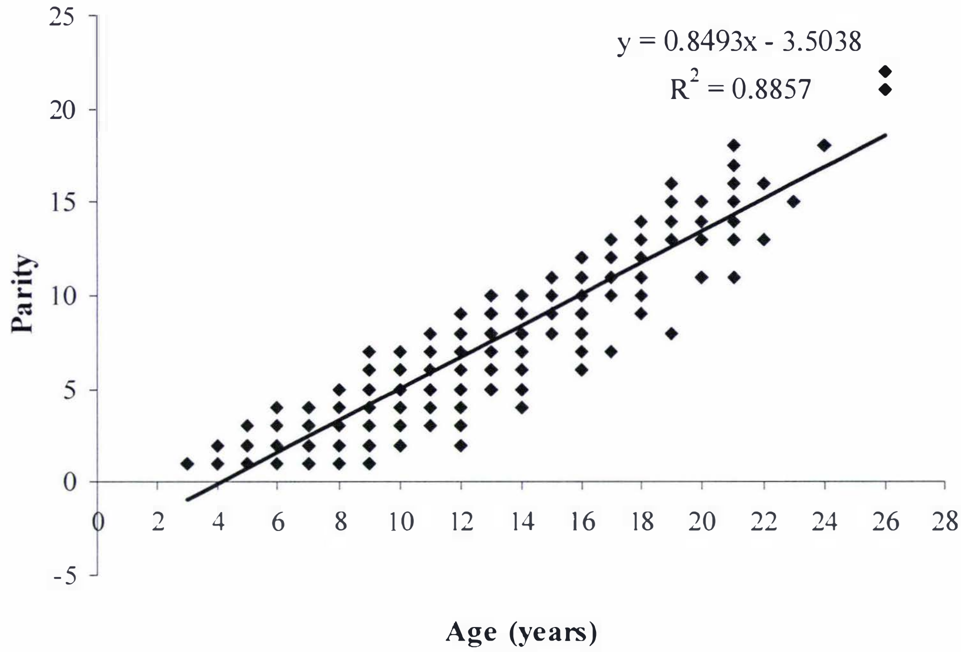

***Figure 4.4:** The correlation between age and parity of mares in the Waikato Stud sample population*

4.2.2 Newmarket Lodge population

A total of 57 mares foaled during the 2004 foaling season at Newmarket Lodge. Data was collected from the 49 mares that foaled between 01/09/04 and 01/12/04.

The age distribution of these mares (n = 49) did not follow a normal distribution pattern (Figure 4.5). The mean age of mares was 10.80 ± 0.85 years (mean ± S.E.M). Their age ranged from five to 19 years.

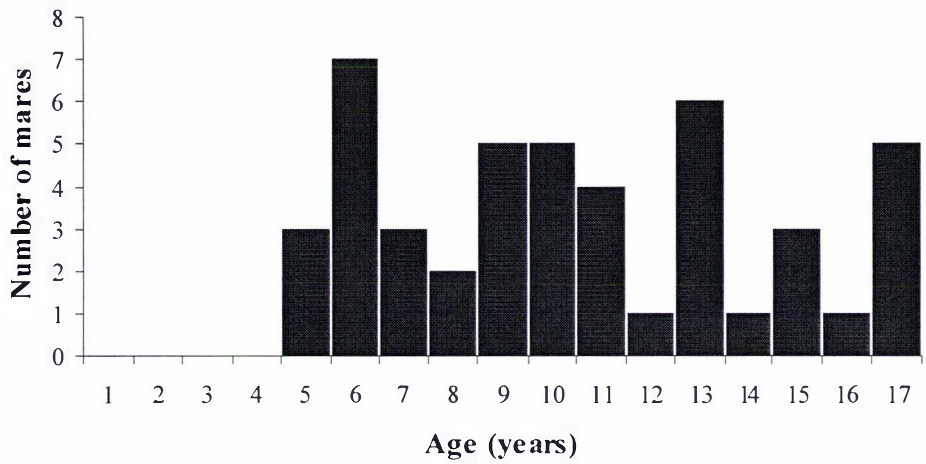

Figure 4.5: *Age distribution of Newmarket Lodge mares*

The mean parity within the Newmarket Lodge population was 4.50 ± 0.41 (mean ± S.E.M) and the median was four. There was an inverse relationship between parity and the number of mares (Figure 4.6). Most mares in the Newmarket Lodge population were up to their fourth parity, and there were very few mares were over their ninth parity. The range of parities within the Newmarket Lodge population was from one to 13. Mare age and parity were highly correlated (correlation coefficient = 0.84) (Figure 4.7).

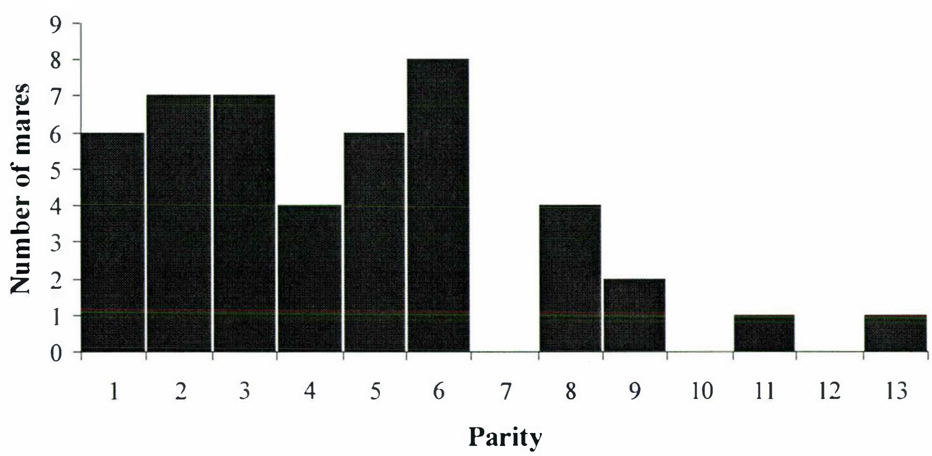

Figure 4.6: *Parity distribution of Newmarket Lodge mares*

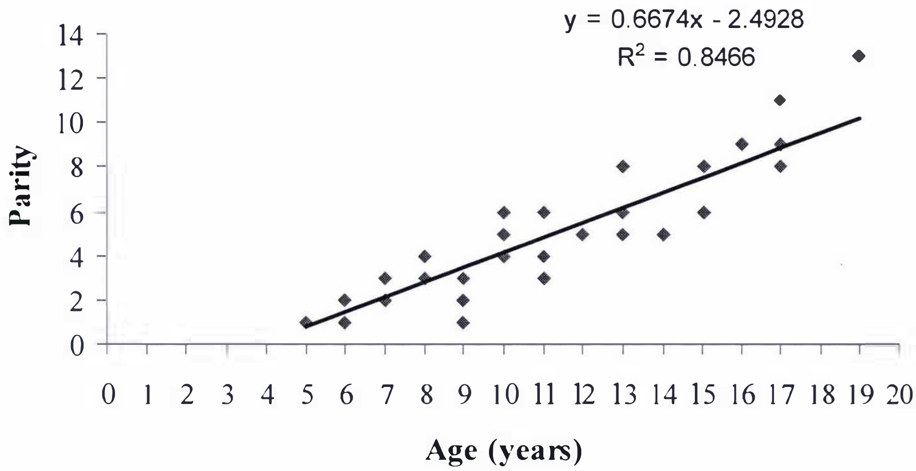

Figure 4.7: *The correlation between age and parity of mares in the Newmarket Lodge population*

The effect of parity on the sex of the foal was investigated, and it differed considerably between the Newmarket Lodge and Waikato Stud populations (Table 4.1), reflecting the difference in population size.

Table 4.1: *A comparison of the sex ratio between the Newmarket Lodge and Waikato Stud populations according to the parity of the mare*

	Newmarket Lodge		Waikato Stud sample	
	Filly	***Colt***	***Filly***	***Colt***
Primiparous	50.0%	50.0%	47.0%	53.0%
Multiparous	60.5%	39.5%	50.8%	49.2%
Total	41.0%	59.0%	50.3%	49.7%

4.3 Effect of mare age and parity on length of gestation, placenta size, and foal sex ratio and birth size

The age and parity of 46 mares of the Newmarket Lodge population were analysed in terms of their effect on length of gestation, sex of foals, and foal birth weight and height.

The length of gestation was not significantly (P = 0.32) affected by the age and parity of the mares (Table 4.2). In addition, the month of birth of the foal did not significantly (P = 0.89) affect the length of gestation of the mare. The mean length of gestation was 355.67 ± 1.26 days, and ranged from 338 to 375 days.

There was a negative relationship between gestation length and the wet birth weight of the foal (P = 0.01, n = 22; Figure 4.8) but not between gestation length and the day 1 weight of the foal (P = 0.24, n = 45; Figure 4.9). Mares with longer gestation periods gave birth to lighter foals than mares with shorter gestation periods. However, the correlation coefficient (R^2) was 0.25.

Table 4.2: *The mean length of gestation of mares in the Newmarket Lodge population according to age and parity*

	Length of gestation Mean ± S.E.M.
Primiparous (n = 4)	360.25 ± 3.68
Multiparous (5 – 10 years old) (n = 19)	353.05 ± 1.75
Multiparous (11 – 15 years old) (n = 14)	356.85 ± 2.44
Multiparous (≥16 years old) (n = 8)	357.37 ± 3.33
Significance	P = 0.23

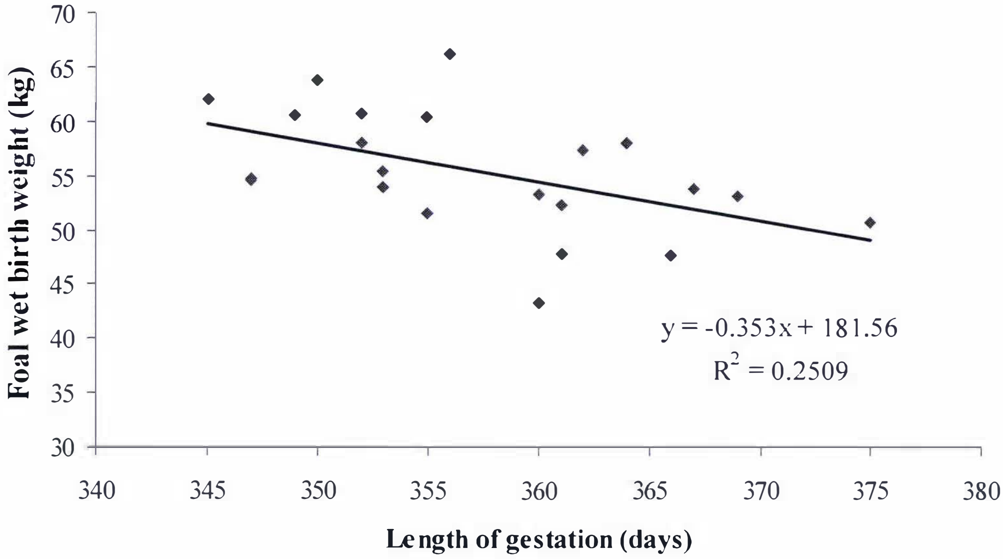

Figure 4.8: The relationship between length of gestation and the wet birth weight of the foal

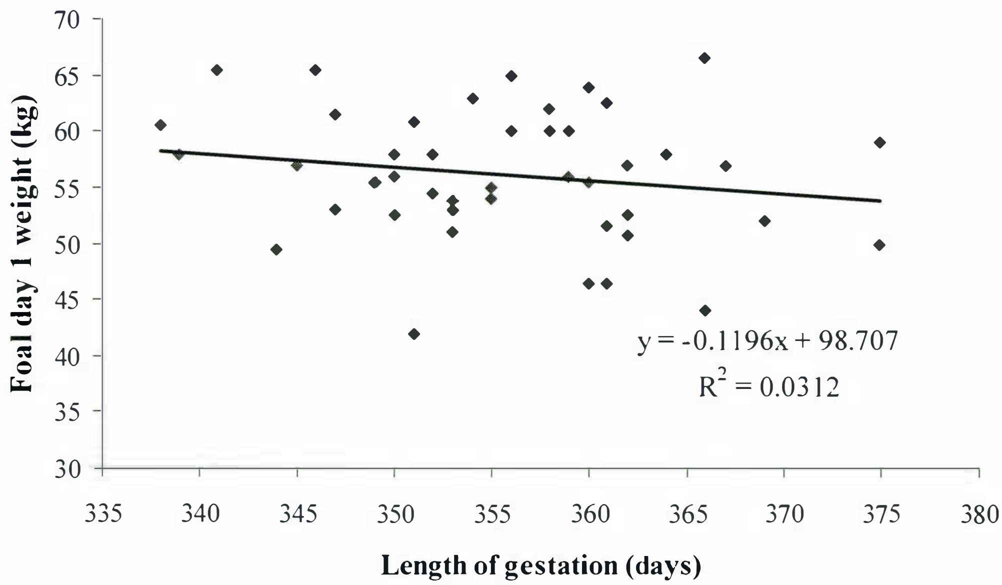

Figure 4.9: The relationship between length of gestation and the day 1 weight of the foal

In the Newmarket Lodge foals, the proportion of fillies and colts was 41% and 59%, respectively. The age and parity of the mare did not affect the number and sex ratio of foals (P = 0.07 and P = 0.83, respectively; Table 4.3).

Table 4.3: *The number and proportion of colts and fillies according to the age and parity of the mare in the Newmarket Lodge population*

	Number of foals		**Sex ratio**	
	Filly (n = 19)	***Colt (n = 27)***	***Filly***	***Colt***
Primiparous	3	3	0.5	0.5
Multiparous (5 – 10 years old)	7	12	0.37	0.63
Multiparous (11 – 15 years old)	6	9	0.4	0.6
Multiparous (≥16 years old)	3	3	0.5	0.5
Significance	P = 0.07		P = 0.83	

The age and parity of the mare influenced the birth weight (wet weight) and day 1 weight of the foal. There was a trend between the age and parity of the mare and the wet weight of the foal (P = 0.095), while the day 1 weight of the foal was significantly (P = 0.001) affected by the age and parity of the mare (Table 4.4).

Table 4.4: *The wet weight and day 1 weight of the foal according to the age and parity of the mare in the Newmarket Lodge population*

Age and Parity groups	**Wet weight (kg) Mean ± S.E.M.**	**Day 1 weight (kg) Mean ± S.E.M.**
Primiparous	48.82 ± 2.51^{a}	47.25 ± 2.29^{a}
Multiparous (5 – 10 years old)	55.81 ± 1.56^{b}	56.71 ± 1.11^{b}
Multiparous (11 – 15 years old)	55.72 ± 1.82^{b}	57.38 ± 1.45^{b}
Multiparous (≥16 years old)	57.80 ± 3.52^{b}	57.75 ± 2.10^{b}

Means in each column with different superscripts ^{abc} differ significantly from each other (P<0.05)

The wet weight of foals born to primiparous mares was significantly ($P = 0.012$) lighter than foals born to multiparous mares. Furthermore, foals of primiparous mares were significantly ($P < 0.005$) lighter on day 1 than foals of multiparous mares (Figure 4.10). The weights of foals on day 1 ranged from 41 kg to 66.5 kg. The age of the multiparous mare had no significant ($P > 0.6$) effect on the wet weight and day 1 weight of foals.

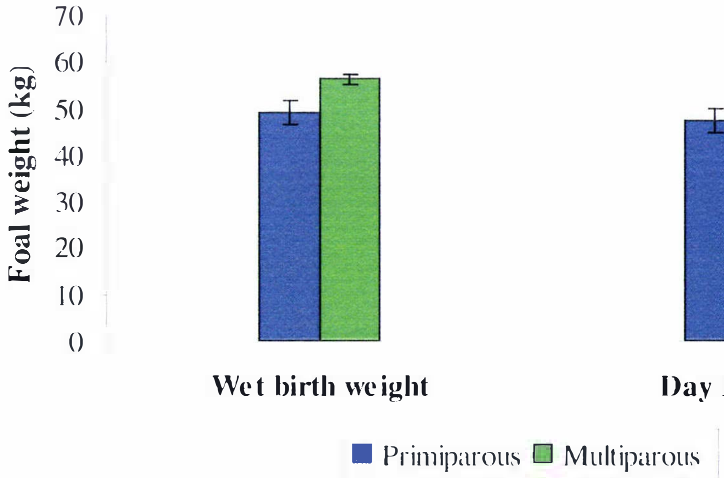

Figure 4.10: *Mean (± SEM) wet weight and day 1 weight of foals according to the parity of the mare*

The mean foal height at birth was 1.028 ± 0.004 m. The height of the foal at the time of birth was significantly affected ($P = 0.0053$) by the age and parity of the mare (Table 4.5). Primiparous mares had significantly ($P = 0.0003$) shorter foals than multiparous. The height of the foals born to multiparous mares, 11 to 15 years of age, was not significantly ($P > 0.8$) different from the height of foals produced by multiparous mares in the other age groups. However, a trend ($P = 0.082$) in foal height was observed between multiparous mares aged between five and ten years and multiparous mares aged 16 and over.

***Table 4.5:** The mean foal height at birth according to the age and parity of mares*

Age and Parity groups	Foal height at withers (m) Mean ± S.E.M.
Primiparous (n = 6)	0.991 ± 0.010 [a]
Multiparous (5 – 10 years old) (n = 19)	1.034 ± 0.004 [b]
Multiparous (11 – 15 years old) (n = 14)	1.034 ± 0.009 [b,c]
Multiparous (≥16 years old) (n = 6)	1.038 ± 0.006 [c]
Significance	P = 0.0053

Means with different superscripts [abc] differ significantly from each other (P<0.05)

The age and the parity of the mare significantly affected the weight of the AC. Primiparous mares (P = 0.003) and multiparous mares aged 16 years and over (P = 0.04) had smaller AC weights than multiparous mares aged five to 15 years. The AC volume was also affected significantly by parity, but not by age. Primiparous mares had lower AC volumes (P = 0.001) than multiparous mares. Furthermore, the volume of the AC from multiparous mares aged 16 and over were slightly (P = 0.07) lower than the volume of the AC from mares aged five to 15 years. There were no statistically significant (P = 0.23) differences in the weight and volume of the AC between primiparous mares and multiparous mares aged 16 years and over (Table 4.6).

***Table 4.6:** The weight and volume of the allantochorion according to the age and parity of the mare*

Age and Parity groups	Allantochorion weight (kg) Mean ± S.E.M.	Allantochorion volume (l) Mean ± S.E.M.
Primiparous	2.95 ± 0.15 [a]	2.33 ± 0.13 [a]
Multiparous (5 – 10 years old)	3.83 ± 0.14 [b]	3.07 ± 0.06 [b]
Multiparous (11 – 15 years old)	3.93 ± 0.15 [b]	2.97 ± 0.11 [b]
Multiparous (≥16 years old)	3.35 ± 0.23 [a]	2.69 ± 0.24 [b]
Significance	P = 0.003	P = 0.004

Means within a vertical column with different superscripts [ab] differ significantly from each other (P<0.05)

4.4 Effect of mare size on foal birth weight, height and sex

The weight and height of 40 mares in the Newmarket Lodge population were obtained before foaling. A further six mares foaled on the same day they arrived at the stud and were measured thereafter. The average size of mares in the Newmarket Lodge population was summarized in table 4.7. The morning after foaling, the weight had decreased by 80.90 ± 2.88 kg (range 42 to 115 kg). The height of the mare ranged from 1.50 to 1.78 m.

Table 4.7: *Mean size of mares in the Newmarket Lodge population*

	Mean ± S.E.M.
Pre-foaling weight (kg) (n = 40)	618.92 ± 7.92
Post-partum weight (kg) (n = 46)	542.93 ± 6.17
Body condition score (n = 42)	2.60 ± 0.03
Height (m) (n = 46)	1.615 ± 0.006

The pre-foaling weight of the mares (Figures 4.11 to 4.13) was significantly associated with the wet birth weight ($P = 0.011$), day 1 weight ($P < 0.005$) and height ($P < 0.005$) of the foal. Furthermore, the post-partum weight of the mare (Figures 4.14 to 4.16) was significantly correlated with the wet birth weight ($P = 0.02$), day 1 weight ($P < 0.02$) and height ($P < 0.01$) of the foal.

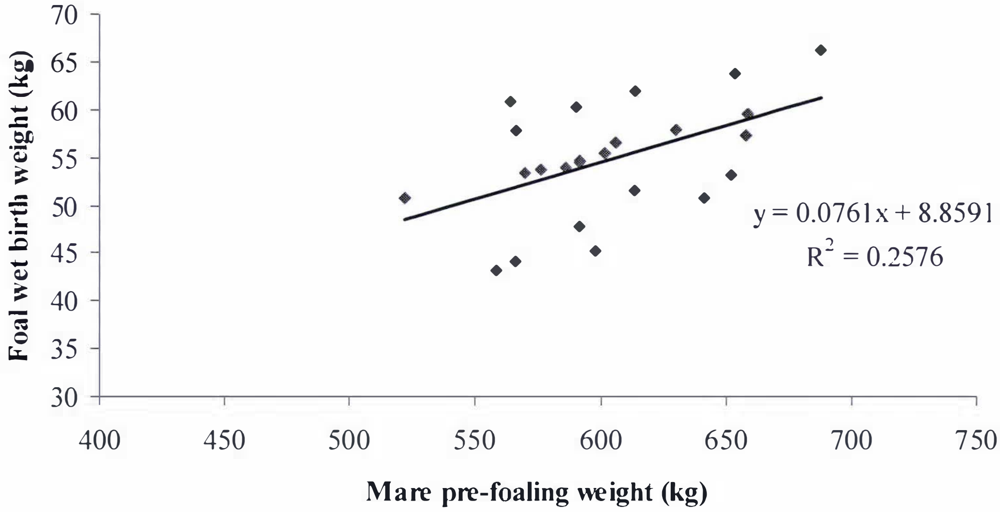

Figure 4.11: *The relationship between mare pre-foaling weight and foal wet birth weight*

The CS of the mare was not significantly correlated with the weight of the mare pre- and post-partum (P = 0.21 and 0.17, respectively). In the study population, the CS ranged from 2.00 to 3.25, and the median was 2.75. The CS of the mare did not significantly influence the wet birth weight of the foal (P = 0.42) and the day 1 weight of the foal (P = 0.74). In addition, the sex of the foal was not affected by the CS of the mare (P = 0.96). The mean CS of mares that produced fillies was 2.70 ± 0.06, and of mares that produce colts was 2.70 ± 0.05.

The weight of the mare pre- and post-partum did not significantly influence the sex of the foal (P = 0.25 and 0.18, respectively). The pre-foaling weight was 630.12 ± 13.97 kg for mares that produced fillies and 611.44 ± 9.30 kg for mares that produced colts. Furthermore, the post-partum weight was 553.23 ± 11.48 kg for mares that produced fillies and 536.31 ± 6.84 kg for mares that produced colts.

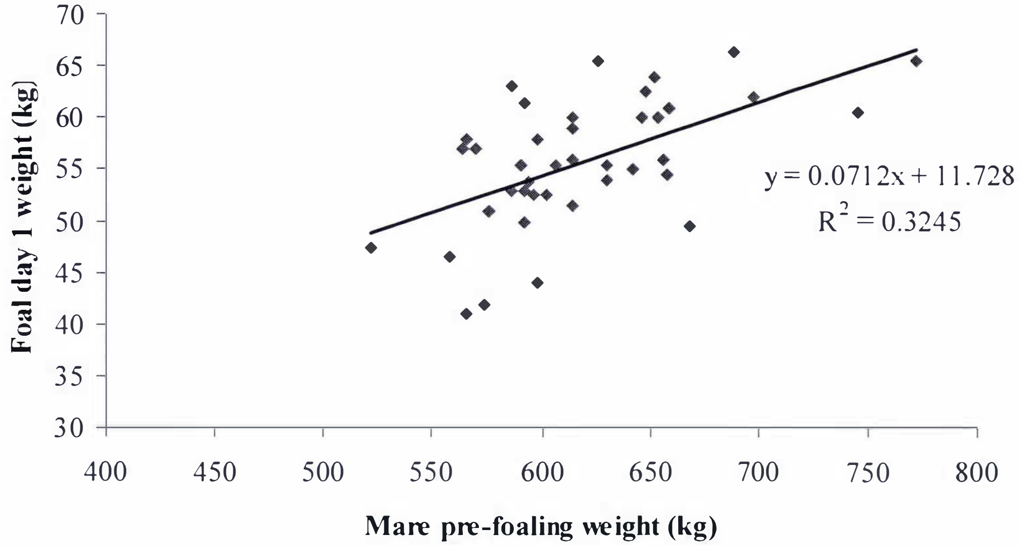

Figure 4.12: *The relationship between mare weight pre-foaling and foal day 1 weight*

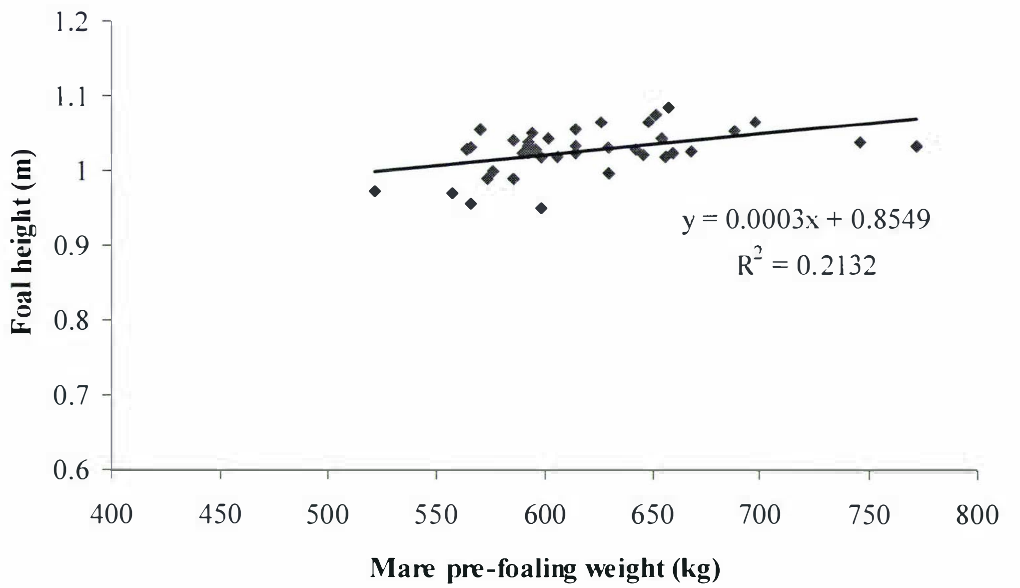

Figure 4.13: *The relationship between mare weight pre-foaling and foal height*

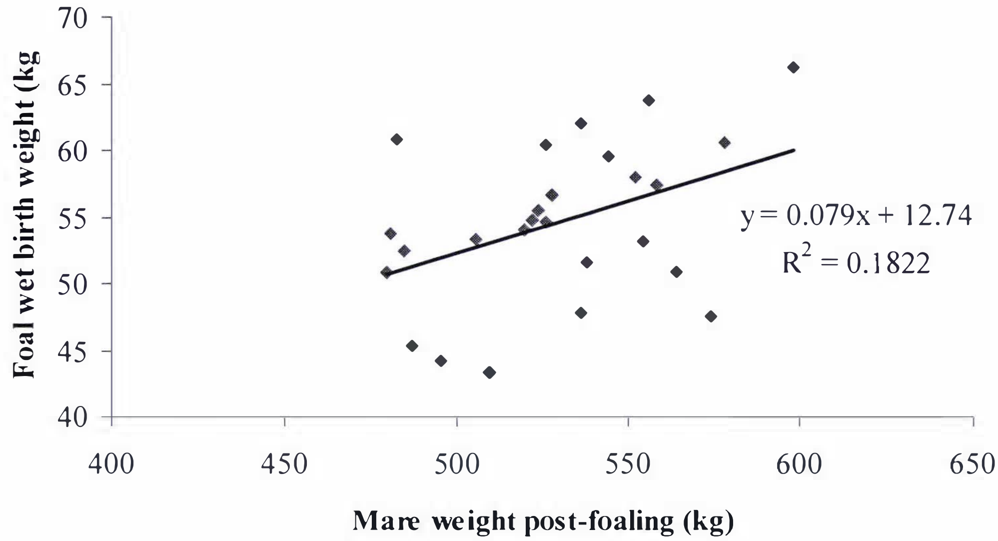

Figure 4.14: *The relationship between mare weight post-partum and foal wet birth weight*

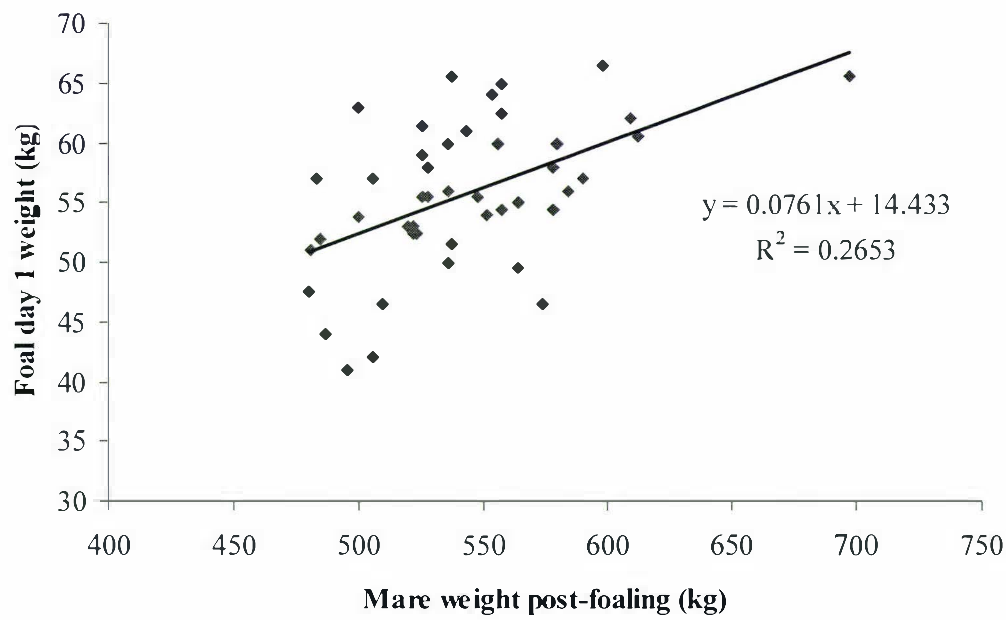

Figure 4.15: *The relationship between mare weight post-partum and foal day 1 weight*

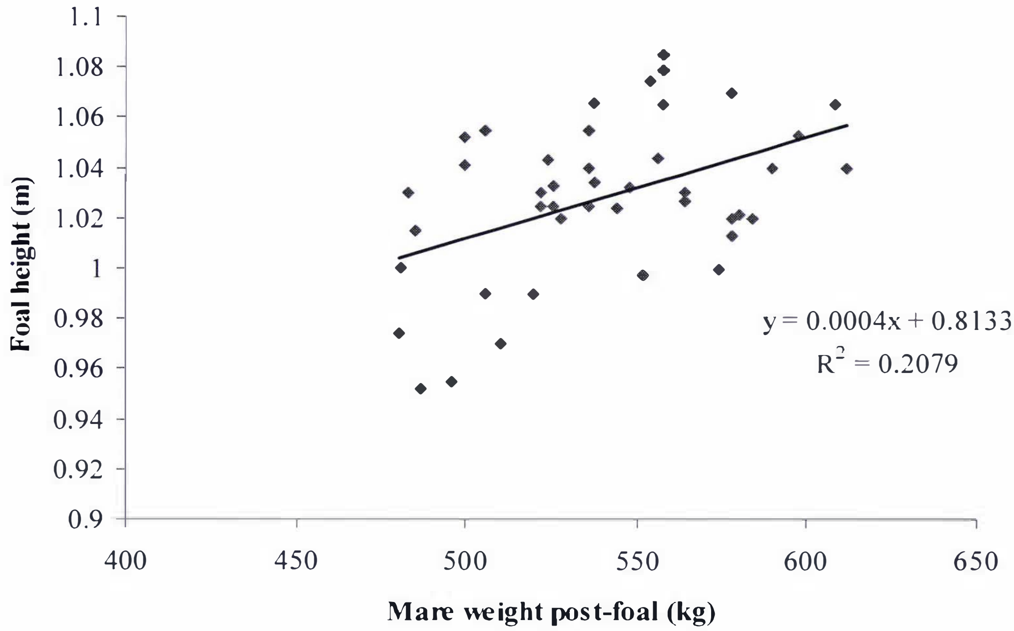

Figure 4.16: The relationship between mare weight post-partum and foal height

The height of the mare had no significant effect (P = 0.72) on the day 1 weight of the foal (Figure 4.17). Furthermore, the height of the foal was not significantly influenced (P = 0.12) by the height of the mare.

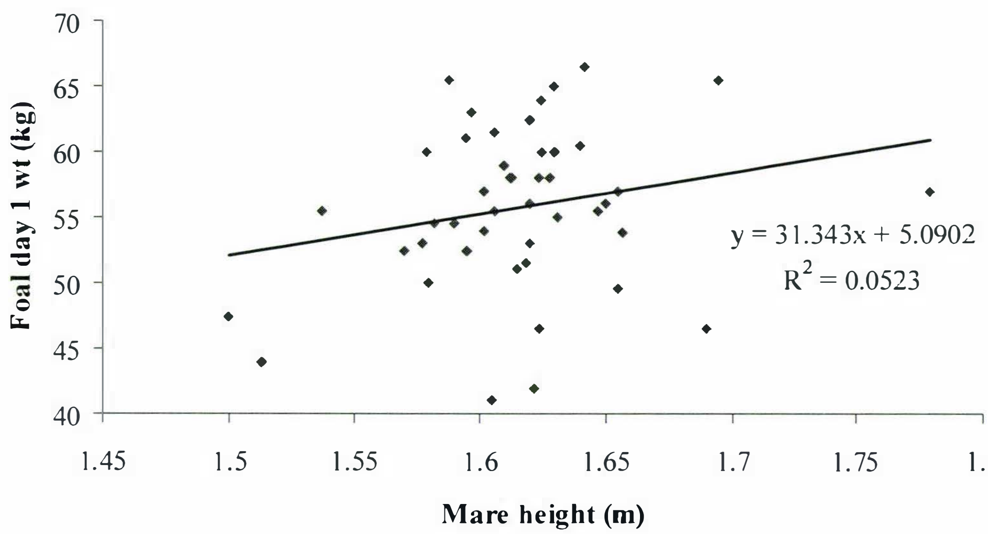

Figure 4.17: The relationship between mare height and day 1 weight of the foal

The weight of the mare was not significantly associated with the weight (P = 0.13) and volume (P = 0.51) of the AC. In addition, the CS of the mare did not significantly affect the weight (P = 0.75) and volume (P = 0.69) of the AC. Therefore, there is no relationship between the weight of the mare and the size of the AC.

4.5 Effect of allantochorion size on the birth weight of the foal

The allantochorions from 47 mares in the Newmarket Lodge population were weighed, and the volume of the allantochorion was measured from 32 mares. The mean allantochorion weight on day 0 was 3.68 ± 0.09 kg, and the mean allantochorion weight on day 1 was 3.66 ± 0.09 kg. Allantochorion (AC) weight on day 0 was highly correlated with (correlation coefficient = 0.993) with the AC weight on day 1 (Figure 4.18). Mare A had a lower weight of the AC at the end of third stage labour than on day 1. Upon closer inspection, it was established that there was an error with the first weight measurement (day 0). The weight of the AC on day 0 should equate to the difference between the weight of the whole placenta and the weight of the amnion and umbilical cord, also measured on day 0), and in this case, the weight of the AC should be equal to the value for the weight of the AC on day 1.

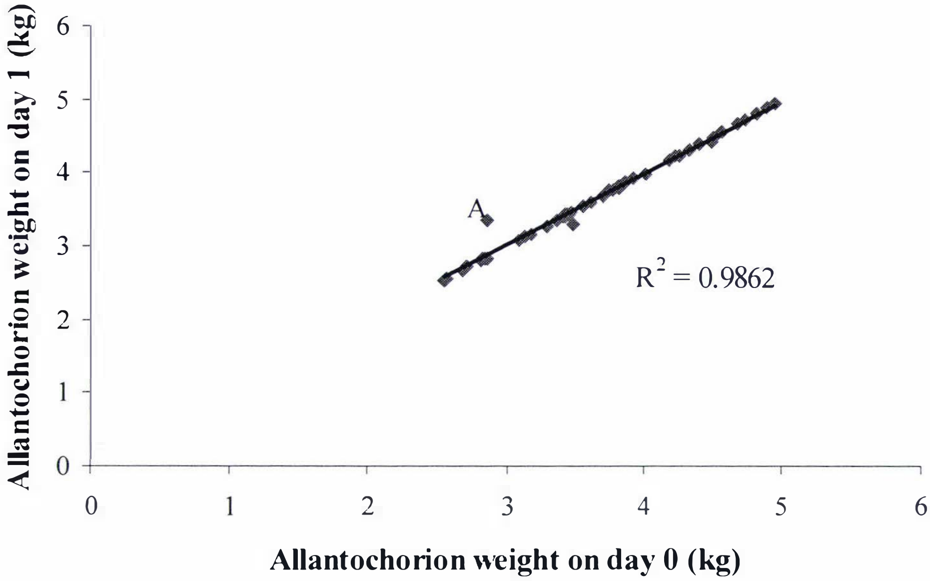

Figure 4.18: *The correlation between the weight of the allantochorion on day 0 and day 1*

The weight of the AC on day 0 had a significant ($P < 0.005$) effect on the wet birth weight (Figure 4.19) and day 1 weight (Figure 4.20) of the foal.

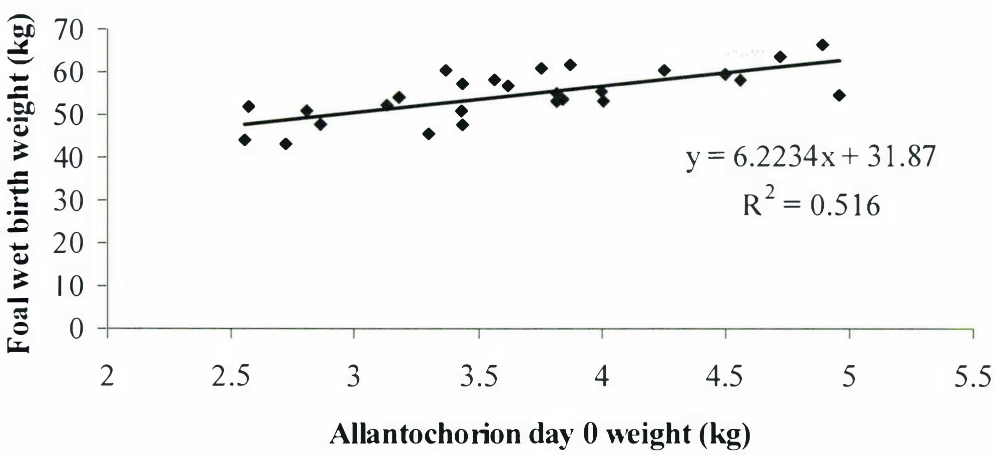

Figure 4.19: *The relationship between the weight of the allantochorion and the wet weight of the foal*

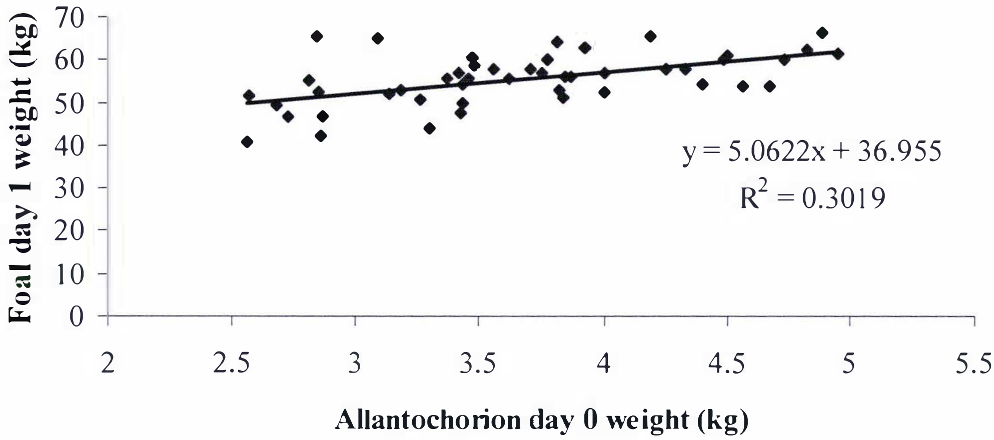

Figure 4.20: *The relationship between the weight of the allantochorion and the day 1 weight of the foal*

There was a high correlation (correlation coefficient = 0.953) between the results of the two different methods of measuring the volume of the allantochorion. The mean allantochorion volume was 2.86 ± 0.07 litres, according to method 1, and 3.07 ± 0.08 litres according to method 2. The volume of the allantochorion significantly ($P < 0.005$) associated with the wet birth weight (Figure 4.21) and day 1 weight (Figure 4.22) of the foal.

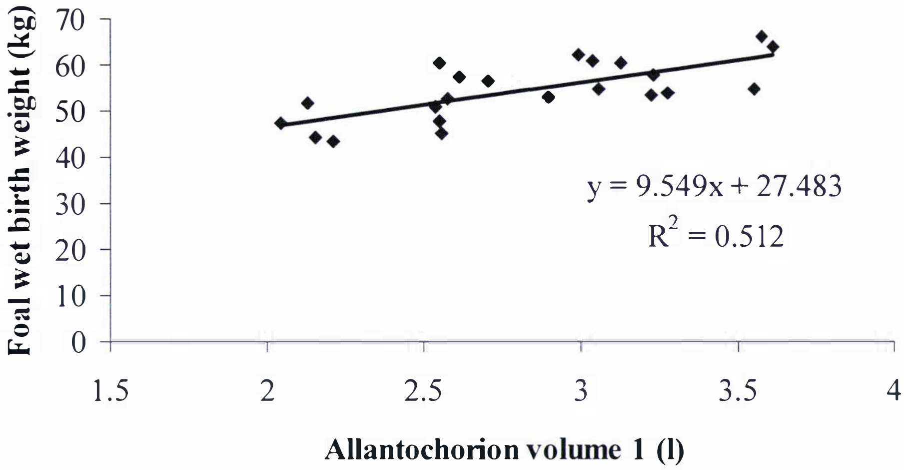

Figure 4.21: *The relationship between the volume of the allantochorion and the wet birth weight of the foal*

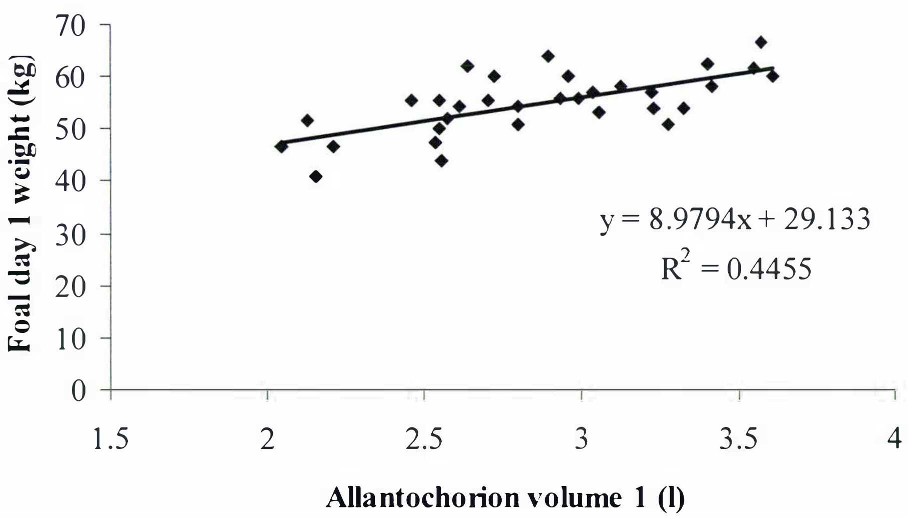

Figure 4.22: *The relationship between the volume of the allantochorion and the day 1 weight of the foal*

4.6 Effect of the sex of the foal on the length of gestation and foal birth weight

The sex of the foal had no significant effect on its wet birth weight (P = 0.73) and day 1 weight (P = 0.56). The mean wet weight of colts was slightly heavier than the wet weight of fillies. The mean day 1 weight for colts was almost 1 kg heavier than the mean day 1 weight for fillies. The wet weight of the filly ranged from 43.3 to 66.3 kg, and the wet weight of the colt ranged from 44.2 to 63.8 kg. The range of day 1 weight for fillies was 42 to 66.5 kg and for colts, it was 41 to 65 kg. The mean foal birth weight and length of gestation according to the sex of the foal is shown in table 4.8.

Table 4.8: *The mean foal birth weight and length of gestation according to the sex of the foal*

	Wet weight (kg) Mean ± S.E.M.	**Day 1 weight (kg) Mean ± S.E.M.**	**Length of gestation (days) Mean ± S.E.M.**
Filly	54.12 ± 2.18	55.16 ± 1.49	356.70 ± 1.91
Colt	54.97 ± 1.35	56.20 ± 1.06	354.80 ± 1.70
Significance	P = 0.73	P = 0.56	P = 0.46

The sex of the foal did not influence the length of gestation (P = 0.46). The length of gestation ranged from 341 to 375 days for fillies, and 338 to 375 days for colts.

4.7 Foal birth weight and growth

4.7.1 Foal birth weight

The wet birth weight of the foal was recorded for 27 foals, while the day 1 weight was recorded for 49 foals. The measurement of wet birth weight for all 49 foals was not possible because of problems with the foal platform, or foals being born in the back paddocks where mares had no alarms on. The relationship between the wet weight of the foal and its day 1 weight (Figure 4.23) was highly significant ($P < 0.005$) and highly correlated (correlation coefficient = 0.79). From the time of birth to day 1, 19 out of 27 foals (70%) lost, on average, 2.26 ± 0.32 kg.

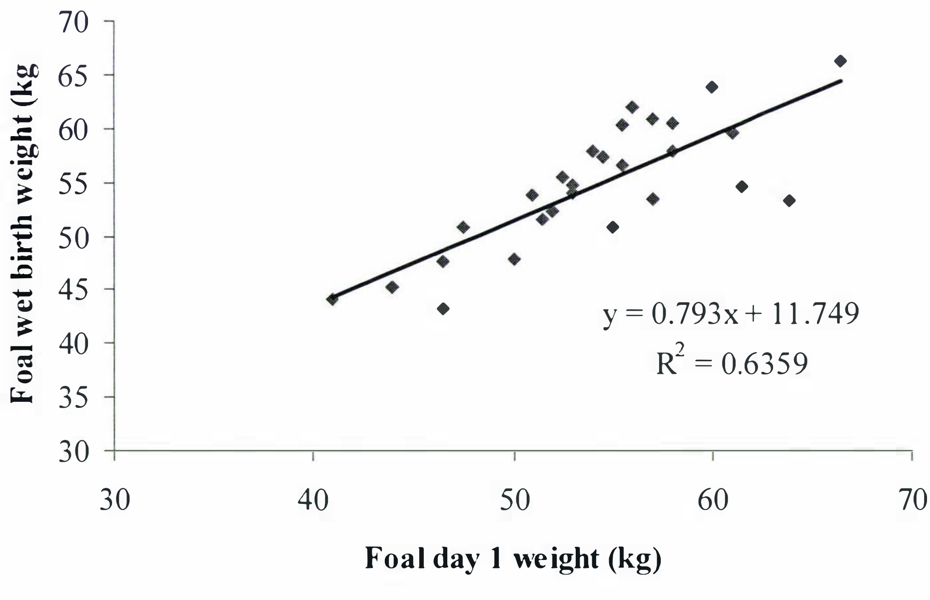

Figure 4.23: *The relationship between foal wet weight and day 1 weight*

The wet birth weight of the foals was adjusted individually using the results obtained from the three extra measurements (explained in section 3.2.4.5.2, page 36), in addition to the wet weight of the foal in the paddock. Although the population size of foals that were weighed within 30 minutes of birth was small, it was apparent that most foals lost weight from birth to 24 hours later, which was not dependant on the time difference between the weigh measurements ($R^2 = 0.49$; Figure 4.24). The wet weight of the foal can be estimated by the equation:

Foal wet birth weight = 0.96 x Foal day 1 weight + 2.76

taking into consideration that the standard error for the regression is 2.59 kg. This equation provides an idea of the weight change of the foal in the first 24 hours of birth. While the gradient of the slope is significant ($P < 0.001$), the y-intercept (2.76) is not significantly different from 0 ($P = 0.59$). Furthermore, an analysis of variance found no significant differences between wet weights and day 1 weights ($P = 0.73$).

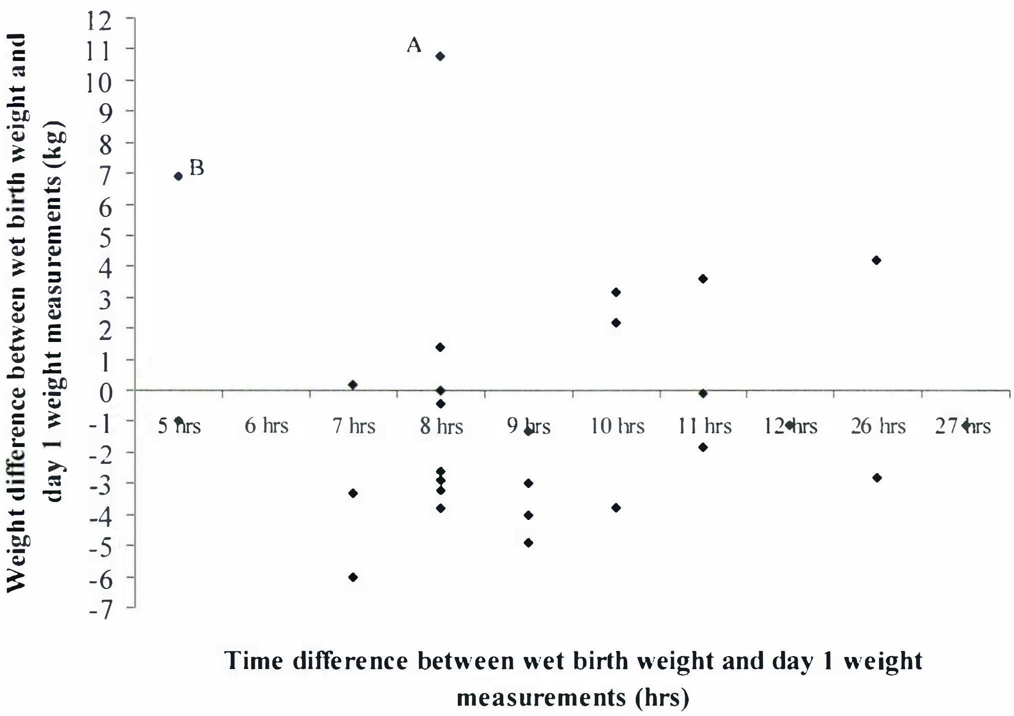

Figure 4.24: *The time difference between the measurements of wet birth weight and day 1 weight of the foal does not affect the weight difference between wet birth weight and day 1 weight.*

4.7.2 Foal growth

A total of 15 mares and foals (six fillies and nine colts) were included in the foal growth longitudinal study. However, only 12 mares and foals (five fillies and seven colts) were weighed for the whole two weeks. The other three mares and foals left the stud before the experimental period had ended, and therefore, they were only included in the analyses for the days they were available (up to day 5 post-partum). The mean foal weights at specific times during the longitudinal study are shown in table 4.8. Foal sex had no significant effect on weight gain in the first two weeks after birth (P = 0.70) or on the daily weight gain during this period (P = 0.63). There was a trend for the mean wet birth weight, day 1 weight and day 14 weight of colts to be greater than (P = 0.07) that of fillies (Figure 4.25). In addition, colts gained on average, an extra kilogram of weight in the first two weeks of life compared to fillies (25.50 ± 1.02 kg and 24.44 ± 1.72 kg, respectively). However, the difference was not significant (P = 0.63). The mean total weight gain of foals was 25.05 ± 3.56 kg in the first 14 days after foaling.

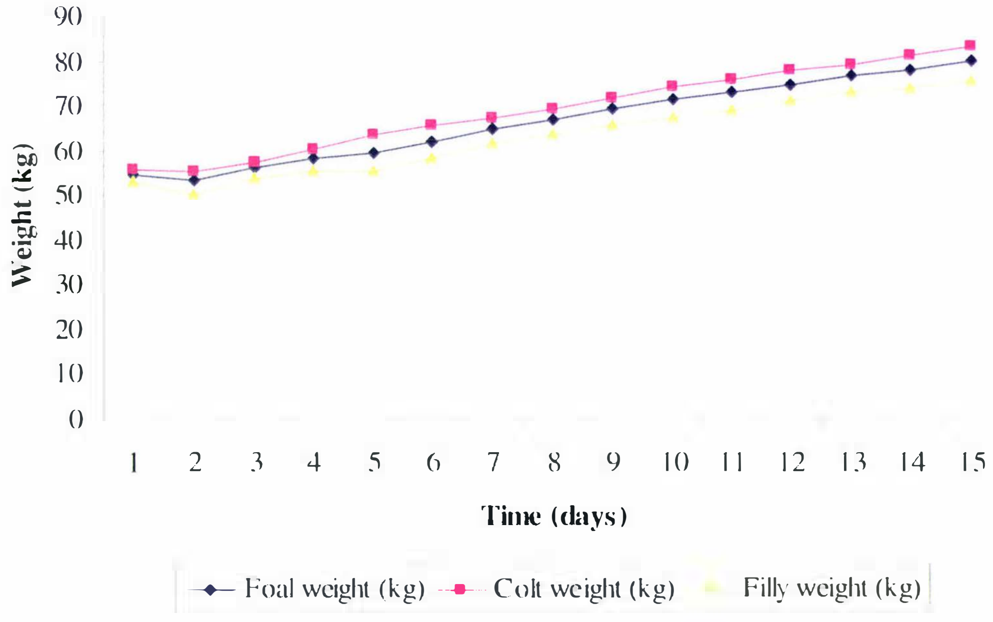

***Figure 4.25:** The mean weight of foals from birth to 14 days of age*

The mean height of foals at birth was 1.019 ± 0.008 m and they grew on average 0.062 ± 0.005 m to reach a mean height of 1.087 ± 0.005 m at two weeks of age (Table 4.9). Foal sex had no significant ($P = 0.87$) effect on the height of the foal at day 1 and day 14. In addition, there was no significant ($P = 0.447$) effect of foal sex on the mean total growth after 14 days.

Table 4.9: *The mean weight and height of foals at specific ages during the longitudinal study*

	All foals	Colts	Fillies
Wet weight (kg) Mean ± S.E.M.	54.67 ± 2.11	55.56 ± 2.37	52.90 ± 4.80
Day 1 weight (kg) Mean ± S.E.M.	53.32 ± 1.38	55.50 ± 1.52	50.05 ± 2.05
Day 14 weight (kg) Mean ± S.E.M.	79.70 ± 1.91	82.92 ± 2.15	75.20 ± 2.39
Total weight gain (14 days) (kg) Mean ± S.E.M.	25.05 ± 1.02	25.50 ± 1.35	24.44 ± 1.72
Daily weight gain (kg) Mean ± S.E.M.	1.71 ± 0.11	1.86 ± 0.09	1.78 ± 0.11
Day 1 height (m) Mean ± S.E.M.	1.019 ± 0.008	1.019 ± 0.007	1.010 ± 0.020
Day 14 height (m) Mean ± S.E.M.	1.087 ± 0.005	1.089 ± 0.004	1.081 ± 0.010
Total height increase (m) Mean ± S.E.M.	0.062 ± 0.005	0.070 ± 0.004	0.060 ± 0.012
Daily height increase (m) Mean ± S.E.M.	0.004 ± 0.002	0.004 ± 0.003	0.004 ± 0.003

On average, foals lost 1.17 ± 0.94 kg, and then gained 2.64 ± 2.18 kg from day 1 to day 2 (Figure 4.26). The difference in weight change from wet weight to day 1 weight and day 1 weight to day 2 weight were significantly ($P < 0.005$) different from each other. The daily weight gain after day 2 was gradual (Figure 4.27) and foals gained on average 1.71 ± 0.11 kg per day until day 14 (Figure 4.28). The differences in daily weight change after day 2 were not significant ($P > 0.08$). The daily weight change for foals in the first two weeks of life ranged from -2.5 kg/d to +5.5 kg/d. The average daily weight gain from day 1 to day 14 after birth was 1.86 ± 0.09 kg/d for colts, and 1.78 ± 0.11 kg/d for fillies. There were no significant differences ($P = 0.63$) between the average daily weight gain from day 1 to day 14 after birth for colts and for fillies. The age and parity of the mare had a significant effect ($P < 0.05$) on the daily weight gain of the foal. However, mare weight and height did not significantly affect the daily weight gain ($P > 0.1$ for both parameters) of the foal.

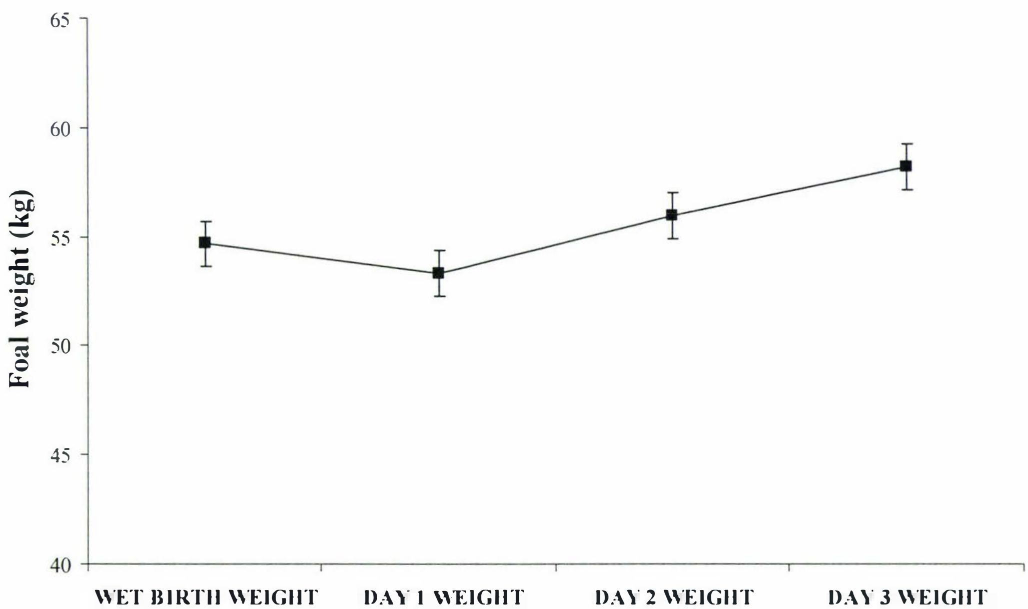

Figure 4.26: *The changes in foal weight in the first 3 days of life*

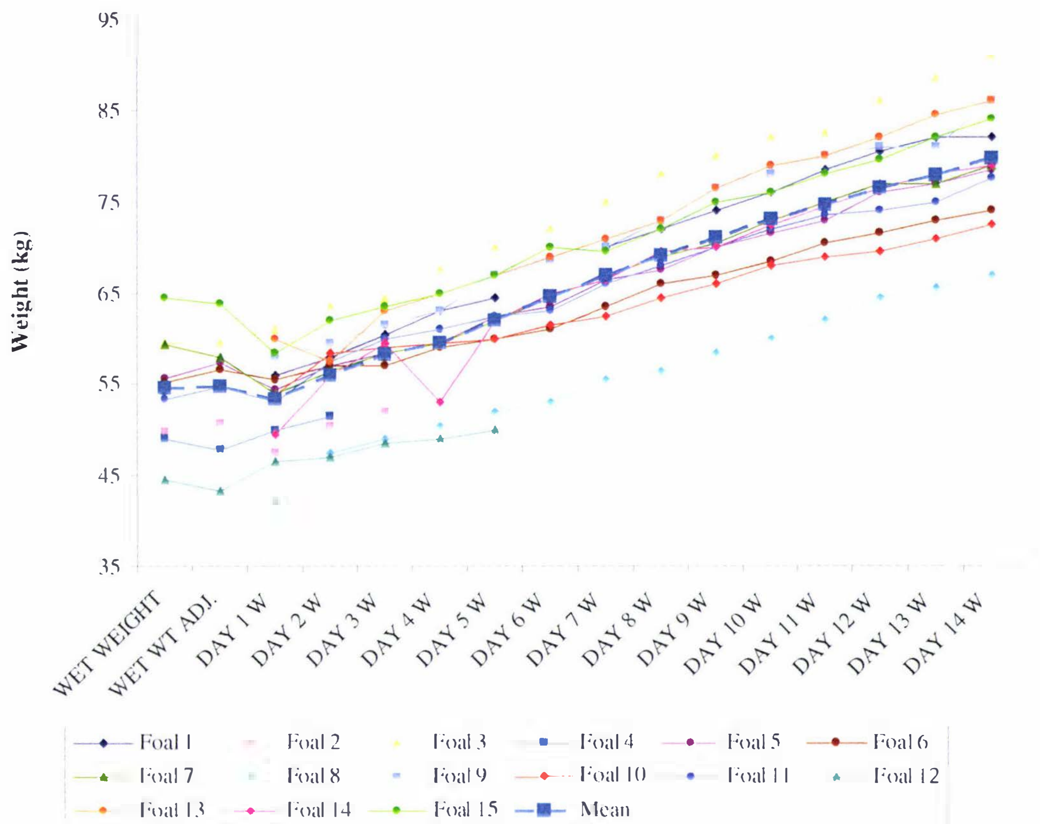

Figure 4.27: *The daily weight of individual foals and the average daily weight of foals in the first two weeks of life*

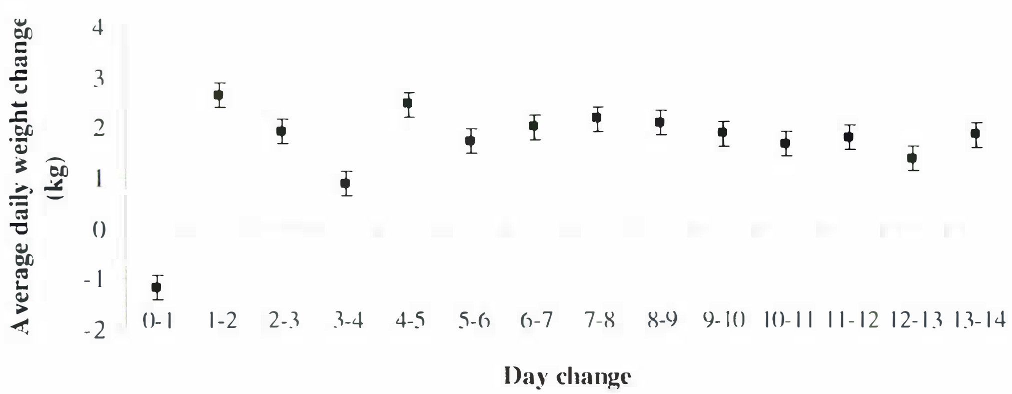

Figure 4.28: *The average daily weight change of foals from birth to 14 days of age*

The mean height of foals was 1.019 ± 0.008 m at birth (day 1) and 1.087 ± 0.005 m at 14 days of age (Figure 4.29). The average daily height increased from day 1 to day 14 was 0.004 ± 0.002 m/d. The mean total foal height increase in 14 days was 0.062 ± 0.005 m. The daily height increase of foals was not constant, with the average daily height increase ranging from 0.001 to 0.011 m (Figure 4.30). However, there was no significant ($P > 0.05$) effect of days of age on the height increase of the foal. In addition, like the daily weight gain of the foal, the daily height increase of the foal was significantly affected by the age and parity of the mare ($P < 0.05$) but not by mare weight ($P > 0.8$) or mare height ($P > 0.3$).

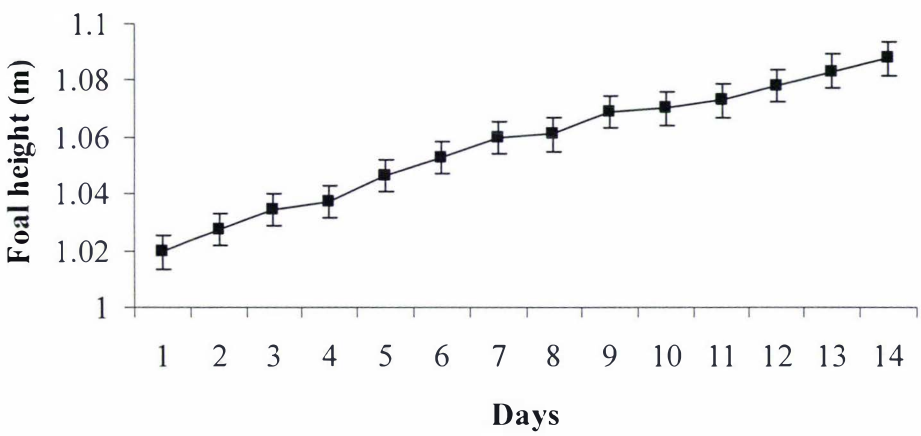

Figure 4.29: *The average daily height of foals in the Newmarket Lodge population from birth to two weeks of age*

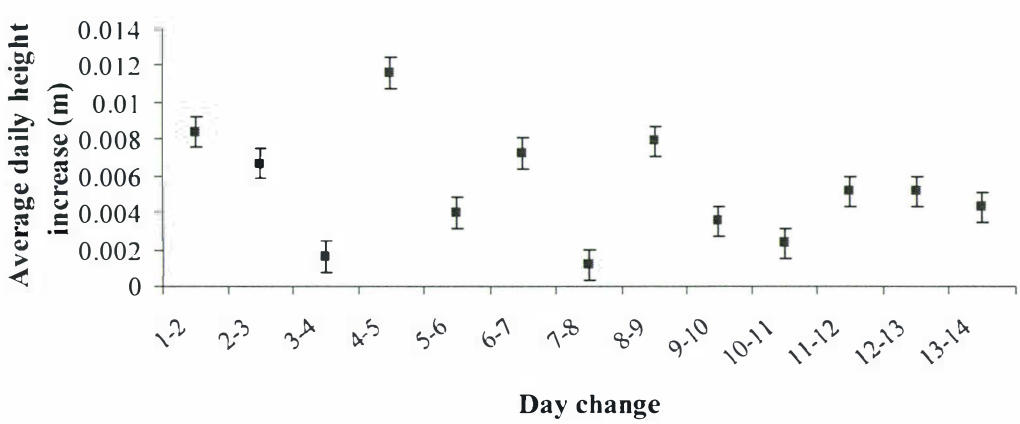

Figure 4.30: *The average daily height increase of foals in the Newmarket Lodge population from birth to two weeks of age*

4.8 Mare weight change two weeks post-partum

The 15 mares participating in the longitudinal study had their weights recorded daily (Figure 4.31). Three mares left the stud early in the study and were not included in the analysis. Mares gained on average 22.50 ± 3.39 kg from day 1 to day 14 post-partum and the weight gain ranged from 6 to 38 kg. The daily weight change of mares was not constant (Figure 4.32) but the average was 1.12 ± 0.56 kg. The range of weight change was large, from -20 kg to 42 kg. The differences in the weight changes between horses and between days were not significant (P > 0.05).

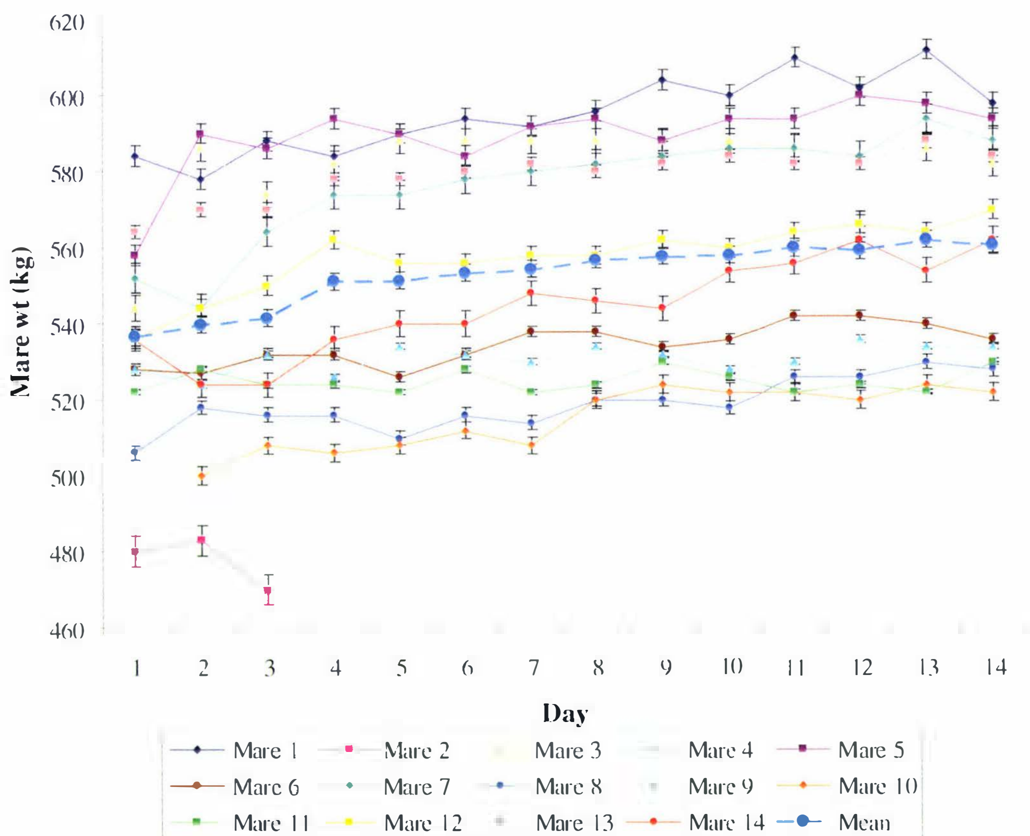

Figure 4.31: *The daily weight of individual mares and the average daily weight of mares in the first two weeks post-partum*

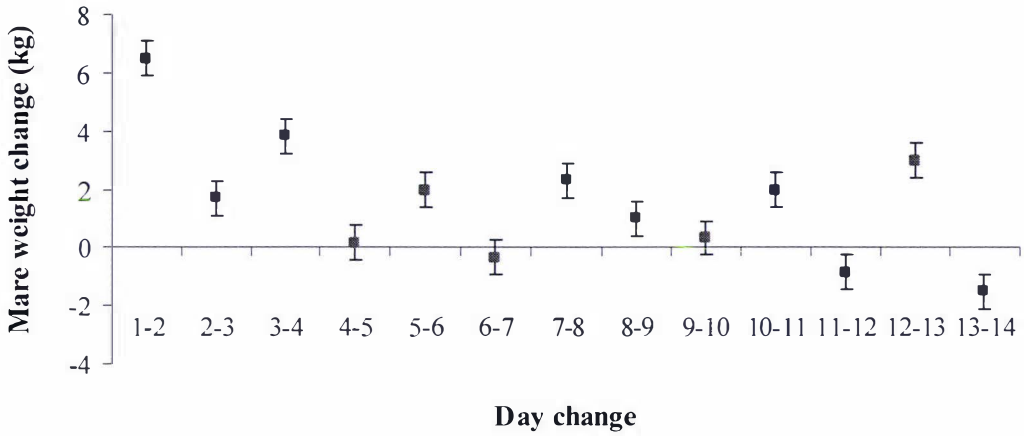

Figure 4.32: *The average daily weight change of mares in the first two weeks post-partum*

Chapter 5

Discussion

5.1 Distribution of mare age and parity, and foal sex ratio of the NZTB study population

In the Newmarket Lodge population, the mean age of mares was 10.83 ± 0.85 years (mean ± S.E.M) and it ranged from five to 19 years. The range of NZTB mare ages in the Waikato Stud sample population was larger (from three to 26 years), and although skewered towards younger mares, it resembles more a normal distribution. However, the mean age was 11 ± 0.20 years (mean ± S.E.M.). Moreover, the NZTB breeders' association (2006a) reported the mean age of mares as 11 years, and the range as three to 26 years.

Despite the small population size, the age data from Newmarket Lodge is comparable to the NZTB breeders' association and the Waikato Stud sample population. Therefore, in terms of mean age, the Newmarket Lodge population can be considered representative of the NZTB population.

The mean parity of Newmarket Lodge mares was 4.5 ± 0.41 (mean ± S.E.M), and the median was 4, while the parity of mares in the Waikato Stud sample population was found to be 5.9 ± 0.18 (mean ± S.E.M), and the median was 5, reflecting the small population size of the Newmarket Lodge population. This can also be seen in the difference in the range of parities observed in Newmarket Lodge (one to 13) and Waikato Stud sample (one to 22; Figure 5.2) populations.

The sex ratio of foals in the Newmarket Lodge population was significantly affected by the small population size of the study. The proportion of fillies and colts was 41% and 59%, respectively. Conversely, the proportion of fillies and colts in the Waikato Stud sample population was 50.3% and 49.7%, respectively. Two studies on TB mares found the majority of foals born to be fillies, as found in the Waikato Stud sample population. Davies Morel ***et** al.* (2002) reported a ratio of 45% colts and 55% fillies in a sample of 433 TB foals. In addition, Hevia ***et** al.* (1994) stated that in a population of 296 TB foals, 53.38% were fillies, while 46.62% were colts.

The effect of parity on the sex of the foal was investigated between the Newmarket Lodge and Waikato Stud populations. The ratios differed considerably between the two populations, and separately, the foal sex ratio of each population seems to be affected by the parity of the mare. However, the small size of the Newmarket Lodge population is likely to have affected the ratio. When the two populations are compared, it is evident that there is no effect of parity on the foal sex ratio. The few reports that exist on the effect of parity on the sex ratio of the foal show no evidence of a relationship between the two parameters (Cameron *et al*., 1999; Garrott, 1991; Monard *et al.,* 1997).

In a wild herd of Kaimanawa horses, no significant variations in foal sex ratio between primiparous and multiparous mares were found (Cameron *et al*., 1999). The sex ratio variations were correlated with the body condition of the mare at the time of conception. This effect was first reported by Trivers and Willard (1973), who hypothesised that "where one sex has more variable reproductive success, such as males in polygynous species, mothers in good condition will be benefited by producing more of that sex, whereas mothers in poor condition will be benefited by producing more of the reproductively stable sex" (Cameron *et al*., 1999). This hypothesis was proposed for animals that are not highly sexually dimorphic and the horse fits the model better than most other species (Cameron *et al*., 1999).

Male offspring are more costly to raise than female offspring. In a natural herd of Camargue horses, Monard *et al.* (1997) found that mares in poor condition at conception gave birth predominantly to fillies in the year following a season of poor food availability. Cameron *et al.* (1999) also reported that mares in poorer condition at conception produced female foals, and mares that had foals of different sexes in different years were in significantly poorer condition when they conceived the female foal. Mares that reared a male in nutritionally poor years tended to experience an increase in the interbirth interval between their two subsequent offspring. In addition, the neonatal mortality rates of male offspring were higher in nutritionally poor years than in good years, whereas nutritional quality in different years had no effect on the mortality of female offspring (Monard *et al*., 1997).

In this study, the CS of the mare prior to foaling had no effect on the sex ratio of the foal (P = 0.96). The study had a small number of horses (n = 40), and the range of CS was small (from 2 to 3.25), which could have affected the data.

5.2 Length of gestation, foal sex and the birth weight of the foal

The gestation length found in the study were longer than those of other studies (Davies Morel *et al.*, 2002; Heidler *et al.*, 2004; Hevia *et al.*, 1994; Kubiak *et al.*, 1988) but are still within the normal range for Thoroughbred pregnancies (Davies Morel *et al.*, 2002; Sánchez, 1998). The longest reported pregnancy resulting in a live foal is 419 days (West, 1994).

The study did not find a significant effect of foal sex on the length of gestation, in accordance with an earlier study by Pozo-Lora (1954) on Arabian and Spanishbred mares, but contradicting the results of Blesa (1999). In fact, most of the literature available supports the argument that the gestation length of colts is longer than that of fillies. This trend was shown in studies by Davies Morel *et al.* (2002), Heidler *et al.* (2004), Langlois (1973), Marteniuk *et al.* (1998), Perez *et al.* (1997), Rophia *et al.* (1969), Roberts (1986), and Vandeplassche (1992).

The reason for this effect of foal sex on the length of gestation is unclear in horses (Jainudeen and Hafez, 2000). It has been suggested by some that the difference is due to different endocrine functions of male and female foetuses interacting differently with the endocrine control of parturition. This hypothesis is supported by Nogueira *et al.* (1997), who found that gonadal steroid concentrations in fillies immediately after birth were high, decreased to basal levels within the first week of life, and were only elevated again during puberty. Similarly, in humans, the theories developed attribute the differences to androgen action (de Zegher *et al.*, 1999) and to sex-chromosome-linked effects (Pergament *et al.*, 1994; Monteiro *et al.*, 1998).

Mare age and parity did not affect the length of gestation, in accordance with reports by Hintz *et al.* (1979), Arora *et al.* (1983), Pérez *et al.* (1997), Kurtz Filho *et al.* (1997), and Sánchez (1998). Nevertheless, earlier data suggested that mares aged 15 and over have longer pregnancies than mares younger than 15 (Demirci, 1988; Platt, 1979). In addition, Pool-Anderson *et al.* (1994) found that the gestation of primiparous Quarter Horse mares was longer than the gestation of multiparous mares by ten days.

There has been no report of the length of gestation influencing the birth weight of the foal. In this study, the length of gestation significantly influenced the wet birth weight of the foal ($P = 0.01$, $n = 26$) but had no effect on the day 1 weight of the foal ($P = 0.24$, $n = 45$). The R-squared values were small for both wet weight and day 1 weight analyses ($R^2 = 0.25$ and 0.03, respectively), indicating that the model only explains 25% and 3%, respectively, of the variation in the data. The small number of foals available for the analysis of the relationship between the wet weight of the foal and length of gestation may have affected the results. The power analysis indicated that we needed 60 foals to be able to show this relationship. Heidler *et al.* (2004) found no correlation between the length of gestation and foal birth weight in Lipizzaner horses, and stated that the weight of colts and fillies does not differ significantly neither at birth (day 3 after birth) nor anytime thereafter.

5.3 The effect of mare size on foal birth size

The mares in the study lost on average 80.9 kg with the birth of the foal, which corresponds to 12% of the weight of the mare post-partum. It has been reported that mares gain on average 16% of their initial body weight during pregnancy (Lawrence *et al.,* 1992). Kubiak *et al.* (1988) showed that the mare loses almost all the weight gained during pregnancy with the process of parturition, attributing the weight gain to the foetus, placenta, and associated fluids. During lactation, the nutritional requirements needed to compensate for energy losses are achieved mainly by increasing feed intake and not by mobilisation of body fat (Heidler *et al.*, 2004).

Kubiak *et al.* (1988) reported that the amount of weight the mare loses with the foaling process is affected by the condition of the mare, and obese mares lose more weight than mares in good condition. The proposed reasons for the greater weight loss in obese mares were a decrease in feed and water intake prior to parturition, or an increase in fluid loss. The CS of the mares of Newmarket Lodge had a range between 2.5 and 3.25 in the 1 to 5 scale (Carroll and Huntington, 1988). This range was too narrow to show significant influences on the weight loss by the mare or the size of the foal at birth. According to Cameron *et al.* (1999), the condition of the mare at conception is an important predictor of foal sex; however, this could not be verified in this study as CS was performed in the third trimester of the pregnancy.

The weight of the mare significantly influenced the size of the foal at birth, contrasting with the results by Wilsher and Allen (2003), who found no correlation between the maternal weight and the birth weight of the TB foal. Furthermore, an earlier study on Quarter Horses also found no correlation between the weight of the mare and the birth weight of the foal (Kubiak *et al.*, 1988). The weight of the mare is moderately correlated with the height of the mare ($r = 0.47$), but the height of the mare had no significant effects on the size of the foal.

There is a genetic component and an environmental component to the size of the foal. Foetal growth can be either increased or restricted from the normal genetic potential by varying maternal size (Swali and Wathes, 2006). Therefore, some of the growth of the foal is determined by the uterine environment and some will be dictated by genetics, so that foals gestated in restricted environments will demonstrate some postnatal compensatory growth (Allen *et al.*, 2004).

The two maternal factors in the study that led to maternal constraint were maternal size and parity. Therefore, the constraint was supply-limited, limiting the growth of the foetus presumably by limiting nutrient availability and/or the metabolic-hormonal drive to grow (Gluckman and Hanson, 2004). Uterine size is directly related to the size of the mare (Allen *et al.*, 2002b); therefore, the size of the mare controls the area for placentation and influences foetal growth.

Mare size also affects the postnatal growth of the foal. Foals developed in a restricted environment showed a 15% decrease in birth size compared to control foals. However, by three years of age the difference had declined to 5% (Allen *et al.*, 2004).

5.4 The effect of placenta size on foal birth size

The uterine environment has been estimated to be responsible for 60% of the variation in size at birth in cattle (Swali and Wathes, 2006). The maternal and paternal genotypes contribute 20% each to the variation. The development of the microcotyledons is influenced by mare age and parity, with the microcotyledon surface density being lowest in aged multiparous mares.

The age and parity of the mare significantly affected the size of the AC. Primiparous mares and mares aged 16 years and over produced a smaller AC than multiparous mares aged five to 15 years. The weight and volume of the AC were also found to be highly correlated (r = 0.91), therefore confirming an earlier study by Allen *et al.* (2002b), who showed how the placental parameters are correlated with each other. The area, mass and volume of the AC were all lowest in the primiparous mare and showed a tendency to increase with parity and age to a maximum in multiparous mares aged 10 to 15, then plateaued or declined slightly in the mares aged 16 and over (Wilsher and Allen, 2003). Consequently, the measures of AC weight and volume are representative of the size of the AC.

The results show that the mean AC weight is comparable to the values reported by Allen *et al.* (2002b), but the values for AC volume was lower than previously reported, and were half-way between the values for the mean AC volume for TB-in-TB and P-in-TB pregnancies, with the exception of primiparous mares, whose ACs had weights and volumes comparable to the P-in-TB pregnancies.

The weight and volume of the AC had a significant impact on the birth weight of the foal, confirming earlier studies (Allen et al., 2002b; Wilsher and Allen, 2003). The differences are greatest when analysed in terms of the parity and age of the mare. The limiting effect that primiparity has on the uterine environment significantly reduces the size of the foal at birth. The uterus needs to be primed by a first pregnancy to bring about changes in microcotyledon morphology and efficiency. However, the mechanism that brings about the increase in the efficiency of the uterus after the first pregnancy is unclear. A reduced intrauterine space for the growing foetus in the first pregnancy, occasioned by a reduced ability of the uterus to stretch, is often cited as the likely reason for the lower birth weight of the first foal (Bhuvanakumar and Satchidanandam, 1989).

Wilsher and Allen (2003) found that foetal genotype was a significant factor in determining the gross area of the AC. The genetically smaller pony foal with its reduced volume of foetal fluids did not stretch the TB uterus to its full potential and, although constrained by the smaller pony uterus, the TB foal still managed a modest increase in the gross area of the AC over a P-in-P pregnancy (Allen et al, 2002). Wilsher and Allen (2003) also considered the work of Rice (1998), who developed the hypothesis that the foetus could be primarily responsible for uterine expansion, and therefore, a smaller foal would result in reduced expansion of the uterus. He considered the involvement of the mechano-transcription pathway in gestational remodelling of the uterus to accommodate placental and foetal growth, in which growth of the foetus together with associated tissues and fluids may represent the mechanical stimulus which contributes to, and determines the associated growth of, the uterus.

Aged mares produced foals that were comparable in size to foals born to primiparous mares, and were significantly smaller than foals born to multiparous mares aged five to 15 years. Placental development is affected by age- and parity- related endometrosis (Wilsher and Allen, 2003). Microcotyledon development in aged mares is delayed between days 80 and 150 of gestation (Bracher *et al.*, 1996), and includes fewer, shorter and blunter macro- and microvilli, compared to younger, fertile animals. Furthermore, the total microscopic area of foeto-maternal contact and how efficient the contact is in transferring nutrients and waste products to and from the foetus are also affected by the age and parity of mares (Wilsher and Allen, 2003) and, in turn, affect the birth weight of the foal. There are advantages to increasing the surface area of the foeto-maternal apposition and bringing the two circulations as close together as possible. Clinically, this is relevant to any consideration of breeding from mares in which uterine morphology and health is compromised by such factors as age and/or chronic infection (Bracher *et al.*, 1996) or a disparity between sizes of stallion and mare (Allen et al., 2002; Wilsher and Allen, 2003). Such effects decrease the surface area available for placental growth and foeto-maternal microvillar interdigitation (Wooding and Fowden, 2006), and therefore affect the birth weight of the foal. In addition, limitations in body size due to disturbances *in utero* trigger a stress response that influences postnatal adaptation and viability (Ousey *et al.*, 2004).

5.5 Foal growth from birth to two weeks of life

Foals reach 39% of their mother's weight at 18 weeks of age. At 7 months (or 30 weeks), Thoroughbred foals reach 47% of their mature body weight and 84% of their mature height, depending on growth rate pattern used by the breeding manager (Pagan, 2005). Since Thoroughbred horses are expected to be successful athletes at 2 years of age (2-3 years before they reach physical maturity), sometimes it is necessary for breeders to follow moderate growth patterns or rapid growth patterns by adjusting their nutritional intake. The disadvantage with these growth patterns is that they are more likely to produce skeletal problems. It is a balancing act to obtain the optimal growth rate that result in a desirable body size at a specific age with the least amount of developmental problems (Pagan, 2005).

Due to the nature of stud management, where there is a large movement of foals from the stud, because of either sales or agistment, it is often impractical to monitor the growth of the foal from birth to maturity. Experimental studies usually contain a small number of horses, and growth is measured at large time intervals. In addition, since the majority of mares foal at night, the birth weight of the foal immediately after birth is not usually available, especially for mares foaling in paddocks.

Some earlier studies suggest that active growth starts immediately after birth. However, most of these studies measure the growth of the foal at 14-day intervals, and the average daily weight gain is estimated. Nothing was known of the pattern of growth in the first 14 days of life. The NZTB foal is usually kept on pasture with their dams in their first months of life, and in the first two weeks of life they only have access to the dam's milk, pasture and hay, with milk being the greater source of energy. Therefore, maternal factors exert more influence in the early growth of the foal than environmental factors, which will play a greater role in the development and growth of the foal after weaning.

The birth weight of foals in this study are comparable to other reports of Thoroughbred foal birth weights (Allen *et al.*, 2002b; Allen *et al.*, 2004; Jelan *et al.*, 1996; Kavazis and Ott, 2003; Pagan, 2005; Staniar *et al.*, 2004b). Most studies weigh the foal either immediately after birth or on the day of birth, and then only 14 days after birth, there were no reports on how the weight of the foal changes daily from birth to 14 days of age. It was found that the 70% of foals lost weight between the time of birth and the next measurement in the morning of birth. The average weight loss was 2.26 ± 0.32 kg/d for the 70% of foals that lost weight. The most likely reason for this weight loss is drying off. Although early neonatal weight loss in newborn infants has been associated with primiparity (Wright & Parkinson, 2004), there was no relationship between parity and early neonatal weight loss in the foals in this study.

In the longitudinal study that comprised 15 foals, foals gained on average 2.64 ± 2.18 kg/d from day 1 to day 2. The sex of the foal did not influence this weight change. The mean total weight gain of foals was 25.05 ± 3.56 kg in the first 14 days after foaling. At 14 days of age, the mean foal weight was 79.7 kg, which is slightly higher than a previous report on Thoroughbred foals in Kentucky (Pagan *et al.*, 1996).

The daily weight change of foals in the first 2 to 3 days of life is variable. It is only after this that the daily weight stabilises. The daily weight gain after day 2 was gradual, with foals gaining on average 1.71 ± 0.11 kg per day until day 14. This result is very similar to the daily average weight gain of Thoroughbreds in Ireland (Jelan *et al.*, 1996). They reported that in the first month, average daily growth was in excess of 1.6 kg/d, and it was the period of most rapid growth. It is after the first month that growth decreases to

0.9 to 1.0 kg/d (Jelan *et al*., 1996). Pool-Anderson *et al.* (1994) and Heidler *et al*. (2004) reported lower values for the average daily weight gain of Quarter Horses and Lippizaners, respectively.

In the first two weeks after foaling, Lippizaner foals that were born heavier gained less weight than foals born lighter (Heidler *et al*., 2004). However, this compensatory effect is not apparent in the early neonatal growth of Thoroughbred horses. The average daily weight gain of foals in the study was similar for every foal after the second day of life. These findings are supported by data on the effect of parity on the growth of Quarter Horse foals (Pool-Anderson *et al.,* 1994). Multiparous mares had heavier foals at birth, and they remained so through early lactation. The compensatory growth only occurred after early lactation, and by late lactation (3 months to weaning) no difference was found. The runting effect only persists through life when the uterine restriction is extreme (a uterus smaller than the normal range).

5.6 Limitations

5.6.1 Assessing the weight of foals and mares

The body weight of an animal provides an essential measure of its size. To weigh an animal accurately, the scales must be calibrated regularly. When there are problems with the calibration of the scales, the accuracy and validity of the data is compromised. The calibration mass should be proportional to the weight of the animal being weighed. This was not possible during this experiment since the only standard weight was 21 kg.

It is impractical to calibrate scales for large animals. The calibration of the scales for lower weights will provide an idea of the validity of the scales, and most scientists rely on the fact that good quality weighing scales, such as Tru-test, are tested extensively before they are sold. Unless there is an obvious discrepancy with the measurements, the scales are not tested for linearity, accuracy, and reliability in the experimental setting.

In this experiment, the weight recorded for the standard weight (21 kg water container) gradually decreased until the container was accidentally emptied. This standard weight was subsequently substituted by a 15 kg test weight, which only fluctuated in weight on four occasions. Because the 21 kg water container was emptied, it is impossible to know if it was losing weight. Although the container was closed tightly, we cannot know if it was airtight and therefore, if any water could have evaporated. The fact that the 15 kg test weight was being measured accurately indicates that the container was faulty. Therefore, the foal and mare weight data was adjusted individually based on the weight of the 21 kg water container or the 15 kg test weight to counteract the inaccuracies with the weighing.

The calibration protocol could be improved by using a container filled with sand instead of water. In addition, to ensure accuracy, the number of containers used should be increased to obtain a total weight of about 70 kg, which equates to the maximum weight obtained for two-week-old foals during the experiment. It is harder to calibrate the scales for mares because they can weigh up to 700 kg close to foaling. At the beginning of the experimental period, it would have been useful to weigh a group of about 10 people on the airport scales, since the airport was on the way to the stud and their scales are monitored closely, and subsequently weighed them on the mare platform at the stud. This would have given an indication of the linearity of the scales.

In a practical application, the greatest sources of error of scales are moisture and position. Moisture can get into the load cells damaging the electrical equipment and affecting the data produced. In addition, platform scales require an even surface (preferably concrete) clear from debris that may go underneath the platform and prevent it from weighing accurately. Moving the scales from one location to another may cause differences in the readings. Therefore, the scales need to be recalibrated every time they are moved to a new location.

Some precautions must be taken to avoid gathering misleading data, such as checking scale validity and linearity, minimising variation in gut fill of the animal, and checking the accuracy, reliability, repeatability, and reproducibility of the measurements. Measurement accuracy can be checked by the consistency of the zero reading at regular intervals, and by checking the precision and repeatability of the values given for standard weights (calibration). Ideally, the standard weight should cover the range of animal weights expected, but any object of known weight will provide some indication of problems in this area.

5.6.2 Assessing the weight, area and volume of the placenta

Both digital and balance scales can be used to weigh the equine placenta. The advantage of using balance scales is that the weight of the placenta is compared to proven weights in every measurement, and therefore, the reliability of the data is ensured. Sources of errors such as dirt and grass on the placenta, blood loss, as well as tears and cuts on the allantochorion can affect the measurements of weight and volume. Because of the size of the allantochorion, it is more practical to cut it before measuring its volume, to make it easier to handle. In addition, cutting the allantochorion minimises the number of air spaces forming underneath the tissue when it is introduced to water.

For the water displacement method, inaccuracies can be reduced by minimising the meniscus. This can be achieved with narrow containers. Furthermore, shorter distances between the volume markings on the container help improve accuracy. In contrast, the width of the container is not important for the 'weight of water displaced' method. However, it is important that the container possess a lip to guide the overflow of water. The container must be secure and always in the same position so there is no variation between measurements, and it must be at the point of overflow before the placenta is placed inside. For both methods, it is important that the placenta be placed into the water slowly and carefully to avoid loss of water due to splashing, and therefore, decrease inaccuracy in the measurements.

5.7 Conclusion

The success of the breeding industry is dependant on the growth of the foal, and the birth weight of the foal is affected by maternal factors, such as mare age, parity, weight, and placental size. In addition, other studies have shown that there is a relationship between the sex of the foal, the length of gestation and the birth weight of the foal, however we could not demonstrate this relationship because of our small population size. Length of gestation tends to be longer for colts than for fillies, and the sex of the foal influences the birth weight of the foal. However, there is no direct effect of the length of gestation on the birth weight of the foal.

The age and parity of the mare also act in the same manner. It indirectly influences the birth weight of the foal by its effects on the size of the allantochorion. Primiparous mares produce smaller foals than multiparous mares aged five to 15 years, but multiparous mares aged 16 years and over produce foals with birth weights comparable to primiparous mares. This occurs because of the effects of age and parity on the total area of foeto-maternal contact and depends on how efficient the contact is. The total microscopic area of foetomaternal contact at the placental interface is positively correlated with foal birth weight. The uterus of primiparous mares needs to be primed by a first pregnancy before it is able to fully expand, and age-related endometrosis causes the uterus to deteriorate, affecting the structure and function of the microvilli and reducing the efficiency of the placenta. Therefore, nutrient and waste exchange is not optimal, and the foal is affected by IUGR.

Maternal size is closely associated with the size of the allantochorion. Mare size is directly proportional to uterine size, and the size of the uterus dictates the area available for placentation, which influence foetal development. In addition, the genotype of the mare influences the size of the foal, whose genotype also plays a part in determining the extent of placental development. The birth weight of the foal is positively correlated with the weight and volume of the allantochorion. In addition, placental parameters are highly correlated with one another, so the measures of weight and volume of the allantochorion can be considered representative of the size of the placenta, and more specifically, the total microscopic area of foetomaternal contact and placental efficiency.

The NZTB foal loses weight from the time of birth to day 1 of life, which was measured usually about 6 to 12 hours after the foal was born. After the initial weight loss, foals gain 1.71 ± 0.11 kg daily from day 2 to day 14 of life, and the mean weight gain for this two-week period is 25.05 ± 1.02 kg. Foals had a mean birth weight of 54.68 ± 1.13 kg and a mean weight at day 14 of 79.70 ± 1.91 kg (about 14% of its mature weight). This information can be included in guidelines for a normal growth pattern of Thoroughbred horses. For example, foals that are likely to be restricted *in utero* because of maternal and placental size would likely benefit from having a larger stallion as sire. The growth of these foals could be more closely monitored and growth rate adjusted with nutritional supplements. Furthermore, since the CS of the mare at conception influences the sex of the foal, managers can mate mares in poorer condition to less valuable stallions and leave the younger multiparous mares in better condition to be bred to stallions that are more valuable. The chances of conceiving a male is increased in mares in better condition, and male foals are more commercially valuable than a female foal. A young, large multiparous mare will provide the best environment for the development of a male foal and reduce the risk of IUGR.

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