INFLUENCES ON VARIATION IN FERTILITY OF SOWS

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Philosophy

Massey University

1996

Abstract

This thesis presents the results from a series of studies related to factors influencing fertility of sows in New Zealand. The conclusion from an analysis of longitudinal pig reproductive performance data is that summer-autumn infertility was not a significant problem on the farms included in this study during the time period investigated. In New Zealand there are probably certain specific conditions when seasonal infertility does become a problem for a particular pig herd, and this may be more evident on farms in the South Island which are using a group housing husbandry system for their sows. The intervention trials into increased dry sow ration in newly mated sows and of the management technique of split weaning both failed to demonstrate these techniques improved reproductive performance. Economic simulation modelling suggests that while there does not seem to be an overall benefit from the increased dry sow feed intake, it would yield an economic benefit on some farms. Possible explanations for this are discussed in this thesis. The investigation into the usefulness of ultrasound scanning for determining early pregnancy status in sows demonstrated the effectiveness of this diagnostic technique in detecting pregnancy, but did not show a level of loss of early pregnancies sufficient to justify more intensive investigation of embryonic mortality. Cull sows sent to slaughter were examined for their pregnancy status and any pathological changes. A large proportion of these animals showed endometritis and urinary tract pathology, indicating that both of these conditions were more common in the cooperating herds than had been suggested by earlier clinical evidence.

Acknowledgments

I have been part of the epidemiology group since February, 1994. When I first arrived, it was like being thrown in a big deep hole but when I needed help I was given a ladder or sometimes a lift to climb up to the light at the top. Looking back, the hole is not so big or deep anymore, and the world is smaller than it was. I am particularly grateful to my supervisor, Professor Roger Morris for giving me an opportunity to study at Massey University. He gave me invaluable assistance, I could rely on him for help when I needed it and I was encouraged by his optimism and willingness to tackle and solve problems. Thanks also go to Professor Norm Williamson, my other supervisor, for his valuable suggestions when questions have arisen. I thank Dr. Dirk Pfeiffer for helping me to understand many methods of analysis and for encouraging me to try more procedures and learn more and his advice that "even if it doesn't work, at least you will have learnt something".

I gratefully acknowledge my *ajarn* (super-teacher - in Thai), Dr. Ron Jackson, for his excellent supervision, understanding, warm encouragement, constructive criticism, and endless patience in discussions and correction of my English. His enjoyable way of life is to be recommended.

I would also like to thank other members of the epidemiology group; to Robyn O'Connor, who is backbone of the group with her 'any questions' queries, to Todd Cochrane for helping me with computer work, to Mrs. Fiona Dickinson for her help in so many things, to Barb Frey for her useful information, to Vanessa for helping in field work, and to Dr. Sirichai Wongnarkpet for getting me started.

I owe thanks to Dr. Selwyn Dobbinson for his helping to find cooperative farms and sharing his field work experience, to Dr. Nigel Perkins for his support with ultrasound scanning examinations, to Associate Professor Maurice Alley for his instruction in histopathology, to Pam Slack and Pat Davey for tissue preparations, to Dr. Joanne Meers for her help with ELISA, and to farmers for their help with data collection.

I would also like to thank the New Zealand Government - my sponsor through the New Zealand Official Development Assistance Programme, and staff and friends at Kasetsart University in Thailand for their support and doing my work while I was away.

A very special thanks go to my parents for their love and endless support, and to my best friend, Patamaporn, for her encouragement.

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CHAPTER 1

INTRODUCTION

Chapter 1: Introduction

Worldwide, the swine industry has grown from small farmyard family activity farms to large-scale efficient production systems in the last 25-30 years. Many advances have been made in breeding and genetics, health control, nutrition and feeding practices over that time. However, there remains substantial variation in reproductive performance of pig herds, and many herds in New Zealand and elsewhere have periods of poor reproductive performance, principally from mid-summer to mid-autumn.

The studies in this thesis were performed to understand some of the factors which can influence reproductive performance of gilts and sows in New Zealand and to test the effect of modifying some of these factors examined using first data from farms which are all using the same computer-based recording health and management programme. This provides an overview of the extent of variation in reproductive performance, and of factors which may be associated with it.

Because of the importance of summer-autumn infertility worldwide, a large trial was conducted to evaluate the production effects of increasing feed intake of sows over the period of risk for impaired reproductive performance, and to assess the economic benefit of this feed supplementation. At the same time, a study was conducted in a single herd which used no supplementation, to assess the use of repeated ultrasound examination for quantifying the extent of pregnancy loss, and to evaluate ultrasound examination as a diagnostic tool in reproductive investigations.

A possible alternative tool for manipulating both reproductive performance and piglet performance, especially in gilts, is split or fractionated weaning. The effects of this practice were investigated in two herds, where subsequent gilt and litter performance were assessed.

Sows which have continuing problems with reproductive performance are usually culled from herds. A sample of such animals from commercial herds was examined, together with sows culled for other reasons, to identify the extent and nature of pathological processes which may be occurring in such animals, and their possible impact on reproductive performance in the herds.

Together, these studies demonstrate a range of approaches which can be applied to investigating and solving reproductive problems in pig herds, both in New Zealand and in other countries.

CHAPTER 2

SEASONAL VARIATION IN REPRODUCTIVE PERFORMANCE OF COMMERCIAL HERDS

Chapter 2: Seasonal variation in reproductive performance of commercial herds

Literature review

Seasonal infertility - the disorder and its causes

Seasonal infertility (SI) is the term used to describe a complex syndrome with multiple causes which affects reproductive performance of sows and boars (Hennessy, 1987a) during summer and autumn. Production losses associated with the problem are more serious in continental climates than in Mediterranean and tropical climates (Leman, 1986). The condition has been reported from many European countries-Greece (Menegatos, 1987), Portugal (Vieira and Vieira, 1987), Spain (Perez and Gutierrez, 1987), Yugoslavia (Cerne, 1987), Italy (Mattioli, 1987), U. S. A. (Hurtgen and Leman, 1980) but is not considered to be a serious problem in Ireland (Lynch and Kearney, 1986) and Belgium (Robijns, 1987). It occurs in large pig breeding units in Britain (Stone, *et al.*, 1986; Wrathall, 1987) and has also been reported in one other island country, New Zealand (Sprey, 1980). The prevalence of seasonal infertility is highest in late summer and early autumn, but in some herds, signs are present throughout the whole year. In the northern hemisphere, fertility may be reduced by 10-30% during June to September, compared with the rest of the year.

According to Hennessy (1987a), the signs of a seasonal infertility problem include:

- an increased weaning to mating interval
- delayed onset of puberty and/or poor oestrus expression in gilts
- decreased litter size
- increased prevalence of stillbirths and/or mummified foetuses

Love (1981a) considered the following signs to be indicative of a seasonal infertility problem:

- delayed onset of oestrus after weaning in a larger proportion of sows
- an increased number of sows with mating to return oestrus intervals greater than 24 days
- increased incidence of abortions
- an increased number of sows "not in pig" shortly before expected farrowing date

He did not consider a higher proportion of returns to oestrus at intervals of 18-24 days, or a reduction in litter size to be reliable indicators of a seasonal infertility problem (Love, 1981a).

Observed anoestrus is more likely to be due to reduced behavioural expression of oestrus rather than a true anoestrus, since it is usually accompanied by ovulation (Love, 1981a). By far the most important aspect of the seasonal infertility is a reduced farrowing rate (Love *et al*., 1993), commonly evidenced by delayed (>24 days) return to oestrus (usually 25 to 35 days after mating) (Love, 1981a). In summer the incidences of failure to maintain pregnancy and delayed return to oestrus are increased (Dial and Xue, 1993). Wrathall (1987) noted that problems associated with summer included depressed fertility in boars, delayed puberty in gilts (Cameron, 1980), delayed post-weaning oestrus and a higher incidence of returns to oestrus following mating (Cameron, 1980). Te Brake and Aalbers (1987) reported that the proportion of sows coming into oestrus within seven days of weaning was lowest during the summer months. They also reported that conception rates to first mating and litter sizes were lowered during spring and winter time respectively. On the other hand, analyses of 33 herds through 1980-1983 in North-western Germany indicated that the smallest litters were born in summer and the largest in winter; and that the age at first mating and the weaning to oestrus interval reached a maximum in summer and autumn and a minimum in winter (Plonait and Lahrmann, 1987). Wrathall (1987) suggested that environmental temperatures might not be causally associated with autumn abortions as autumn abortions have been reported predominantly from cooler parts (more northerly latitudes) of Europe and North America.

Using plasma progesterone levels 18-21 days after mating as the criterion for diagnosis, Williamson *et al*. (1980) were able to categorise seasonal infertility into 3 distinct classes:

- high progesterone levels indicating pregnancy or a luteinized ovarian cyst
- low progesterone levels indicating non-pregnancy
- high progesterone levels 10 days after the first test indicating cycling with undetected oestrus

More recently, Claus and Weiler (1994) have hypothesised that seasonal infertility results from the effects of stressors that cause early embryonic deaths, luteinized ovarian cysts, small ovarian cysts, poor oestrus expression or undetected early abortions, and caution against it being regarded simply as a consequence of embryonic death, or endocrine imbalance.

The majority of sows returning to oestrus during summer do so between 25 and 38 days post-service (Love, 1981b; Leman, 1986; Reilly and Roberts, 1991) with a secondary small peak occurring between 46 and 57 days (Reilly and Roberts, 1991). This phenomenon appears to be associated with the maximum daily temperatures during the period and to be unrelated to minimum daily temperature or daily duration of sunlight (Reilly and Roberts, 1991). A retrospective study of pig farms in the U. K. showed that SI did not decrease litter size (Reilly and Roberts, 1991). Conversely, Martinat-Botte (1987) recorded reduced litter sizes in sows in Brittany which were mated during the latter part of winter/spring period, lower fertility with summer matings.

Multiparous sows returned to oestrus after weaning earlier than did primiparous sows but the risk of post-weaning oestrus failure was higher in primiparous sows, especially during summer and autumn (Hurtgen *et al.*, 1980b; Hurtgen and Leman, 1980; Love, 1981a). The interval between weaning and oestrus was shortest in autumn at 5 - 6 days, and extended to more than 30 days after weaning in summer (Claus and Weiler, 1987). These authors also reported improved conception rates in autumn/early winter matings and then again in May/June in Germany. However Hurtgen *et al.* (1980a) pointed out that while most sows have a normal weaning to oestrus interval, a minority of sows (and in particular the parity one group) have considerably prolonged weaning to oestrus intervals (>30 days) and thus increase the mean interval. Wu (1986) found the incidence of delayed puberty in gilts was highest in summer, particularly for pure-bred Hampshire and Landrace gilts (Wu, 1986). Seasonal variations in litter size were more pronounced in sows than in gilts (te Brake and Aalbers, 1987).

Many researchers have analysed data from case studies, but cohort studies have also been conducted to evaluate the effect of heat treatments, changes in the photoperiod, alterations to animal husbandry procedures, other stressors known to cause hormonal changes and changes in eating habits. Some authors consider seasonal infertility to be a natural phenomenon with the signal for reduced fertility coming from decreasing day length (Leman, 1986).

The literature review to this point has clearly shown that SI is essentially a collective term which conveniently describes a wide range of infertility manifestations in pigs including the following:

- increased weaning to oestrus intervals
- delayed onset of puberty in gilts and/or poor oestrus expression in gilts and sows
- increased incidence of return to service in gilts/sows
- increased incidence of abortions
- increased incidence of "not in pig" gilts/ sows
- increased prevalence of stillbirths and/or mummified foetuses
- decreased litter sizes and/or numbers of pigs born alive

Seasonal infertility on boars

While there is not universal agreement on the issue, some authors classify the following conditions in boars as seasonal infertility:

- decreased libido
- decreased sperm concentration and/or total sperm count
- decreased volumes per ejaculate

Causes of seasonal infertility

For purposes of discussion, the various causes of seasonal infertility may be conveniently classified as:

- effects of photoperiod on SI
- effects of heat on SI
- effects of housing on SI
- effects of stress on SI
- effects of season on hormonal system
- effects of nutrition on SI
- effects of the boar on SI

Photoperiod and seasonal infertility (SI)

Pigs are essentially short-day breeding animals (Peacock *et al.*, 1987) and the seasonal breeding effect is largely determined by changes in the daily photoperiod. Photoperiodism is the outstanding environmental factor involved in seasonal alterations to reproductive responses (Mauget, 1987; Love *et al.*, 1993).

High light intensity and neural pathways

The natural light mechanisms which influence seasonal breeding in farm animals are complex and subject to dynamic change. The length of day (or night) has a greater influence on photoperiodic responses than light quality (Fraser and Broom, 1990) and photoperiodism-induced breeding responses are readily produced if the natural day length is extended with artificial lighting of very low intensity. While the duration of the photoperiod is more important than the intensity of light, adequate light intensity is critical for the generation of distinct circadian rhythms of melatonin which play an important role in regulation of fertility (Love *et al.*, 1993). Love *et al.* (1993) also points out that while the critical light intensity has not yet been precisely determined, reliable induction of a nocturnal melatonin rise appears to require a light intensity of 200-300 lux.

Ellendorff and McConnell (1987) described the mammalian neural pathways followed after light is received by the eye and transmitted initially to the brain via the optic nerve. One of the first fields of projection is the suprachiasmatic nucleus (SCN) in the hypothalamus. This site must be considered of paramount importance for light-induced rhythms, including reproductive rhythms. From the SCN, fibres project to the paraventricular nucleus (PVN) of the hypothalamus and from there using the medial forebrain bundle (MFB) via the reticular formation into the intermediolateral cell column (IML) of the spinal cord. An important outflow of fibres from the IML is to the superior cervical ganglion, which in turn uses the nervi conarii to direct the potential signal into the pineal gland.

A signal is also sent from the retina to the pineal gland via the sympathetic pathways. In the pineal gland, the neural message is changed to a humoral message (indoleamine melatonin) which affects the photoperiodic response in both long-day and short-day breeders. All mammals have a daily nocturnal rise in melatonin concentration (Peacock *et al.,* 1987).

The pineal gland has an important role in the transduction of photoperiodic information and parenchymatous pinealomas are associated with depressed gonadal function. It is considered that light is transmitted to the mammalian pineal via sympathetic fibres and it is probable that dark is transmitted via cholinergic pathways (Maxwell *et al.,* 1991). Light provides an inhibitory stimulus to the sympathetics and reduces pineal activity while augmented activity of the gland during darkness is due to a normally high tonic rate of somatic activity. In addition, the pineal gland may have its own independent rhythms of activity. The pineal is believed to have an antigonadal effect in mammals and a progonadal effect in birds (Maxwell *et al.,* 1991). In various domestic mammals, the light photoperiod facilitates the release of gonadotropic hormones whereas the dark photoperiod results in their increased synthesis. Prolongation of the light photoperiod causes decreased gonadotropin production consequent to a fatigue phenomenon brought about by inadequate duration of the dark photoperiod (Maxwell *et al.,* 1991). Long photoperiods increase the sensitivity of the GnRH pulse generator to the negative feedback effects of oestrogen, markedly decreasing LH pulsatility. In the absence of ovarian steroids, long photoperiods have considerably less influence on LH pulsatility (Love *et al.,* 1993). Evidence that the pineal gland may exert its antigonadotropic effect via the hypothalamic areas concerned with gonadotropin-releasing factors came from an experiment which demonstrated that the degree of acceleration of pubertal onset in female rats was the same following pinealectomy as for rats with anterior-basal hypothalamic lesions. The pineal gland does not induce persistent oestrus in constant light but has a role in controlling cycle length when photoperiods are shorter (Maxwell *et al.,* 1991).

Melatonin

Because light regulates the breeding cycle of seasonal species it therefore has special significance when animals are transferred to new latitudes (Yeates *et al.*, 1975). Photoperiod influences melatonin secretion and English *et al.* (1986) suggest that the duration of melatonin secretion is an important factor in the transduction process of photoperiod information in sheep. Ewes must be exposed to a minimal period of long days before they are able to respond to short days, either by early pubertal development or by an early onset of oestrous cycles in adults (English *et al.*, 1986). In immature female rats melatonin causes a decrease in ovarian growth. Melatonin has been found to be concentrated not only in the pineal gland, but also in the iris, ovary, brain, pituitary and vagina. In humans, melatonin has been shown to increase progesterone synthesis by the corpus luteum and stimulate the incorporation of acetate-1-^{14}C into androstenedione in the ovarian stroma. Melatonin thus seems capable of exerting a direct stimulatory effect on human ovarian steroidogenesis (Maxwell *et al.*, 1991).

Ellendorff and McConnell (1987) report that melatonin secretion in pigs remained at baseline levels in both short - dark (16 h light : 8 h dark) or long - dark (8 h light : 16 h dark) conditions, but there was a clear nocturnal surge of melatonin under 12 h light : 12 h dark conditions in 4 of 5 animals investigated in spring and in 2 of 4 animals following a 9 day adaptation period in autumn. Love *et al.* (1993) considers that nocturnal increases in melatonin are most likely to occur in pigs maintained under high light intensities and fed *ad libitum.*

The effects of duration of light periods on fertility

In a study of seasonal infertility in Cornwall (a mild climate county in the UK) Hancock (1988) reported that the period of subfertility coincided with the period of maximum total monthly hours of direct sunlight.

In a study by Peacock *et al.* (1987) in which sows were exposed to 16 h, 8 h, and natural photoperiods, no difference was found in weaning-to-oestrus interval, conception rate, farrowing rate or litter size. The same authors found that gradual reduction of light from 15 h 20 minutes by 20 minutes per week for 1 month resulted in a reduction of the weaning-to-oestrus interval from 23.6 days with natural photoperiod to 5.7 days under the lighting programme (Peacock *et al.*, 1987).

It seems that pigs are unable to respond appropriately to sudden changes in photoperiod (Love *et al.*, 1993). Perera *et al.* (1980) showed that sows exposed to a 24 hour-light regime exhibited behavioural oestrus for a longer period than those in a 12 hour-light : 12 hour-dark regime. The number of days to oestrus from weaning, conception rate, and litter size were the same for both light regimens and maximum serum levels of LH and oestrogen showed no differences. Mattioli *et al.* (1987) reported that a constant long day photoperiod (14 h light :

10 h dark) did not affect the weaning to oestrus interval but significantly improved the farrowing rate throughout the year (see summary information in Table 2-1). In line with previous proposals by Maxwell *et al.* (1991), Relkin (1976) proposed that the duration of the dark photoperiod, rather than the amount of light per day or the light : dark ratio, determines reproductive organ activity.

Table 2-1: Summary information for 3 separate studies on the effect of various light periods on sow fertility

	Peacock *et al.* (1980)	**Peacock *et al.* (1987)**			**Peacock *et al.* (1987)**	**Mattiole *et al.* (1987)**
Time exposed to light	24 h	16 h	8 h	natural	15 h 20 min. (-20 min./week for 1 mth.)	14 h
Wean-to-service interval	none	none	none	none	reduced from 23.6 d to 5.7 d	none
Conception rate	none	none	none	none		
Farrowing rate	none	none	none			improved
Litter size	none	none	none	none		
Oestrous behaviour	longer than 12 h					

Onset of puberty

Increasing day length advances the onset of puberty in gilts but temperature may interact with photoperiod in a more complex way. Thus while spring-born animals are stimulated to reach puberty earlier, this photoperiod effect is inhibited by high environmental temperature. Conversely, autumn-born gilts are stimulated by lower temperatures and inhibited by a shorter photoperiod (Enne and Greppi, 1993).

Photoperiod and boar fertility

Peacock *et al.* (1987) noted that for boars the total number of spermatozoa per ejaculate was higher in short day conditions than in long day conditions. They concluded that photoperiod changes sperm production by influencing the hypothalamo/pituitary axis, whereas high temperature has a direct destructive effect on the germ cells. They pointed out that in a trial conducted in Germany, boars showed improvement in libido, ejaculate volume, number of spermatozoa per ejaculate and number of insemination doses obtained per ejaculate when exposed to short light conditions. In bulls, sperm production was related to the length of the photoperiod although there was individual variation in sensitivity to day length. When the influence of the duration of the photoperiod and average monthly temperature on bull sperm production was investigated, greater variation was observed in relation to the photoperiod than to the temperature and humidity changes (Predojevic *et al.*, 1988). In the boar the pineal gland is not only involved in short-photoperiod-induced testicular regression, but it also participates in mediating the accelerating effects of long photoperiods on testicular development (Maxwell *et al.*, 1991).

Supplementary light

Wrathall (1975) reported that the average ovulation rate in gilts held in continuous light for one complete oestrous cycle did not differ from those in gilts kept in natural light. Conditions of light during lactation were found to have no effect on the weaning-to-oestrus interval in sows (Wrathall, 1975) but Hughes and Varley (1980) suggested that a lighting regime of 12 hours on and 12 hours off in the service house was optimal. Leman (1986) recommended 16 hours of light and 8 hours of darkness in breeding herds throughout the year with ½ watt for each square foot of living space. Tsoutsis (1986) recommended a minimum of 8 hours light for pregnant sows and 12 hours or more for others, while Lahrmann and Plonait (1984) favoured a constant 12 to 14 hour-day or an increasing photoperiod. The latter authors also suggested a tendency for smaller variations in fertility due to husbandry methods and seasonal factors if the service area was provided with more natural light. Wrathall (1987) recommended a regular 12-14 hours of light; 500-1000 lux at pig eye level each day to counteract the rapid decline in daylength in late summer and autumn which may induce the autumn abortion syndrome.

The duration of oestrus tends to be slightly longer in gilts when they receive extra light. When light treatments were continued post-mating into pregnancy, there were consistent increases, both in the number of embryos at 25 days, and in the number of piglets born at term. Light has a stimulating effect on corpora lutea and the increased progesterone levels from this effect result in enhanced embryo survival. A day length of 17 hours was found to be adequate (Wrathall, 1975). Supplementary lighting to give a 17 hour photoperiod increased the number of boars and gilts reaching puberty earlier than under normal natural light (Cornes, 1984). Continuous exposure to light does not affect ovulation rates but continuous darkness has been reported to hasten the onset of puberty (Peacock *et al.*, 1987). The feedback interplay between gonadal hormone and gonadotrophin is seasonally modified by a photoperiodic alteration of hypothalamic-pituitary activity (Mauget, 1982). In wild sows, the secretion of prolactin (Prl) was apparently influenced by seasonal variation in daylight and/or temperature. As in cyclic ewes, Prl of wild cyclic sows is high during anoestrus and sexual inactivity but it has not been clearly demonstrated that Prl causes anoestrus. The influence of light on Prl secretion in domestic pigs is low (Ravault *et al.*, 1982).

Both length of day and light quality influence photoperiodic response. The pineal gland has an important role in photoperiodic information transduction. It does not induce persistent oestrus in constant light but has a role in controlling cycle length when photoperiods are shorter. In sheep, melatonin secretion is an important factor in the transduction process of photoperiod information. In pigs, a nocturnal surge of melatonin was found under 12h light: 12 h dark condition.

The pineal gland is believed to mediate or control an anti-gonadal effect in mammals. Prolongation of the light photoperiod causes decreased gonadotropin production as a consequence of a fatigue phenomenon brought by an inadequate duration of the dark period. Pigs are unable to respond adequately to sudden changes in the photoperiod.

Heat and SI

Although the skin of the pig contains apocrine glands resembling sweat glands, physiological evidence indicates that these are non-functional (Signoret *et al.*, 1975; Baxter, 1984; Maijara, 1991). The pig's ability to dissipate heat is greatly increased by its wallowing behaviour and experimental evidence has shown that a coating of mud extends the period over which water is lost by evaporation (Baxter, 1984; Maijala, 1991). When the skin is wetted with clean water, the effect is short-lived, but when coated with wet mud, a high rate of evaporation persists for 2 hours (Signoret *et al.*, 1975). The environmental temperature range within which pigs do not have to make special efforts to maintain body temperature is called the thermo-neutral zone. The point at which the environmental temperature falls below this range is called the critical temperature, and at and below that point an increase in metabolic rate is necessary to maintain body temperature. At the point at which the environmental temperature rises above the thermo-neutral zone, attempts are made to expel excess heat (Peacock *et al.*, 1987). At environmental temperatures about 30 °C, pigs are able to cope well and only increase their rectal temperature by about 1 °C. However, beyond 30 °C, core temperature increases up to a point where the life of the animal is in danger (Nelson, 1979). While adult pigs will die if exposed to air temperatures over 36 °C and direct sunshine, they can withstand exposure to this temperature indefinitely if given access to mud wallows (Mount, 1968). Small rises above normal body temperatures of 39-42 °C may be fatal for pigs (Lambooij and van Putten, 1993).

Cooling mechanisms

Warm blooded animals exchange heat with the environment as evaporative and non-evaporative (sensible) heat (Baxter, 1984). Whereas evaporative heat loss essentially involves vaporisation of water, sensible heat exchange is effected through radiation, convection, and conduction (Mount, 1968). Pigs lose heat principally through conduction and convection (Signoret *et al.,* 1975; Baxter, 1984; Serres, 1992). Radiation, conduction and convection aid heat dissipation but the extent of each is dependent upon temperature, humidity and other environmental factors (Jensen *et al.*, 1980; Baxter, 1984).

Convective heat exchange depends on air temperature and the air movement rate in the vicinity of the subject. Conductive heat loss is often considerable since the pig spends a variable but often large proportion of time lying down (Mount, 1968). Loss of heat through the skin is a function of ambient temperature and loss of heat through the floor as a result of conduction can be significant (Serres, 1992). Conductive heat loss to the floor was reduced by 33% in piglets when the posture changed from stretched out and relaxed to crouched with limbs under the body with minimal floor contact (Signoret *et al.,* 1975). Nevertheless it is important to point out that floor temperature should not be maintained too low as this may cause vasoconstriction and reduce heat loss through conduction (Serres, 1992). Dilated blood vessels increase blood flow to surface tissues and induce heat loss (Baxter, 1984). If ambient temperatures are greater than 30 °C, floor temperatures between 25 and 27 °C are optimal for heat loss (Serres, 1992).

Up to an ambient temperature of 30 °C, ventilation has a beneficial effect on heat loss in relation to surface area. However, at 35 °C this is much lower as heat loss into the atmosphere is virtually nil (Serres, 1992). Relative heat losses by convection, radiation and conduction decline as environmental temperatures increase (Jensen, 1963; Mount, 1968; Baxter, 1984), to a point where animals respond by rapidly increasing the respiratory rate in an attempt to increase heat loss by the evaporation of moisture from the lungs (Jensen, 1963).

Evaporation of water is an important mechanism for heat loss (Jensen, 1963; Serres, 1992), and according to Serres, evaporation is achieved by loss of water vapour through the lungs during exhalation. He concluded that losses through evaporation predominate at temperatures above 30 °C. At high temperatures, evaporation necessarily becomes a major avenue of heat loss, even in pigs (Mount, 1968, Baxter, 1984). Evaporation of water from the snout and larynx is also an important part of the cooling system of pigs. The nasal and laryngeal cooling mechanisms of domesticated pigs have only 1/¼ the capacity of those of wild boars as a result of selection for short faces in domesticated pigs (Lambooij and van Putten, 1993).

At and below 25 °C, non-evaporative heat loss through the skin is the most important mechanism (Serres, 1992). Pig lungs are relatively small and it has been calculated that an increased respiratory rate from 20 to 250 breaths per minute would be required to reduce heat, but pigs can only endure 120 to 150 breaths per minute (Serres, 1992). Beyond this rate, pigs are unable to compensate and if panting is prolonged, the results can be fatal (Serres, 1992). High humidity also reduces pulmonary evaporation (Serres, 1992). At 30 °C, an increase in humidity from 30% to saturation at 94% will result in a modest increase in respiration rate in pigs of 90 kg live-weight. At 35 °C, animals are stressed and achieve heat balance with difficulty by increasing body temperature by 2.5 °C and doubling respiration rate (Serres, 1992).

Pigs exchange relatively small amounts of heat through cutaneous evaporation compared to man. In bare-skinned animals, evaporation of water from the body surface takes up most of the heat required for the process from the body itself, and so constitutes an efficient cooling mechanism. The actual quantity of heat involved per unit mass of water, whether this is derived exogenously or from sweat, depends not only on the latent heat of vaporisation, but also on the cooling of the vapour to ambient temperature, and its expansion to the water vapour pressure of the surrounding atmosphere (Mount, 1968). Serres (1992) calculated the average percentage heat loss from the various mechanisms as a function of ambient temperature (Table 2-2).

Table 2-2: Calculated relative average percentage heat loss from radiation, conduction and convection at different ambient temperatures with relative humidity 50%, air speed 7.5 m/min. for pigs of 50 kg and 150 kg liveweight (Serres, 1992)

Pigs of about 50 kg live weight				
Ambient temperature (^{0}C)	Loss through radiation (%)	Loss through conduction (%)	Loss through convection (%)	Latent heat (evaporation of water %)
10	35	11	46	8
15	33	12.5	42	12.5
20	18	8	40	24
25	16.5	8	37	28.5
30	18	6.5	31.5	44
35	5.5	4.5	15	75
Pigs of about 150 kg liveweight				
10	45	14	24	17
15	37	14	37	12
20	27	12	43	19
25	21	11	38	29
30	18	6	24	52
35	7	6	12	75

Heat stress and reproductive efficiency

Ambient temperatures which cause heat stress (denoted by an inability of the animal to maintain normal body temperature) may also affect reproductive function. Uterine lumen temperature is influenced by changing hormonal levels (presumably via changes in blood flow), and by the significant general body temperature rises which occur during oestrus. Low environmental temperatures generally do not affect reproduction, except when they reduce energy production in the animal (Hennessy, 1987a). Table 2-3 (Serres, 1992) shows the detrimental effects of higher ambient temperatures on reproduction.

Table 2-3: Effects of ambient temperature on reproductive behaviour and efficiency in sows

	26-27 °C	30 °C	33 °C
Number of sows	74	80	80
Number on heat	74	78	80
Number anoestrus	0	2	7
Number returning to oestrus	2	8	8
Number of sows pregnant	67	67	62
Pregnant sows (%)	90.5	84.8	77.5

From Serres (1992)

Heat stress and embryonic and foetal survival

Heat stress was considered to be the main factor causing either hormonal imbalance or whole litter losses (Hennessy, 1987a). Jensen (1963) reported that while temperature had no influence on number of eggs ovulated or conception rate, gilts placed into a 32 °C environment 3 days after breeding had fewer embryos than those left at 16 °C.

Sows were also found to be sensitive to heat at or around the time of mating (Hurtgen *et al.*, 1980b) and Almond (1992) noted that the decline in reproductive performance typically began in advance of the onset of hot weather. High temperatures during the first 15 days after mating may depress pregnancy rate, litter size, and embryo survival, but high temperatures between 15-30 days post mating or 53-61 days post mating had no effect on those parameters and did not lower reproductive performance (Paterson and Pett, 1987). Heat stress (35 °C) during days 1 to 5 of gestation appears to reduce the number of live embryos to a greater extent than heat stress imposed at day 20 to 25 (Pond and Maner, 1984), but in a separate study, temperatures of 35°C for 24 hours for pigs at 1, 5 and 20 days of gestation had no significant effect on reproductive performance, despite an increase in respiratory rate and rectal temperature. The effect of heat stress on pregnancy is considered to be most critical between days 8 and 16 for causing embryonic death, and again at days 100 to 110 for causing stillbirths (Reilly and Roberts, 1991).

Controlled experiments have been used extensively to investigate the effects of heat. Stress about mating time causes hormonal imbalances which are associated with delayed returns to oestrus. Cameron (1980) suggested that the effect of heat on sow fertility was more severe if it was imposed after 7 days post-mating rather than immediately following mating. Trujano and Wrathall (1986) demonstrated that cultured porcine embryos at the late primitive-streak early neural fold stage, are very sensitive to small rises in temperature. An adverse effect on embryonic survival was shown when thermal stress was applied during days 1 - 5 of gestation

(Tompkins *et al.*, 1967) when embryos at early cleavage stages are the most sensitive to heat damage. Between the end of the second week of pregnancy (after attachment) and the end of the third month, exposure even to very high environmental temperatures appears to have little or no direct effect. The adverse effects of very high temperature during late pregnancy on foetal and neonatal survival may be due to suppression of the spurt in adrenal growth and function which occurs in the foetus between day 100 of gestation and parturition (Dial *et al.*, 1984).

Exposure to high ambient temperature in the final stage of pregnancy (90-115 days) may produce foetal deaths and even sow deaths, as shown in a study by Paterson and Pett, 1987 in which exposure to high temperatures was sufficient to kill two gilts. Heat stress during early pregnancy caused total embryo loss in affected sows (Cameron, 1980). Heat stress four weeks after mating has resulted in whole litter loss with a subsequent delayed return to oestrus (Wrathall, 1975), while heat stress during late pregnancy increased the prevalence of stillbirths at farrowing (Day, 1979). Wrathall (1975) found that when pigs were exposed to extreme heat during the two weeks before farrowing, almost half of the piglets were born dead. In contrast, Heitman *et al.* (1951) and Pond and Maner (1974) found that parturition was normal in pregnant sows (85 days of pregnancy to term) exposed to temperature as high as 37.2 °C. On the other hand, Day (1979) considered elevated ambient temperature to be a major cause of decreased fertility. Exposure to high temperatures causes foetal death in some animals, but it seems that the sow is comparatively less sensitive to high-temperature stress, or at least to stress causing foetal mortality (Pond and Maner, 1984).

Heat stress and oestrus

High temperatures during the oestrous cycle have little effect on the proportion of sows which display oestrus, but there is evidence that cycle length, duration of oestrus and the timing of ovulation may be affected (Paterson and Pett, 1987).

Paterson and Pett (1987) showed that oestrous cycles were lengthened by 1.4 days in gilts held at a temperature of 38 °C for a period of 17 hours and 32 °C for 7 hours continued over 6 days before expected oestrus. If the treatment was given 3 days before expected oestrus, there was no effect on oestrous cycle length. The same authors reported a decline in plasma progesterone in gilts exposed to high ambient temperatures (38 °C for 17 hours and 32 °C for 7 hours) from days 13 to 18 of the oestrous cycle. Oestrous cycles of sows may be disrupted by short periods of high temperature if they correspond to the time of luteal regression or the late follicular phase (Paterson and Pett, 1987). High environmental temperatures (in excess of 33 °C) have been shown in both field studies and under experimental conditions to cause an increase in the incidence of anoestrus, embryonic death and in the prevalence of stillborn piglets (Cameron, 1981a). The relationship between anoestrus and ambient temperature does not appear to be simple, and body weight, age and parity also appear to play a role (Reilly and Roberts, 1991).

In a retrospective study on two farms in England (from October 1987 to August 1988), Reilly and Roberts (1991) found that the percentage of regular returns to oestrus in summer remained constant at 7.13%, as for the other months of year; but the percentage of irregular and late returns increased from 7.24% to a peak of 20.4% in July. No significant association was found between maximum, minimum and mean temperature, daily sunlight and rate of change of all these factors with daily percentage abnormal returns to oestrus. Of those returning abnormally, 66% returned between 35 days and 38 days post service, 24% returned between 46 days and 57 days post service, and the remaining 10% after an interval of >67 days. High temperatures were associated with abnormal returns to oestrus and, furthermore, they had their effect predominantly between 6 and 9 days prior to the sows returning. Most sows returned in the normal period of between 22 and 37 days.

Warnick *et al.* (1965) found no difference in ovulation rate in pigs kept in pasture lots under Florida summer conditions and pigs kept at controlled temperatures of 15.6 and 32.2 °C during breeding. They suggested that the stress imposed was not sufficiently severe to influence the rate. On the other hand, Tompkins *et al.* (1967) reported a decrease in the number of viable embryos per 100 corpora lutea when the pigs were exposed to heat for 48 hours.

Although the duration of the oestrous cycle is apparently unaffected by moderately high environmental temperature, ovulation rates may be slightly reduced in heat stressed gilts, particularly when the period of exposure lasts for several days prior to ovulation (Wrathall, 1975). Exposure to extreme heat during the pre-attachment period (0-14 days) in pregnant gilts and sows can undoubtedly have adverse effects on embryo survival, with partial and whole litter losses. The underlying cause may be due to direct temperature effects on the conceptuses, or from the effects on the maternal endocrine mechanism (Wrathall, 1975).

Gilts exposed to high environmental temperature may show delayed and shortened oestrus and a decrease in conception rate and early embryonic survival (Day, 1979). High ambient temperatures have a detrimental effect on fertilized eggs and may impair egg implantation particularly during the first two weeks after breeding. Affected animals return to oestrus within the normal period or a few days later (Wu, 1986).

Different LH levels of response were found between breeds in cycling Duroc and Hampshire gilts, kept at either 21 °C and 35% relative humidity or 32 °C and 75% relative humidity. The LH level responded to the hot environment quite differently between the breeds. No real difference was seen in the preovulatory LH surge in Durocs, but a 3.5 to 6 fold increase was recorded in Hampshires (Jöchle and Lamond, 1980).

Summary

Pig sweat glands are non-functional and heat regulation is effected mainly through conduction and convection but these mechanisms become ineffective at high ambient temperatures and high humidity. Pigs then respond by increasing the respiratory rate in an attempt to increase heat loss by evaporation of moisture from their lungs. This mechanism predominates at temperatures above 30 °C.

High temperatures during the first 15 days after service may depress pregnancy rate, litter size, and embryo survival. The effect of heat on sow fertility has been shown to be more severe when imposed > 7 days after service than when experienced immediately post service. The duration of the oestrous cycle does not appear to be affected by moderately high environmental temperatures.

Effects of housing on SI

Sows confined to crates after weaning had a higher farrowing rate than sows in groups of 6 - 20 sows (Cameron, 1987; Devendra and Fuller, 1979; Dial *et al.*, 1984; Hurtgen *et al.*, 1980a). Almond (1992) reported that placement of sows into individual stalls at weaning reduced the weaning to oestrus interval, allowed multiple matings, improved farrowing rates, and increased the percentage of sows bred within 7 days after weaning. The rate of post-weaning return to oestrus was 10.4% greater for sows confined to crates than for sows in group-housing systems, but the seasonal pattern of post-weaning returns to oestrus was not altered (Buddle and Hawkins, 1984; Cameron, 1987). Wratthall's (1975) contrasting conclusion that weaning-to-service intervals could often be very unsatisfactory when sows were confined in stalls after weaning was supported by Fahmy and Dufour's (1976) study, which showed that individual penning of sows leads to fewer sows becoming pregnant after service, or attempted service, than was the case for sows reared in groups.

Groups of bred females with a boar present after mating had a markedly higher farrowing rate than groups of sows housed in the absence of boar. This effect was due to a lower incidence of delayed repeat breedings and a reduced prevalence of "not-in-pig" sows. The explanations offered by Wilson and Love (1986) for the effect was that the fighting between females at mixing and consequent stress was reduced by the presence of a boar, while pheromones present in the grouped females' urine induced oestrus suppression and pseudopregnancy. In contrast, Pearce and Pearce (1992) reported that sows in oestrus have a stimulating effect on induction of oestrus in weaned sows. Mixing of older pregnant sows with young newly mated sows under the normal crowded conditions associated with domestication adversely affected pregnancy rate in the younger sows, suggesting an effect from dominance on reproductive success (Wilson and Love, 1990). Love *et al.* (1993) found seasonal infertility to be clustered in some groups of pigs at the same time and in the same building, and suggested that group size and social contacts may influence reproductive success. Their study suggested that groups of five or six sows appear to be less affected by seasonal infertility than larger groups.

Te Brake and Aalbers (1987) found the proportions of sows coming into oestrus within 7 days of weaning and within 7 days of PG600 treatment to be similar for sows housed individually or in groups of 5 after weaning. Tethered gilts came into first oestrus on average 4 days later than group-housed gilts (Jensen *et al.*, 1970), while Mavrogenis and Robinson (1976) found even larger differences between gilts in stalls and gilts housed in groups.

The use of evaporative cooling or water sprinkling systems during the postweaning period appeared to have no useful effect on seasonal anoestrus (Cameron, 1980). It has been suggested that either high environmental temperatures may not be solely responsible for seasonal anoestrus (Hurtgen and Leman, 1980), or that under conditions of saturated relative humidity the efficiency of evaporative cooling systems is reduced (Holmes, 1979). Hurtgen and Wingert (1980) found that water fogging for gilts or boars for 2 months prior to breeding to at least 6 weeks after breeding gave no benefits for oestrus, pregnancy or farrowing rates. Mechanical methods of cooling sows and gilts during warm weather similarly had little effect on oestrus activity and fertility of sows and gilts. On the other hand, Cerne (1987) reported that cooling breeding animals during hot summer time by water fogging was superior to sprinkling or using water lagoons and helped to prevent infertility.

Reproductive problems may reflect poor welfare during the gestation period and problems at farrowing (Fraser and Broom, 1990). On commercial farms which have well-managed stall units, reproductive problems are generally thought to be no more frequent than on units with group-housing. It is likely that variation in unit size or in stockmanship modify effects and contribute to some of the differences reported (Fraser and Broom, 1990).

In summary, placement of sows into individual stalls at weaning reduced the weaning to oestrus interval, permitted multiple matings, improved farrowing rates, and increased the percentage of sows bred within 7 days after weaning. In group systems, the presence of a boar after mating can be expected to markedly improve farrowing rates. Older pregnant sows may dominate young newly mated sows under crowded conditions and lead to reproductive failure in the younger sows.

Although the issue is not yet completely resolved it appears that the use of evaporative, water sprinking, or fogging cooling systems offer no advantage for oestrus, pregnancy or farrowing rate. This suggests that factors other than heat are more important in reproductive failure in pigs.

Stress and SI

Stress is a non-specific, long term response of an animal, which is attempting to resist or to adapt to stressors in order to maintain homeostasis (Wrathall, 1975). The stressor agent may be pleasant or unpleasant but still produce the same biological stress response, which is non-specific and common to all types of exposure (Andrews, 1992). It is a general adaptive mechanism involving a variety of behavioural and physiological changes, with particular reference to changes in endocrine balance within the pituitary-adrenal axis (Wrathall, 1975) causing release of glucocorticoids, mainly cortisol and corticosterone (Andrews, 1992). Stimuli (stressors) affect the adrenocortical system primarily via neural/pathways to the hypothalamus where neuronal secretion of CRF into the hypothalamo-hypophyseal portal vasculature is stimulated (Dallman and Wilkinson, 1979).

Raised corticosteroid levels are an indicator of stress but they are also influenced by circadian rhythms, age and reproductive and emotional status (Andrews, 1992). Acute stressors activate the hypothalamic-pituitary-adrenal axis and cause rapid elevations in plasma ACTH and glucocorticoids (Harbuz and Lightman, 1992). Corticosteroid levels tend to rise abruptly when ruminants and pigs are subjected to acute stress (Andrews, 1992). Under the influence of constant or chronic intermittent stressors, plasma ACTH and/or glucocorticoids decline despite continued stimulus application (Rivier and Vale, 1987) due to a decrease in receptors on adrenohypophyseal corticotropes to corticotropin release factor (Andrews, 1992). Chronic intermittent stressor-associated changes occur in the function of the porcine pituitary-adrenal axis which are not apparent when considering only basal hormonal concentrations (Klemcke, 1994). ACTH release increases corticosteroid and, in particular, cortisol to help counteract the stressor by combining the physiological modifications. This sequence of events is known as the general adaptation syndrome (GAS) (Andrews, 1992).

Stress-related endogenous opioid peptide release plays a physiological role in suppressing ovarian activity in sows (Almond, 1992). The endocrine responses clearly become more difficult to assess when proceeding from short-term to long-term adaptation, and there is often a tendency to try to predict the acquired pattern from the immediate responses to temperature change. This may not be justified, for when adaptation has occurred, exposure to the given temperature is no longer stressful, unless there is reversion to the unadapted condition again (Collins, 1978).

Heat and cold weather cause significant changes in the immune system of animals. Both antibody and cell-mediated immunity are affected and different environmental stressors can facilitate or suppress either of these responses. Additionally, a single stressor can enhance or suppress cell-mediated immune events (Kelley, 1982).

Wan and Hennessy (1987) reported seasonal variation in the total level of stress acting on breeding pig populations and an association between basal plasma cortisol concentrations and subsequent reproductive performance. They demonstrated a predisposition to stress-related infertility in individual pigs which showed a large adrenal response to stress (high responders) and differences in body condition and/or sexual behaviour between infertile and fertile pigs.

Adrenaline released via stressors causes increased blood pressure and raised heart rate and cardiac output. In chronic distress there may be persistent secretion of adrenaline and noradrenaline with decreasing levels of plasma glucocorticoids (Andrews, 1992). Psychological stress or any psychosomatic factor may inhibit the timely passage of semen and it is well established that adrenaline release under stress conditions has an antagonistic effect on oxytocin and inhibits the myometrial contractile responses (Huges and Varley, 1980). Infertile pigs had a greater adrenal response to higher level of stress acting in summer (Wan and Hennessy, 1987).

In conclusion, the level of stress for breeding pig populations varies with season of the year and there is an association between basal plasma cortisol concentration and subsequent reproductive performance. Pigs respond to a stressor by increased secretion of ACTH, which in turn, results in increased corticosteroid production, depending on the sensitivity of the hypothalamus, hypophysis and adrenal gland. ACTH or corticosteroids can completely inhibit oestrous behaviours.

Season of year and the hormonal system

In thermoregulation two main components of the neuro-endocrine system are involved. Firstly, the hypothalamo-hypophyseal axes that control thyroid, growth, and adrenocortical hormones, act together with the sympathico-adrenomedullary system with a dual response from

(a) the stress of a change in environmental temperature and

(b) increased metabolic requirements in cold and reduced metabolism in hot conditions (Aschof, 1978a).

Dial and Almond (1987) consider that the failure of some sows to resume oestrous activity following weaning during the summer is not a consequence of either pituitary or ovarian dysfunction, but is more probably due to failure of the hypothalamus to recommence normal pulsatile GnRH secretion following weaning. Insufficient production of GnRH in summer may be a factor in seasonal anoestrus (Peacock *et al.*, 1987) and postweaning anoestrus (Almond, 1992; Love *et al.*, 1993). It seems that the hypothalamo-hypophyseal-ovarian axis of the anoestrus sow is potentially functional, but failure to commence increased pulsatile LH secretion is reflected by inadequate follicular development following weaning. Thus, the failure of increased follicular secretion of oestrogen precludes the preovulatory surge of the LH required for the final follicle maturation and ovulation (Almond, 1992). The hypothalamic feedback centres of the seasonally anestrous sows are more responsive to ovarian oestradiol in sows which are able to resume oestrous cyclicity following weaning during the summer (Dial and Almond, 1987). These same authors also report that the feedback inhibition by ovarian steroids is greater in anestrous sows than in cyclic females and consider that this hyper-responsiveness may be mediated via ovarian oestradiol.

During the breeding season, a high basal, high frequency, low amplitude pattern of LH secretion is seen, while during the non-breeding season a low basal, low frequency, high amplitude pattern occurs. In addition, during summer both basal LH levels and pulse amplitude are higher than in the other seasons (Peacock *et al.*, 1987). When such an LH increase occurs the breeding season commences, but if the LH rise fails to occur anoestrus prevails (Karsch *et al.*, 1980). Karsch *et al.* (1980) put forward the view that photoperiod evokes its action independently of oestradiol, with the steroid being required for expression of this effect in terms of LH secretion. A study by van de Wiel and Booman (1993) on primiparous sows showed that during lactation the basal and mean levels of LH were significantly lower in anoestrus than in oestrus sows, and the post-weaning basal and mean levels of LH were also significantly lower in anoestrus than in oestrus sows. They concluded that lowered secretion of LH may play a role in the aetiology of post-weaning anoestrus in the sow. Oestradiol exerts its stimulating effects on gonadotrophic secretion in the pig via the hypothalamus rather than via the pituitary. Pituitaries of anoestrus sows are far less able to respond to GnRH with LH release than those of the cyclic sow and this reduced response may simply reflect a deficiency in hypothalamic trophic support of the pituitaries of the acyclic females (Dial *et al.*, 1984).

During each oestrous cycle, progesterone is an important steroidal inhibitor of LH secretion. In ovariectomized ewes, there is a profound seasonal change in the capacity of oestradiol to inhibit tonic LH secretion (Karsch *et al.*, 1980). Luteal progesterone, perhaps acting in concert with low levels of oestradiol produced by small ovarian follicles, inhibits LH release in dioestrus sow (Dial and Almond, 1987). Seasonal changes in tonic LH secretion have also been reported in the ram, in numerous other mammals, and in birds (Karsch *et al.*, 1980).

In sows in early pregnancy, mean plasma LH concentrations were higher in summer than in winter, but in late pregnancy, gilts had lower mean and baseline LH concentrations in summer than in winter. This findings led Love *et al.* (1993) to suggest the lower LH concentrations in summer as the cause of the 'autumn abortion syndrome'. They also hypothesised that the high plasma concentrations of LH in sows during early pregnancy may provide an inappropriate stimulus to ovarian receptors (causing down regulation), and result in lower progesterone production generally, and failure to maintain corpora lutea in some sows. Steroid dependence might signify an influence of photoperiod on the intracellular oestradiol-response system within the centre(s) controlling tonic LH secretion. On the other hand, steroid-independent changes may signify a direct photoperiodic drive on the tonic control centre(s) by mechanisms not involving steroid-hormone action. Oestradiol is required for the seasonal change in LH, regardless of the time of day. In ewes, it appears that there may be a seasonal shift in tonic LH secretion which does not depend on gonadal steroids (Karsch *et al.,* 1980).

Progesterone levels were significantly lower in September (autumn) in England than in other months (Wrathall, 1982). It seemed that hormonal support for reproduction was weaker in the autumn than at other times, and he suggested that lower LH and progesterone levels, associated with declining daylength, might be a predisposing factor for the autumn abortion syndrome. The corpora lutea formed in summer and autumn were apparently competent and responsive, but their lower autumnal progesterone production probably resulted from reduced luteotropic stimulation at that time, rather than any inherent luteal deficiency (Wrathall, 1987).

Martinat-Botte *et al.* (1987) suggested that high prolactin levels probably enhance corpus luteum function and progesterone secretion but lower autumn prolactin levels may reflect more sensitivity to lowered LH levels due to negative feed back mechanisms. They suggested that prolactin might be involved in the control of oestrogen production and in this way in conceptus survival in the sow, because excess of oestrogen (production in autumn) may have a deleterious effect on litter size.

Luteinizing hormone (LH)

A study by Dial and Almond (1987) showed that oestradiol was present in sufficient concentrations in the blood of the anestrous sow to inhibit pulsatile LH release, resulting in infrequent, irregular pulses prior to ovariectomy. The hypothalamo-hypophyseal axis of the anoestrus sow was more responsive to the negative feedback effects of the ovary than the cyclic female. Removal of feedback inhibition by ovariectomy resulted in an exaggerated LH release in the anoestrus sow. Ovarian inhibition of the seasonally anoestrus sow was greater than that of the cyclic sow. They concluded that the reason sows become anoestrus after weaning is probably due to rising levels of oestradiol (as sows progress in lactation there is a gradual increase in follicle size and circulating levels of oestradiol) inhibiting increases in the pulsatile LH releases which typically occur following weaning. Subsequently, there is little follicular development, and the sow remains persistently anoestrus following weaning during the summer, until it becomes less responsive to ovarian secretions when it enters the fall breeding season. Following weaning, there is an initial increased pulsatile secretion of LH in sows destined to remain anoestrus similar to that occurring in sows which resume oestrous cyclicity following weaning. These postweaning increases in LH secretion initiate follicular development with modest increases in circulating levels of oestradiol, which are nevertheless sufficient to prematurely shut-down the pulsatile secretion of LH in the hyper-responsive sow, with persistent anoestrus resulting.

Adrenocorticotropic hormone (ACTH)

Both ACTH and corticosteroids can completely inhibit oestrus behaviour. Sows injected with ACTH during oestrus form cystic follicles resulting in return to oestrus after a normal cycle length, delayed return to oestrus or prolonged anoestrus (Day, 1979; Love, 1981b; Wan and Hennessy, 1987). In pigs, frustration can raise ACTH levels, and corticoid levels accordingly, to interfere with and either suppress or postpone ovulations (Jöchle and Lamond, 1980). ACTH and hydrocortisone suppress pituitary responsiveness to LH-RH and/or decrease the secretion of LH-RH from the hypothalamus. Adrenocorticoid activation in the pre-implantation phase has also been reported to inhibit fertility. Euker and Riegle (1973) reported that although ACTH injection during the pre-implantation phase did not alter the time interval required for ova to enter the uterus in rats, the number of implantations was reduced. The same authors noted that stress and/or increased adrenal corticosteroid in sheep have been associated with increased embryonic losses following implantation. It is still unclear whether the effects of heat stress on infertility include suppression at the hypothalamus or pituitary level, or whether there is direct action on the ovaries with disruption of the differentiation of FSH-stimulated granulosa cells (Wan and Hennessy, 1987). Plasma concentration of 17-hydroxy corticosteroids in the pig have been shown to increase during exposure to 40 °C for 40 minutes, and plasma concentration of corticosteroids and adrenocorticotrophic hormone (ACTH) similarly increased during acute terminal heat exposure of pigs (Holmes, 1979). Jackson and Hennessy (1987) found that the diurnal pattern of serum cortisol was influenced by photoperiod. Adrenal responses showed highly significant between-farm, between-month and between-sex differences but the variation between months was not correlated with environmental temperature. Pond and Maner (1974) showed that urinary excretion of breakdown products of adrenal medulla hormone increased sharply during exposure to extreme temperature (cold-5 °C or heat-33 °C) and decreased during starvation.

Pigs may be divided into 2 groups, - high and low responders - on the basis of their response to stress. Adrenocortical cells from high responders produce less cortisol, on a per-cell basis, than low responders. High responding pigs have longer adrenal glands and higher adrenocortical cell density, and these factors may be responsible for higher output of cortisol after ACTH administration or exposure to stressors. Pigs of the same age, sex, body weight and genetic strain vary considerably in adrenocortical response to a standard dose of ACTH, although in pigs of the same genetic origin, the metabolic clearance rate of cortisol was similar for high and low responders. The ability of young pigs to produce adrenocorticoids probably allows them to adapt quickly and efficiently to new environmental conditions (Zhang *et al.,* 1990).

Pigs respond to stressors with increased secretion of ACTH, which in turn results in increased corticosteroid secretion depending on the sensitivity of the hypothalamus, hypophysis and adrenal gland (Hennessy *et al.,* 1988). Pigs which produce large amounts of cortisol in response to stressful events are more likely to suffer from delayed puberty or seasonal infertility. Wan and Hennessy (1987) found that parity 1 pigs which showed a high response to ACTH had lower farrowing rates than other parities, where rates were similar for both low and high responding animals. They concluded that sows with parity >1 had a greater capacity for adaptation to stress than parity 1 sows. In turkeys and chickens, similar between-line differences in adrenocortical responsiveness to temperature stress have been reported (Hennessy *et al.,* 1988).

Progestagens

The secretion of adrenal progestagen is increased by excessive ACTH, irrespective of whether the source is endogenous or exogenous. Progesterone treatment inhibits ovulation in pigs and also can produce a high incidence of cystic ovaries by suppressing the pre-ovulatory surge of LH. ACTH bring about (through stimulation of adrenal gland) a suppression of the LH release. Both corticosteroid and ACTH administration depresses testicular steroid production resulting in reduced reproductive performance and loss of libido (Wrathall, 1975).

Mean progesterone levels have been found to be high in both cyclic and pregnant wild pigs. In wild pigs with no functional corpus luteum, progesterone levels were somewhat higher than the generally reported basal levels (about 1 ng/ml) of domestic sows (Mauget, 1987). Measurements of sex steroids in uterine luminal fluids of animals have shown selective concentration of particular steroids in histotroph relative to plasma (Stone *et al.,* 1986).

Prolactin

Prolactin, unlike the other anterior pituitary hormones, appears to be primarily controlled by an inhibiting factor, prolactin inhibiting factor (PIF), which holds hormonal secretion in check, and without which excessive secretion of prolactin results. In male rats, constant darkness depressed concentrations of pituitary prolactin and elevated plasma prolactin levels. Constant darkness increased pineal activity by restraining PIF activity, in turn causing an increased release of prolactin from the pituitary with resultant decreased pituitary prolactin stores and raised plasma levels (Maxwell *et al.*, 1991). Prolactin appears to be an endocrine link between changes in daylength and changes in metabolism (Mauget, 1987). Stone *et al.* (1986) suggest that prolactin may be involved in implantation because it is released by human endometrial tissue during the menstrual cycle, and they also suggest that prolactin promotes the survival and transport of spermatozoa within the uterus. In pigs, the rate of secretion of prolactin increases at higher temperatures (Holmes, 1979). The sensitivity of wild boars to the annual variations of photoperiod was indirectly investigated by studying seasonal changes in plasma prolactin concentration. A seasonal rhythm occurred with peak levels in summer and minimum values in winter in accordance with seasonal changes in natural daylength (Mauget, 1982). The annual cycle of prolactin secretion reported in wild sows reflects sensitivity to the length of daylight (Mauget, 1987).

Progesterone

High temperature during early pregnancy alters the reproductive endocrine system and in particular the control of luteal function. High temperatures increase plasma oestrogen which reduces embryo survival and extends luteal function (Paterson and Pett, 1987).

Hennessy and Williamson (1984) conducted a study in a 600 sow breeding farm in Australia and found that separate distinct levels of plasma progesterone concentration in sows bled 18 days after mating allowing 2 classes of non-pregnant infertile sows to be distinguished; those with high plasma progesterone 18 days after mating and those with low progesterone. They suggested that high progesterone levels 18 days after mating pointed to embryonic death and resorption of embryos without regression of corpus lutea, or porcine parvovirus disease. High progesterone and absence of cyclic activity is consistent with luteinized ovarian cysts. Low progesterone and non-cycling are consistent with production of small ovarian cysts later regressing and leaving inactive ovaries. High progesterone and low oestrone sulphate levels are probably associated with delayed returns to oestrus and failed pregnancies with embryo deaths very early in pregnancy, so that by 3 weeks, oestrone sulphate concentrations have fallen, but the corpora lutea have not regressed (Hennessy and Williamson, 1984).

Based on these principles, Mattioli *et al.* (1987) recommended treatments with PMSG (day

15 post-partum) and HCG (day 18 post-partum) to induce fertile oestrus in lactating sows and eliminate the problem of the increased weaning to oestrus intervals occurring during the summer. Animals with normal lactation lengths treated in this way had reduced farrowing intervals and larger litters. Van de Wiel and Booman (1993) conducted a limited trial with seven primiparous anestrous sows (Dutch-Swedish Landrace crossbred - a breed known for its high incidence (up to 70%) of post-weaning anoestrus in primiparous sows) and showed that injection of gonadotropins resulted in an LH surge, oestrus and ovulation in only three sows, although oestradiol levels were increased in six sows.

In summary, summer GnRH insufficiency may be a factor in seasonal anoestrus and post-weaning anoestrus. Feedback inhibition by ovarian steriods is greater in anoestrus sows than in cyclic females and it is likely that this hyper-responsiveness may be mediated via ovarian oestradiol. LH was significantly lower in anoestrus than in oestrus sows, indicating a role for LH in the aetiology of post-weaning anoestrus in sows. Luteal progesterone, with low levels of oestradiol produced by small ovarian follicles, inhibits LH release in dioestrus sows.

High plasma concentrations of LH in sows during early pregnancy may provide an inappropriate stimulus to ovarian receptors, resulting in lower progesterone production and failure to maintain the corpora lutea in some sows. Low LH and progesterone levels associated with declining day length may be a predisposing factor for the autumn abortion syndrome. It is likely that sows become anoestrus after weaning because rising levels of oestradiol inhibit the increase in the pulsatile LH release that typically occurs following weaning.

Prolactin appears to be an endocrine link between changes in daylength and changes in metabolism. Constant darkness increases pineal activity by restraining PIF activity, which in turn causes increased release of prolactin from the pituitary with resultant decreased pituitary prolactin stores and raised plasma levels.

Nutrition and SI

Farmers usually alter their pig feed ration in summer. An altered ration may cause overall physical and physiologic changes with specific effects on the reproductive system. Animals "at risk", *i.e.* with no prophylactic adaptation to the altered feed ration, have a relative risk of about 2-3 of developing failure of reproduction and/or metabolic disturbances. Sows require a high level of nutrients in order to achieve maximum ovulation rates, and the practice of flushing before oestrus is now commonplace in piggeries, but the levels need to be reduced immediately after mating in order to achieve maximum implantations (Jöchle and Lamond, 1980). Extreme changes should be avoided as Stork (1979) found that rapid and extreme changes in energy balance from positive to negative could result in abortion.

The level of nutrition can affect reproductive performance in a number of ways. Undernutrition delays the development of the reproductive system and may impair its function after puberty. Nutritional inadequacies are reflected in decreased secretion of pituitary hormones involved in reproductive function, such as the FSH, LH and prolactin. Undernutrition and in particular hypoglycaemia lead to a reduction or inhibition of GnRH secretion (Bondi, 1987). Undernutrition of sexually mature females may prevent ovulation or fertilization, or increase the incidence of early embryonic mortality (Bondi, 1987).

Dry sow feed of 3-3.5 kg per day of a 12.5 MJ/kg diet for group-housed sows and approximately 2.7 kg per day for individually housed sows for the first 4 weeks of pregnancy during summer and autumn have been recommended to alleviate the low farrowing rate problem (Love, 1993).

The efficiency of energy utilization for pregnancy is far superior in pigs compared to ruminants. Although pigs deliver litters of 4-12 piglets, the relative increase in the amount of energy required for pregnancy is comparatively small (Bondi, 1987).

Sows that lose an excessive amount of body weight or condition during lactation have extended remating intervals and an increased incidence of anoestrus. Inadequate protein or amino acid, and in particular lysine intakes during gestation and lactation result in delayed resumption of normal oestrus activity (Ferrell, 1991). The same author also found that loss of body fat during lactation was more highly correlated with delayed return or non-return to oestrus than weight loss. Almond's (1992) suggested that energy intake during lactation may not be as important as was previously thought, whereas protein intake during lactation probably exerts a far greater influence on the weaning to oestrus interval in first-litter sows, and furthermore that the effect of protein intake occurs independently of energy intake. In wild animals, low food availability has been often reported to delay onset of puberty or the onset of sexual activity (Mauget 1982, 1987). Reese *et al.* (access in 1994) found that sows fed supplementary fat (4 or 8% rapeseed oil) had a lower incidence of infertility and seasonal anoestrus than unsupplemented sows.

Pigs respond to heat by reducing their food consumption and as a result produce less heat and ease problems of heat dissipation (Devendra and Fuller, 1979). Ambient temperature has been shown to influence food intake: pigs ate less as ambient temperatures increased from 4 °C to 38 °C (Signoret *et al.*, 1975). The decrease in appetite was not progressive and feeding behaviour was unaltered under conditions of constant temperatures up to 30 °C. A sudden onset of loss of appetite occurs when animals come under metabolic stress at temperatures about 35 °C (Serres, 1992). The effect of sow feed intake appears to be mediated mainly through body condition rather than overall body weight, since body condition influences post-weaning fertility more than body weight. Body condition scoring is commonly used to gauge nutritional status and the degree of fatness at weaning. Progesterone levels are reduced by prolonged underfeeding (Wrathall, 1987) and this response may be the physiological pathway for the underfeeding effect on the autumn abortion syndrome. Problems associated with providing adequate feed intake during lactation are likely to be more serious in high producing herds (Lynch and Kearney, 1987).

Vitamin C

Cerne (1987) reported that the addition of 2.0-4.0 g of ascorbic acid to daily rations during the summer months helped to prevent summer deterioration of semen quality but there appears to be no effect from vitamin C supplementation on sow productivity. Greer *et al.* (1987) reported that vitamin C supplementation had no effect on the weaning-to-conception interval of sows, on the number of piglets born alive, stillborn and weaned per litter, or on pre-weaning mortality or litter and piglet weaning weight. Cox *et al.* (1983) reported that supplementing diets with fat in summer reduced the weaning to oestrus interval from 20.92.1 to 12.62.1 days and increased the percentage of sows in oestrus by 10 days post-weaning from 34 % to 59 %.

Stress, phyto-oestrogens and mycotoxins

Stress may influence adrenal and ovarian function and may also affect the permeability of the gut, permitting transient toxaemias (Stork, 1979). Plant phyto-oestrogen levels vary according to season and alfalfa and clover have their highest levels during the height of the early summer growth season (Jöchle and Lamond, 1980). *Fusarium roseum* is an F-2 toxin producing mould found in many plant materials, and in particular in cereal grain. It grows on standing corn in late autumn-winter and on stored ear corn (Nelson, 1979). Ingestion of the mycotoxin during the stage of early pregnancy caused small litters, and ingestion during the first half of pregnancy resulted in an increased proportion of weak and splayleg piglets (Wrathall, 1975). It is also probable that toxins occurring in mouldy foods are responsible for some autumn abortions (Stork, 1979).

In summary,

- Rapid and extreme changes in energy balance from positive to negative may induce abortions.
- Nutritional inadequacies are reflected in decreased secretion of the pituitary hormones involved in reproductive function, such as FSH, LH and prolactin.
- Sows that lose an excessive amount of body weight or condition during lactation have extended remating intervals and an increased incidence of anoestrus.

- Progesterone levels are reduced by prolonged underfeeding, and this response may be the physiological pathway for the underfeeding effect for the autumn abortion syndrome.

The boar and SI

An increase in testicular temperature will reduce fertility in the boar, as in males of other species. Semen production and semen quality are adversely affected when boars are exposed to temperatures around 31 °C and 35 °C for 72 hours or more (Cameron, 1987). Sperm motility in ejaculates was reduced when air temperatures reached 30 °C and this response was presumed to be from hyperthermia in epididymal tissues, in line with increasing scrotal surface temperature at that air temperature (Stone, 1982). Alterations to both sperm motility and morphology have been also demonstrated 2-4 weeks after heat stress with 35 °C and 40% relative humidity (Larsson and Malmgren, 1984).

The close proximity of scrotal skin and subcutaneous scrotal tissues to the surface of the testis can result in synchronous changes in temperature of the scrotal surface and blood flowing through superficial veins and arteries of the testis. In many male mammals, including the boar, blood perfusing the testis first flows over the testis surface, then toward the mediastinum causing scrotal and testis temperatures to be closely inter-related when air temperatures are high. Changes in temperature of the scrotal surface of boars thus reflect changes in the temperature of testicular and epididymal tissues (Stone, 1982). Local heat treatment (testicular temperature of 40.5 °C) was shown by Cameron (1987) to have an immediate effect on spermatogenesis, with the principal damage being to the spermatocytes, and in particular, the pachytene spermatocytes in stage 8 of the cycle of the spermatogenic epithelium.

Stone (1982) increased temperatures by 1 °C per day from 20 °C for 20 days and reported that the proportion of abnormal types of sperm increased to a maximum in the last week of heating but then returned to pre-treatment values 5 weeks later. The high numbers of sperm with kinoplasmic droplets appearing in ejaculates collected after heating indicates that epididymal cell types in the boar are sensitive to heat (Stone, 1982). Boar reproductive functions seem to be affected only at extremes of temperature and daylight duration (Paquignon, 1987). The critical environmental temperature above which boar fertility is impaired is less than 34 °C and relatively short exposures (6 hr/day for 4 days) of boars to temperatures above that threshold will impair fertility (Stone, 1982). Cameron and Blackshaw (1980) reported that most boars suffered heat stress when rectal temperatures approached 40 °C and the condition was characterised by an increased respiratory rate, excessive drinking and restlessness. They also found that short periods of elevated ambient temperatures affected the quality but not always the quantity of boar semen with the effect most apparent 5 weeks later. At air temperatures above 32 °C, scrota of boars cannot cool by convection or conduction because the temperature of the surroundings and moving air exceeds the scrotal surface temperatures (Stone, 1982).

Kunavongkit and Prateep (1990) conducted an experiment with 10 boars in Thailand and found that the gel-free semen volume during summer was lower than during the rainy season and also that the concentration of sperm was lowest during summer. At an artificial insemination (AI) centre in England it was shown that temperatures in excess of 22 °C were potentially harmful for boar fertility (Stork, 1979), although in Australia no adverse seasonal effects on sperm were reported (Brown and Nestor, 1973). Cameron (1987), working with boars in Nigeria, found that sperm production was correlated with daylength change but not temperature, indicating that there was a photoperiod influence on the rate of sperm production. Einarsson and Larsson (1982) put forward the view that because only minor and inconsistent alterations were found in semen from boars exposed to 35 °C for 24 hours, it follows that the duration of exposure to elevated ambient temperature is the most important factor affecting the severity of testicular disturbance.

Paquignon (1987) concluded that a decreased percentage of motile spermatozoa is a feature of ejaculates in summer whilst sperm characteristics, i.e., volume, number of spermatozoa and motility change only slightly during the year. He also made the point that heat stress effects differ among boars. Some are very sensitive to heat changes, but some seem to be only slightly affected and continue to produce good quality semen (Paquignon, 1987). Some individual animals are able to adapt to heat stress and minimise the rise in body and scrotal temperature and so maintain normal testicular function (Cameron and Blackshaw, 1980). Sperm motility and sperm morphology are the most sensitive and reliable indicators of heat stress damage. Changes do not occur earlier than two weeks after exposure (35 °C, 40% humidity, 100 h), indicating that epididymal spermatozoa are not affected and that semen examinations should ideally be made at least two weeks after a possible stress situation if they are to be of useful diagnostic and prognostic value (Larsson *et al.*, 1988).

Libido

In a prospective study from AI stations in Germany, it was shown that the levels of testosterone increase as daylength decreases and very strong correlations were reported between testosterone levels and libido. Hormone concentrations were also highly correlated with sperm count, measured one month later to allow for the duration of spermatogenesis (Claus and Weiler, 1987).

Libido is seasonally influenced by light but this does not necessarily mean that temperature has no effect upon it (Yeates *et al.*, 1975). In rams and bulls, prolonged exposure to high temperature reduced thyroid activity to a degree sufficient to impair libido (Cameron, 1987). Bulls and boars exposed to high temperatures during the summer in hot climates show marked reductions in libido. It is common in South Africa to find boars extremely inactive during the hot hours of the day, sometimes totally ignoring the presence of oestrous sows. Liberal wetting with cold water is usually effective in improving the sexual activity of such boars (Fraser and Broom, 1990). The number of boars refusing to mount and ejaculate is higher in summer than in winter (Paquignon, 1987). A study from AI stations in Germany by Claus and Weiler (1987) of the reaction time (time between entering a dummy-room and mounting a dummy) demonstrated a high libido (reaction time about 4 minutes) in autumn and early winter reducing to a minimum between April and June (reaction time twice as long). However, the effect of temperature on libido is only partly dependent on temperature, since cryptorchid animals still exhibit libido, and many boars that have been treated by heat are still able to have semen collected with an artificial vagina (A.V).

Boar presence has an important influence on onset of puberty in gilts. Puberty is delayed in the absence of boars. An intimate and continuous association with a boar, as is common practice with domestic gilts, masks their innate seasonal breeding activity (Paterson *et al.*, 1991). The application of this husbandry practice dramatically reduces adverse effects of season on onset of puberty (Love *et al.*, 1993).

In summary, sperm production decreases in summer. A decreased percentage of motile spermatozoa is a feature of ejaculates in summer, whilst sperm characteristics change only slightly throughout the year. Alterations to both sperm motility and morphology occurred 2-4 weeks after heat stress with 35 °C and 40% relative humidity.

Conclusion

In a herd where the overall level of management is high and husbandry and environmental stressors are quite low, any additional heat load by itself will not cause the clinical picture of seasonal infertility to appear. On the other hand, if there are other stressor factors acting on the herd during the year, then the clinical syndrome of seasonal infertility will appear during the hotter months (Hennessy, 1987b).

Strategies which have been recommended to reduce stress responses

- ensure that pigs are reared, housed and managed in a manner which reduces stress (Hurtgen and Leman, 1980; Love, 1981a; Hennessy, 1987a)
- select replacement breeding stock (Hennessy, 1987b)
- attempt to increase oestrus detection rate (Reilly and Roberts, 1991)

- increase vigilance during summer months (Reilly and Roberts, 1991)
- decrease sow stocking rates in 'kennel and yards' (Reilly and Roberts, 1991)
- cover outside sow yard areas to provide shade for sows, and ensure adequate ventilation, thereby improving space utilisation (Reilly and Roberts, 1991)
- use individual gestation stalls (Leman, 1986)
- breed more gilts each year to offset the effect of reduced farrowing rate (Leman, 1986)
- increase boar exposure during the first 45 days of pregnancy (Leman, 1986)
- use a 'one move' gestation technique (Leman, 1986)
- keep breeding herds on a constant 16 hours of light and 8 hours of darkness throughout the year (1/2 watt for each square foot) (Leman, 1986)
- use the Doppler type ultrasound instrument (Love, 1981b)
- aim to pregnancy test all bred females by 35 days after breeding (Hurtgen and Leman, 1980)
- supply extra feed to dry sows (Love *et al.*, 1993).

Strategies for improving litter size will vary from farm to farm depending on the effect that a specific factor has on any particular farm (Hilley *et al.*, 1986b).

Field Study

Introduction

Summer/autumn infertility is a collective term which conveniently describes a wide range of infertility manifestations in the summer and autumn period which include:

- increased weaning to mating interval
- a delayed onset of puberty and/or poor oestrus expression in gilts
- decreased litter size
- increased prevalence of stillborn and/or mummified foetuses

In this study, the contribution which those components made separately and collectively to reduced fertility in the summer/autumn period in selected herds in New Zealand, was examined and measured.

Materials and methods

Data were acquired from farm records of 20 farms designated as A, B, C,...T. All farms record productivity data in PigCHAMP® (University of Minnesota, College of Veterinary Medicine, St. Paul, Minnesota) and the required data was extracted using the database application option. Criteria for inclusion in the study included at least 9 months of records for any particular year and a relatively constant number of served females. Details of the number of gilts/sows served on each farm are set out in Table 2-4.

Table 2-4: Numbers of gilts/sows served stratified by farm, year, and month

Farm	Year	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
A	92	50	45	58	47	47	54	49	47	54			
B	92	16	30	21	25	23	14	26	19	23	29	18	29
	93	37	37	31	24	27	28	32	33	25	41	35	34
	94	29	36	35	36	40	38	39	38	51	44	42	44
C	91	26	27	17	23	17	25	22	17	22	21	16	15
D	91	37	31	41	45	38	25	41	35	42	39	39	39
	92	39	44	38	40	29	30	48	35	38	28	30	46
E	91	27	25	21	25	26	26	25	29	23	26	26	32
	92	22	27	26	22	25	26	24	25	34	21	27	29
F	91	30	24	38	35	20	38	43	37	38	41	39	39
G	91	25	26	22	28	28	35	23	27	32	33	27	32
	92	25	32	33	29	24	34	24	29	28	27	299	339
H	91	22	14	26	27	24	22	20	17	26	24	22	20
	92	22	22	23	24	18	23	17	24	17	19	18	13
I	91	11	11	8	12	8	11	16	10	12	10	10	14
	92	11	10	14	9	10	15	10	10	12	12	10	12
J	91	51	42	49	49	48	41	54	47	27	47	45	49
	92	48	48	50	49	49	54	50	51	54	46	55	786
K	91	51	40	52	64	52	44	62	53	52	57	52	43
L	91	48	32	38	40	38	31	43	36	34	32	35	35
	92	44	42	41	42	26	42	33	42	32	29	42	35
M	91	78	61	66	73	74	78	86	76	81	76	74	87
	92	66	75	78	84	81	80	72	97	77	79	87	65
N	91	72	61	68	64	67	61	62	71	65	73	63	81
	92	58	65	65	69	65	58	65	76	63	57	71	60
O	91	37	39	42	40	45	37	45	38	43	41	31	44
	92	35	35	43	31	40	36	37	39	43	42	37	31
P	93	20	13	18	21	20	19	18	20	19	13	24	16
	94	25	16	16	19	22	19	18	17	19	23	14	14
Q	92	-	-	14	14	20	25	24	28	27	23	28	33
	93	28	40	42	29	20	23	27	29	30	24	21	28
	94	37	30	28	31	30	21	25	30	21	26	27	32
R	92	32	41	49	38	32	49	44	39	39	31	40	33
S	91	126	116	117	137	120	122	139	116	108	117	125	141
	92	124	107	132	134	124	133	121	124	117	90	113	89
T	93	48	47	53	50	51	46	46	49	50	47	47	48
	94	50	42	57	43	55	43	40	53	40	56	50	50
Total		1508	1435	423	1573	1576	1488	1512	1577	1571	1527	1440	1412

1= January, 2 = February, 3 = March, 4 = April, 5 = May, 6 = June, 7 = July, 8 = August, 9 = September, 10= October, 11 = November, 12 = December

Monthly farrowing rates (proportion of gilts or sows farrowed from the service events during a particular month), and the proportions of regular returns, irregular returns, negative pregnancy tests, abortions and not-in-pig sows per month were calculated, based on the number of gilts or sows served in the appropriate month. Sows which were removed from the herd were excluded from the calculations.

Criteria used to designate summer/autumn infertility

Farms were designated as having a summer/autumn infertility problem if the difference between the average farrowing rate during winter/spring and summer/autumn was more than 0.01 for a particular year (see Table 2-5). The farrowing rate had to be below the median of the farrowing rate recorded for the whole of the year for at least 3 months during summer/autumn. An additional restriction was that the farrowing rate over the winter/spring period was not allowed to fall below the annual rate during more than 1 month. This ensured that herds classified as having summer/autumn infertility did not include herds which had a non-specific drop in reproductive performance. Summer/autumn covered the period from December to April and winter/spring the period from May to November. Descriptive statistics of farrowing rate and the differences between the mean rates for winter/spring and summer/autumn stratified by farm and year are set out in Table 2-5 and shown graphically in more detail in Figure 2-1.

Table 2-5: Means, medians and differences between means of farrowing rate for study farms stratified by year

Farm	Year	Farrowing rate		
		Mean	Median	Difference of mean between winter-spring and summer-autumn
A	1992	0.9489	0.9545	0.02435
B	1992	0.8016	0.8441	0.18711
	1993	0.7314	0.732	-0.02157
	1994	0.7791	0.83097	0.15917
C	1991	0.6376	0.636	0.096114
D	1991	0.8078	0.8007	0.12231
	1992	0.8407	0.8377	0.004714
E	1991	0.91896	0.9362	-0.028666
	1992	0.9124	0.9145	0.0398
F	1991	0.8831	0.8875	-0.05163
G	1991	0.9019	0.9077	0.100206
	1992	0.9138	0.9243	0.04675
H	1991	0.8233	0.8288	0.066057
	1992	0.8225	0.8182	0.10117
I	1991	0.9761	1	0.014543
	1992	0.9635	1	0.030343
J	1991	0.9235	0.9375	0.032057
	1992	0.9191	0.9273	-0.01479
K	1991	0.87696	0.87199	0.012343
L	1991	0.8413	0.8452	-0.03523
	1992	0.8454	0.8528	0.009048
M	1991	0.8919	0.886	-0.02277
	1992	0.8955	0.8928	0.000857
N	1991	0.8488	0.8555	0.058829
	1992	0.9352	0.9474	0.014686
O	1991	0.8579	0.8715	0.000886
	1992	0.8782	0.8743	0.0114
P	1993	0.9301	0.9459	0.072686
	1994	0.9427	0.9773	0.10174
Q	1992	0.7989	0.865	0.06281
	1993	0.7639	0.7759	0.10854
	1994	0.7846	0.7929	0.10037
R	1992	0.8405	0.8393	-0.01903
S	1991	0.9009	0.9089	0.025971
	1992	0.8819	0.8871	0.071171
T	1993	0.9039	0.9074	0.064943
	1994	0.8585	0.8675	0.061543

shaded rows indicate problem farms and problem years

Figure 2-1: Individual farm and year farrowing rate patterns

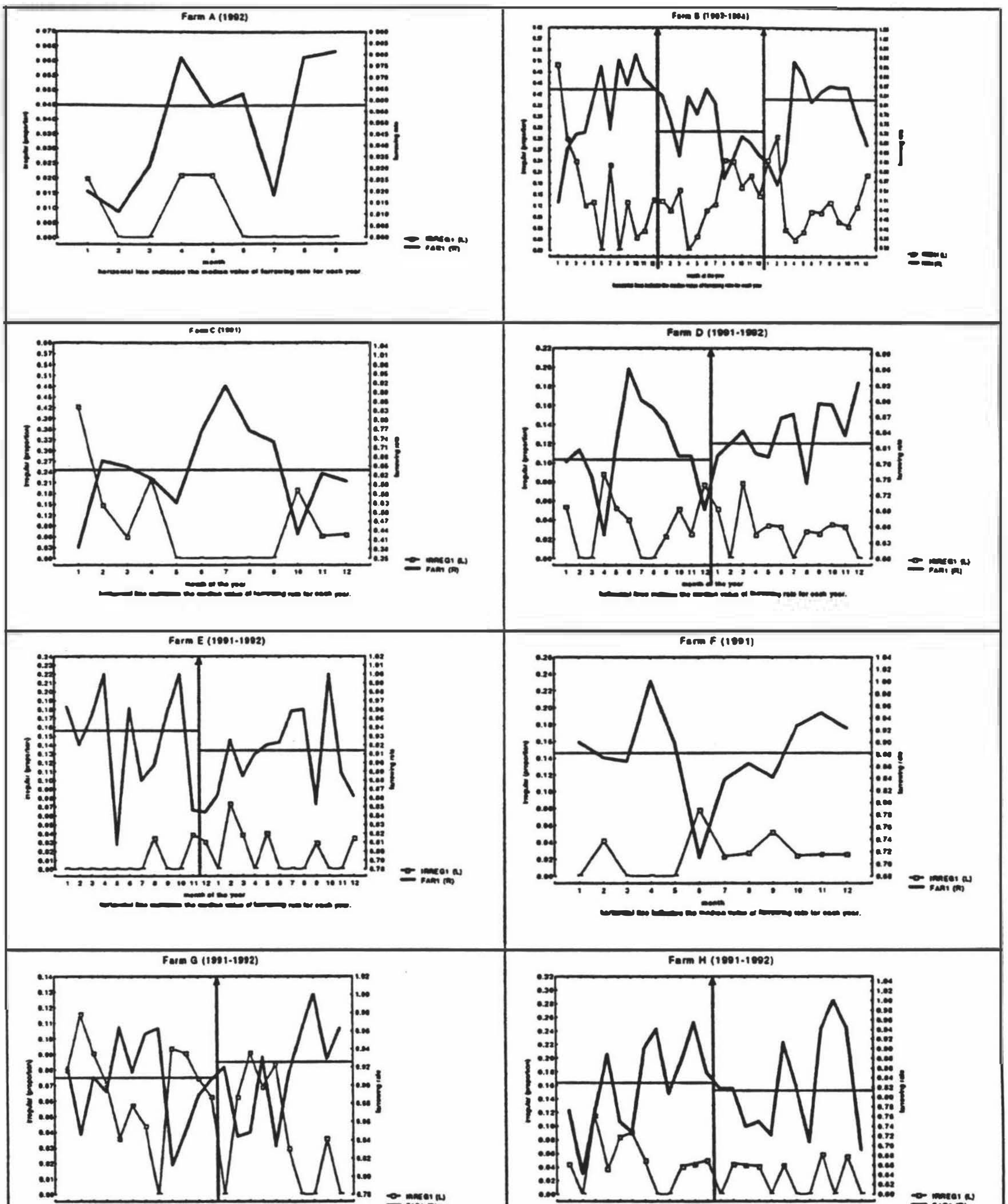


Figure 2-1 (continued)

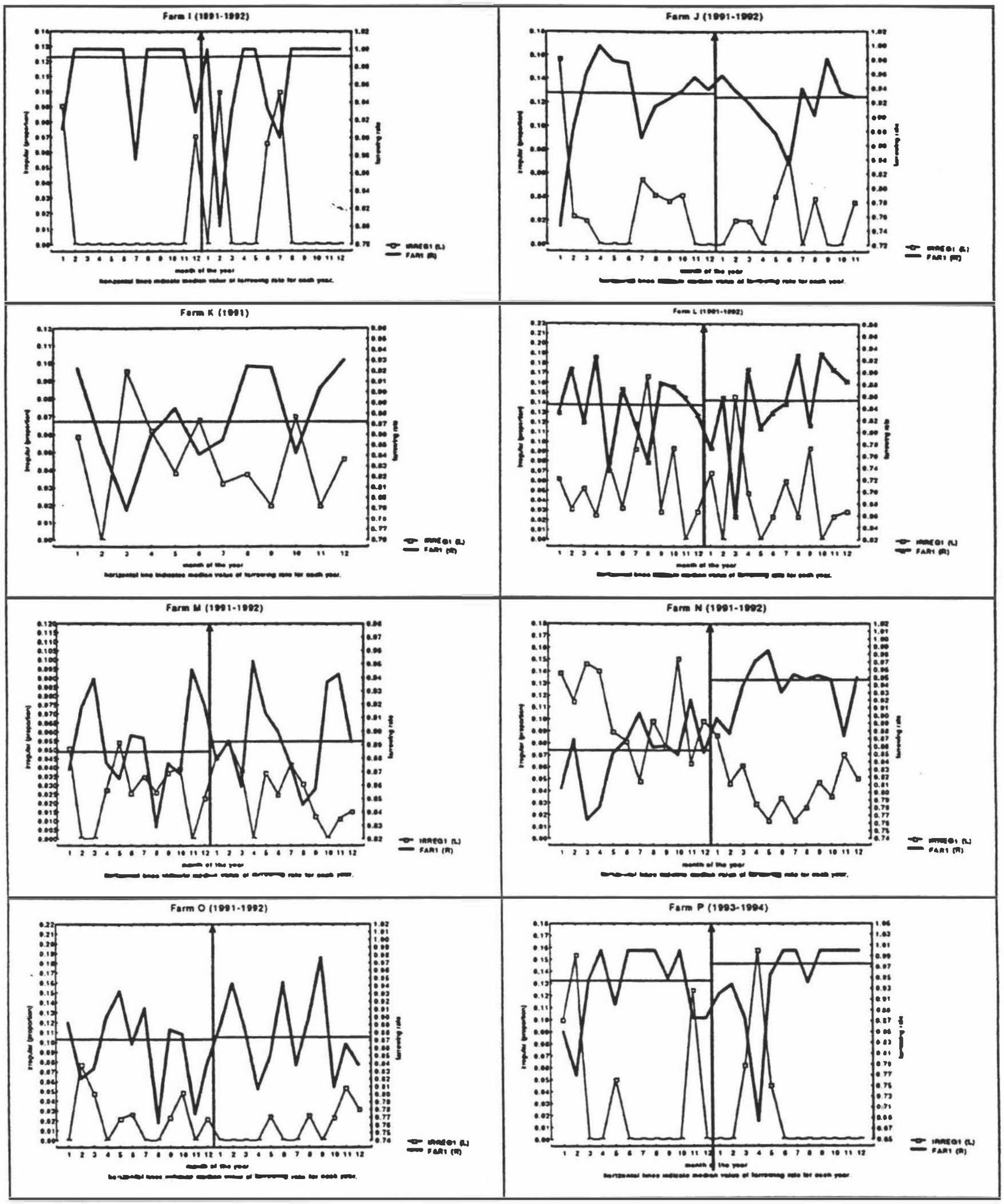
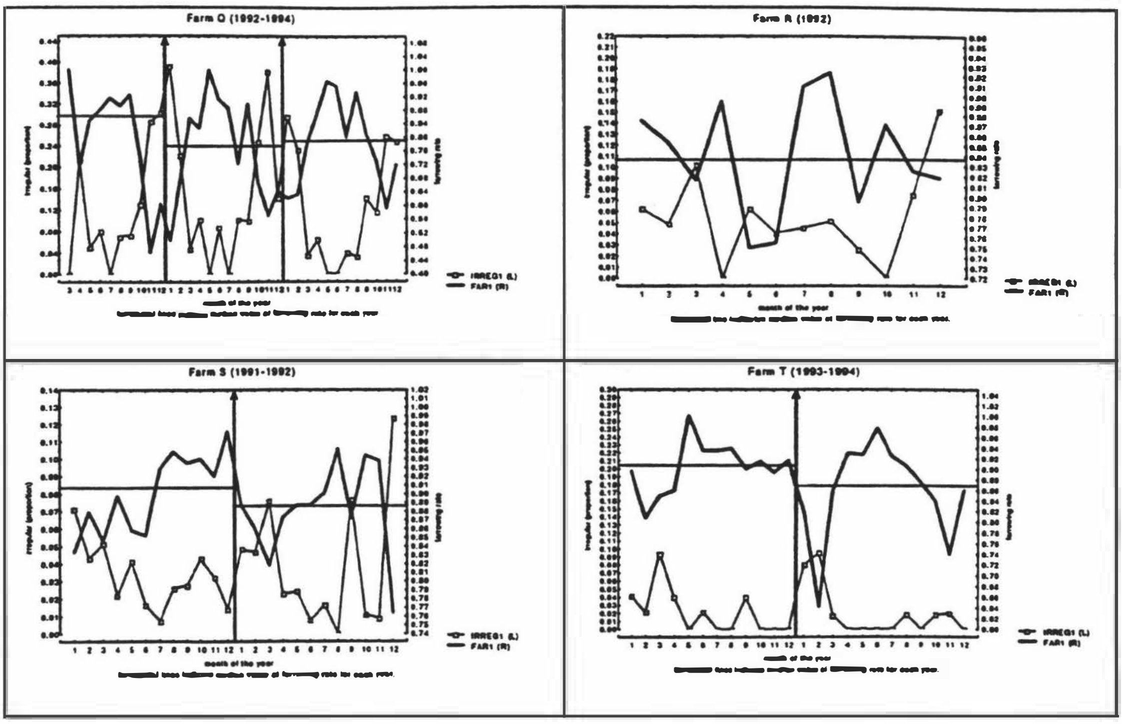


Figure 2-1 (continued)



For the purposes of this study, some farms were classified as having no problems in one year but as problem farms when summer/autumn infertility occurred in another year. Farms with summer/autumn infertility problem years were designated PY as for that year, and the farms which did not show a summer/autumn infertility problem were designated as NPY for that particular year.

The interaction term between PY and summer/autumn was coded as PYS, and all other farm and season interactions (PY in winter/spring + NPY in summer/autumn + NPY in winter/spring) were coded as NPYS.

Farm A (1992), farm B (1992, 1994), farm D (1991), farm N (1991), farm P (1994), farms S (1992), and farm T (1993, 1994) were categorized as PY. Farm P (1993) and farm Q (1993, 1994) were also included in the PY group, although the criteria were not fully met (below the median for 2 months in winter/spring) but the low farrowing rate in January, February, and December was consistent with a summer/autumn infertility problem. The differences between farrowing rates in winter/spring and summer/autumn were 0.072686 for farm P (1993), 0.1085 and 0.1003 for farm Q (1993, 1994) (see Table 2-5 and Figure 2-1).

Analytical confirmation of PY and NPY status

The Mann-Whitney U test was used to compare farrowing rates between winter/spring and summer/autumn separately for each group PY and NPY separately. The results are presented in Table 2-6.

Table 2-6: Results of Mann-Whitney U test for comparison the average farrowing rate between winter/spring and summer/autumn

Group	Rank Sum (winter/spring)	Rank Sum (summer/autumn)	U	Z	p-value
PY	7008.5	3002.5	1232.5	-4.96	<0.001
NPY	26849.5	16180.5	9429.5	-1.52	0.128

The PY farm years had a statistically significantly lower farrowing rate in summer/autumn compared with winter/spring, whereas no significant difference between the two periods was detected in NPY farm years.

Unit of analysis

A comparison between the summer/autumn and winter/spring season was chosen instead of monthly comparisons in order to smooth out the effect of farrowing rate reductions in winter/spring which had occurred in PY. The comparison was then conducted between PY and NPY in summer/autumn.

The analysis of differences in average farrowing rates, abortion rates, regular return rates, irregular return rates, not-in-pig rates and negative pregnancy test rates between PY and NPY farm years was based on a dataset of 436 cases. A total of 17,137 observations were used to compare average totals of pigs born, numbers of pigs born alive, and numbers of stillborn and mummies. The comparisons for average weaning to first service interval and non-productive sow days (NPD) were conducted using 18,729 observations. All variables were derived from the same PigCHAMP® database but farrowing rates and other rates and proportions were calculated as monthly averages for each farm in each year (see Table 2-4).

Statistical analysis

Stepwise logistic regression was used to explain PY and NPY status from farrowing rates, return rates, abortion rates, negative pregnancy test rates, not-in-pig rates, in summer/autumn or winter/spring and to examine the effects of season, PY and NPY, interaction of PY and summer/autumn, and rates of returns, abortions, negative pregnancy tests and not-in-pigs on farrowing rate. These analyses were conducted using the statistical software package Statistix® version 4.1 (Analytical Software, Tallahassee, Florida). Variables were included in the model if their coefficients were significant at a p-value of less than 0.05, except when an interaction term was significant, in which case the main effects represented in the term were included in the model regardless of the p-value. The goodness of fit of the final models was assessed using the Hosmer-Lemeshow statistic based on deciles of risk.

ANOVA was used to compare the means of production indices for summer/autumn and winter/spring periods for PY and NPY farm years. The *Mann-Whitney U test* was used to compare the means of continuous variables where the assumption of an underlying normal distribution was violated. As the range of weaning to first service intervals was large (1-189 days) partly due to missing farrowing dates, the comparison was also constructed for weaning to first service intervals of less than 19 days, because a weaning to first service interval of more than 19 days was unlikely to represent the first oestrus. ANOVA and Mann-Whitney U tests were conducted using the statistical software package, Statistica® for Windows version 5 (StatSoft Inc, Tulsa, Oklahoma).

Graphical presentation

Violin plots, hybrids between density traces (smoothed relative frequency histogram) and box plots, were used to present distributions of farrowing rates, negative pregnancy test rates, regular return rates, irregular return rates, abortion rates, and not-in-pig rates. Violin plots were produced using the statistical software package NCSS® version 6.0.12 (Statistical System for Windows, Kaysville, Utah)

The amount of data included in each density trace calculation in the violin plots was 30%. This is the fraction of data around each calculated point used by the smoothing algorithm. The points that are far from the centre value are weighted using half the cosine function with its peak at the centre value. This decreases symmetrically to zero. Therefore, the further data points are away from the centre point, the less influence they have on the estimated value. The median is shown as a circle and the interquartile range is represented as a thick line connecting the 25th and 75th percentiles.

Box and Whisker plots were constructed to graphically present statistics for the parameters weaning to first service interval, non-productive sow days (NPD), total pigs born, pigs born alive, stillborn, and mummies using the statistical analysis software Statistica® version 5. In this paper, the Box and Whisker plot describes the central tendency of the variables in terms of the median of the values with 25% of observations on each side of the median represented as the box in the plot. The minimum and maximum values of the variables are shown through the line extending from the boxes.

Results

Associations between indices of reproductive performance, seasons of the year and summer/autumn infertility

Explanation of summer/autumn infertility

The explanatory variables monthly farrowing rate, regular return rate, irregular return rate, negative pregnancy test rate, not-in-pig rate, abortion rate, and season (summer/autumn *vs* winter/spring) were included in the stepwise logistic regression for explanation of the outcome variable, summer/autumn infertility farm status during a particular year (PY or NPY). The final model included the parameters farrowing rate, irregular return rate and negative pregnancy test rate (see Table 2-7). The Hosmer-Lemeshow statistic (p-value=0.24) indicates that the model represents a good fit to the data. Monthly farrowing rate, irregular return rate, negative pregnancy test rate had regression coefficients with positive signs. The odds ratios of 1.03, 1.16, and 1.09 for monthly farrowing rate, irregular return rate, and negative pregnancy test rate are not large but indicate that problem herds are more likely to have higher monthly farrowing rates over the whole year and higher rates of irregular returns and negative pregnancy tests. It has to be kept in mind that notably farrowing rate been used to define the dependent variable.

Table 2-7: Unweighted logistic regression model for explanation of summer/autumn infertility status

Predictor variables	Coefficient	Standard error	p-value	95% CL of OR	Odds ratio (OR)
Constant	-7.94	2.12	0.002		
Farrowing rate	0.07	0.02	0.001	1.03-1.12	1.07
Irregular return rate	0.15	0.03	<0.001	1.09-1.23	1.16
Negative pregnancy test rate	0.09	0.03	0.005	1.03-1.16	1.09

Deviance = 520.15, p-value = 0.0023, degrees of freedom = 432, n = 436

Hosmer-Lemeshow statistic (C) = 10.38, p-value = 0.24, degrees of freedom = 8

Dependent variable = summer/autumn status, PY (1) or NPY (0)

Independent variables = farrowing rate, irregular return rate, negative pregnancy test rate

Explanation of farrowing rates

Table 2-8 presents the final stepwise logistic regression model for monthly farrowing rate resulting from offering the variables regular return rate, irregular return rate, negative pregnancy test rate, not-in-pig rate, abortion rate, season of the year (summer/autumn *vs* winter/spring), PY/NPY farm-year status, and interaction between PY/NPY farm-year status and season to the selection algorithm. The Hosmer-Lemeshow statistic (p-value=0.26) indicates that the model represents a good fit to the data. The model includes abortion rate, irregular return rate, PY/NPY farm year status, season, and the interaction term between PY/NPY farm year status and season. The model indicates that amongst the various parameters affecting farrowing rate, the most important were abortion rate and irregular return rate. The interaction between PY/NPY farm year status and season (PYS/NPYS) suggests a reduction in monthly farrowing rate for PY farm year status during summer/autumn (PYS). The positive coefficient of summer/autumn infertilityfarm year status (PY) confirms the association between monthly farrowing rates and problem herd status found in the previous logistic regression model described in (Table 2-7). The model indicates that a farm year status classified as PY results in higher monthly farrowing rate overall than a farm-year status classified as NPY. But during the summer/autumn period monthly farrowing rate will be lower.

Table 2-8: Unweighted logistic regression model for prediction of farrowing rate

Predictor variables	Coefficient	Standard error	p-value	95% CL of OR	Odds ratio (OR)
Constant	2.34	0.04	<0.001		
Abortion rate	-0.09	0.02	<0.001	0.89-0.95	0.92
Irregular return rate	-0.07	0.003	<0.001	0.93-0.94	0.93
PY/NPY	0.2	0.07	0.003	1.07-1.39	1.22
Season	-0.002	0.06	0.97	0.89-1.12	1
PYS/NPYS interaction term	-0.29	0.1	0.003	0.62-0.90	0.75

Deviance = 608.21, p-value = <0.001, degree of freedom = 432, n = 430

Hosmer-Lemeshow statistic (C) = 10.03, p-value = 0.26, degree of freedom = 8

Dependent variable = farrowing rate

Independent variables = abortion rate, irregular return rate, PY/NPY (0 = NPY, 1 = PY), season (0= winter/spring, 1 = summer/autumn), PYS/NPYS interaction term (0= PYS, 1 = NPYS)

Comparisons of production indices between problem and non-problem herds for whole years and summer-autumn seasons, and for all herds between summer-autumn and winter-spring

Univariate analysis was done on production indices between problem and non-problem herds for whole years and summer/autumn seasons, and for all herds between summer/autumn and winter/spring and the results are presented in Table 2-9.

Table 2-9: P-value calculated from Mann-Whitney U test comparisons of medians of farrowing rates, abortion rates, irregular return rates, negative pregnancy test rates, not-in-pig rates and regular return rates, compared between problem and non-problem herds (PY/NPY), between seasons and between PYS and NPYS

	p-value		
	PY/NPY farm year status	Season	Interaction term (PYS/NPYS)
Farrowing rate	0.26	<0.001	<0.001
Abortion rate	0.85	0.62	0.91
Irregular return rate	1.02	0.002	<0.001
Negative pregnancy test rate	0.55	0.23	0.99
Not-in-pig rate	0.75	0.89	0.62
Regular return rate	0.008	0.06	0.006

shaded areas indicate p values < 0.05

Month = January - December. Seasons = summer/autumn *vs* winter/spring

Farrowing rate

The distribution of monthly farrowing rates of the PY group was similar to that of the NPY ($p = 0.26$, see, Table 2-10 and Figure 2-2A). The rates for PY and NPY in summer/autumn were also similar (see Table 2-10 and Figure 2-2B). Summer/autumn infertility was evident in the comparison between PYS and NPYS ($p < 0.001$, Table 2-9 and Table 2-10 and Figure 2-2C), which shows the farrowing rate of the PY group during summer/autumn to be the lowest for all combinations. This is consistent with the logistic regression model for farrowing rates. The seasonal trend becomes evident in the monthly plot of problem farms and shows the higher farrowing rates experienced in winter/spring ($p = 0.004$, see Table 2-9 and Figure 2-2D).

Figure 2-2: Violin plots presenting the distribution of farrowing rate (%) (A: PY and NPY; B: between PY and NPY in the summer/autumn period; C: PYS and NPYS; D: from January (1) to December (12) for PY)

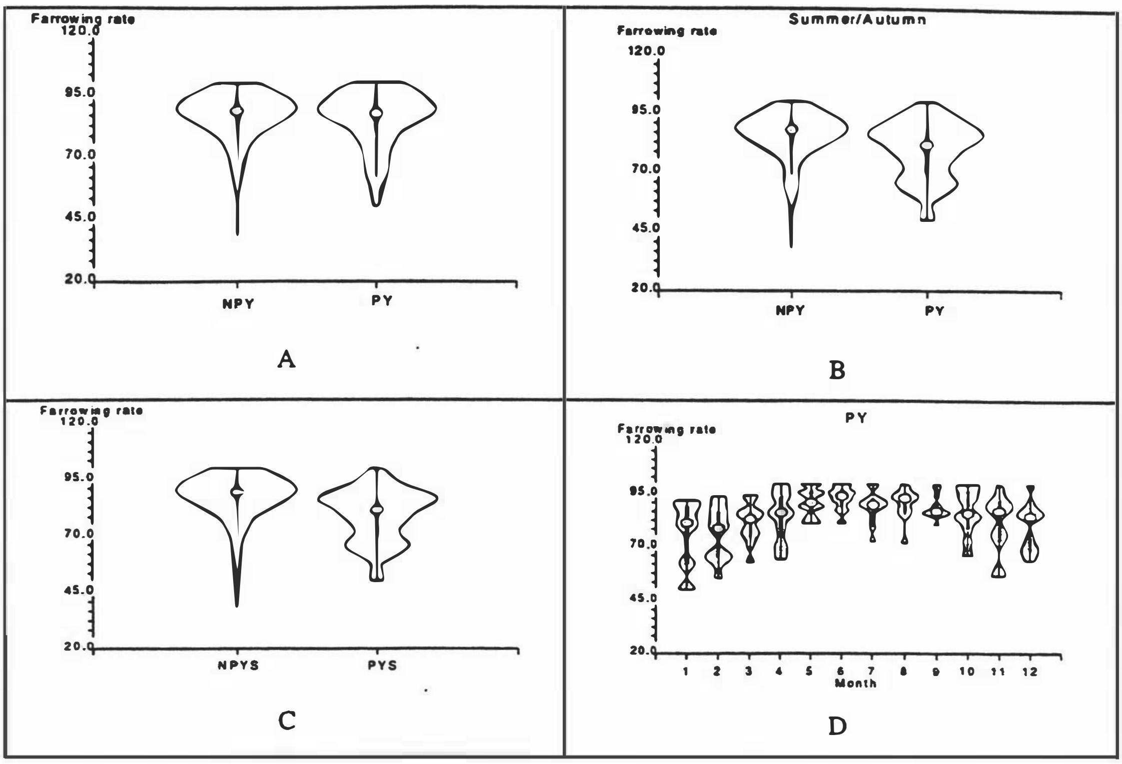


Table 2-10: Descriptive statistics for farrowing rate stratified by herd status and season

Seasons	Status	N	Mean	95% CL	Median	Min-Max	SD
0 and 1	0 and 1	436	86.38	85.39-87.36	88.3	38.5-100	10.46
0	0 and 1	256	88.08	86.91-89.25	89.9	42.9-100	9.51
1	0 and 1	180	83.96	82.3-85.61	86.1	38.5-100	11.27
0 and 1	0	295	86.92	85.78-88.06	88.6	38.5-100	9.95
0 and 1	1	141	85.24	83.34-87.13	87.3	50-100	11.41
0	0	174	87.55	86.09-89.01	89.4	42.9-100	9.76
0	1	82	89.21	87.26-91.17	90.15	57.1-100	8.92
1	0	121	86.03	84.19-87.86	87.9	38.5-100	10.19
1	1	59	79.71	76.52-82.89	82	50-100	12.23
NPYS		376	87.56	86.58-88.55	89.3	38.5-100	9.73

seasons (0 = winter/spring, 1 = summer/autumn), status (0 = NPY, 1 = PY), *e.g.* season of 1 and status of 1 = PYS

Negative pregnancy test

The data and statistics presented in Table 2-9, Table 2-11, and Figure 2-3 show reasonably constant negative pregnancy test rates over all combinations of groups and seasons.

Figure 2-3: Violin plots presenting the distribution of negative pregnancy test rate (%) (A: PY and NPY; B: between PY and NPY in summer/autumn period; C: PYS and NPYS; D: from January (1) to December (12) for PY)

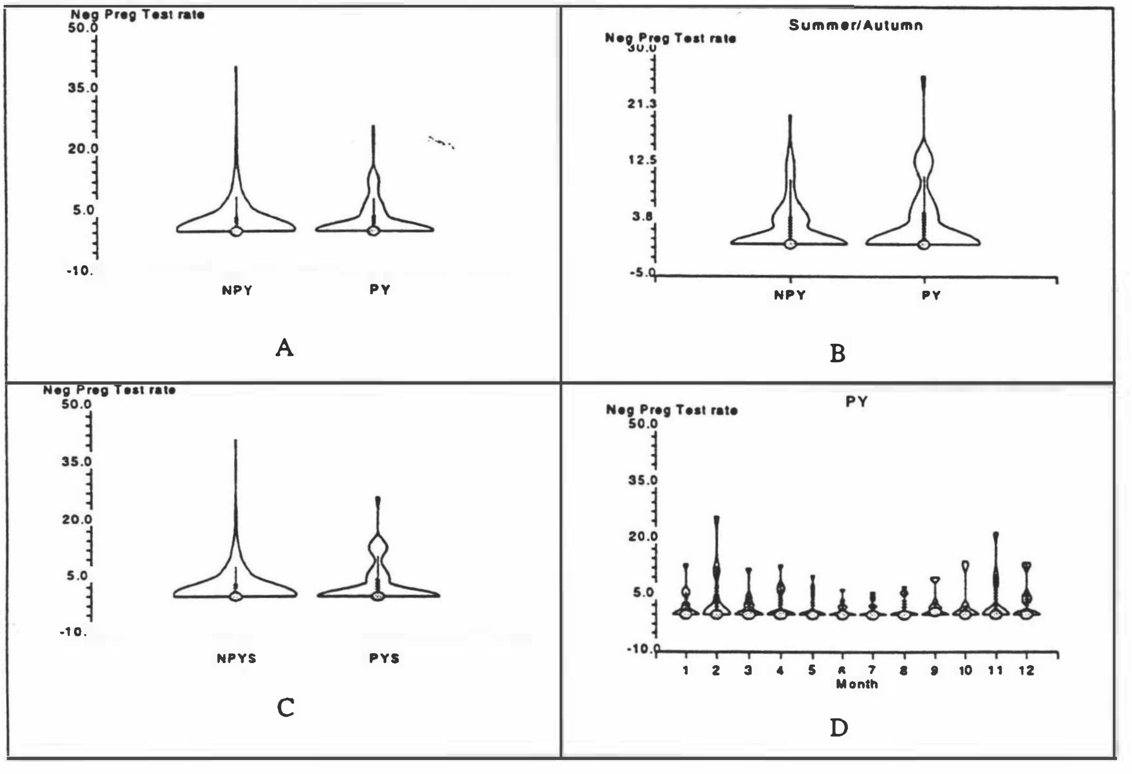


Table 2-11: Descriptive statistics for negative pregnancy test rate stratified by herd status and season

Seasons	Status	N	Mean	95% CL	Median	Min-Max	SD
0 and 1	0 and 1	436	2.49	2.04-2.94	0	0-41.2	4.81
0	0 and 1	256	2.34	1.72-2.96	0	0-41.2	5.06
1	0 and 1	180	2.7	2.05-3.35	0	0-26.2	4.43
0 and 1	0	295	2.42	1.85-2.98	0	0-41.2	4.91
0 and 1	1	141	2.64	1.87-3.4	0	0-26.2	4.6
0	0	174	2.38	1.56-3.2	0	0-41.2	5.48
0	1	82	2.27	1.38-3.15	0	0-22	4.03
1	0	121	2.48	1.76-3.19	0	0-20	3.96
1	1	59	3.15	1.78-4.53	0	0-26.2	5.28
NPYS		376	2.42	1.94-2.9	0	0-41.2	4.73

seasons (0 = winter/spring, 1 = summer/autumn), status (0 = NPY, 1 = PY), *e.g.* season of 1 and status of 1 = PYS

Regular return rate

Regular return rates were significantly higher in NPY than in PY overall (p = 0.008), rates for PY were significantly higher than for NPY in the summer/autumn periods (p = 0.06), and rates for PYS were also higher than NPYS (p = 0.006), (Table 2-9, Table 2-12 and Figure 2-

A-C). The temporal trend of regular return rates over 12 months are shown in Figure 2-D).

Figure 2-4: Violin plots presenting the distribution of regular return rate (%) (A: PY and NPY; B: between PY and NPY in summer/autumn period; C: PYS and NPYS; D: January (1) to December (12) for PY)

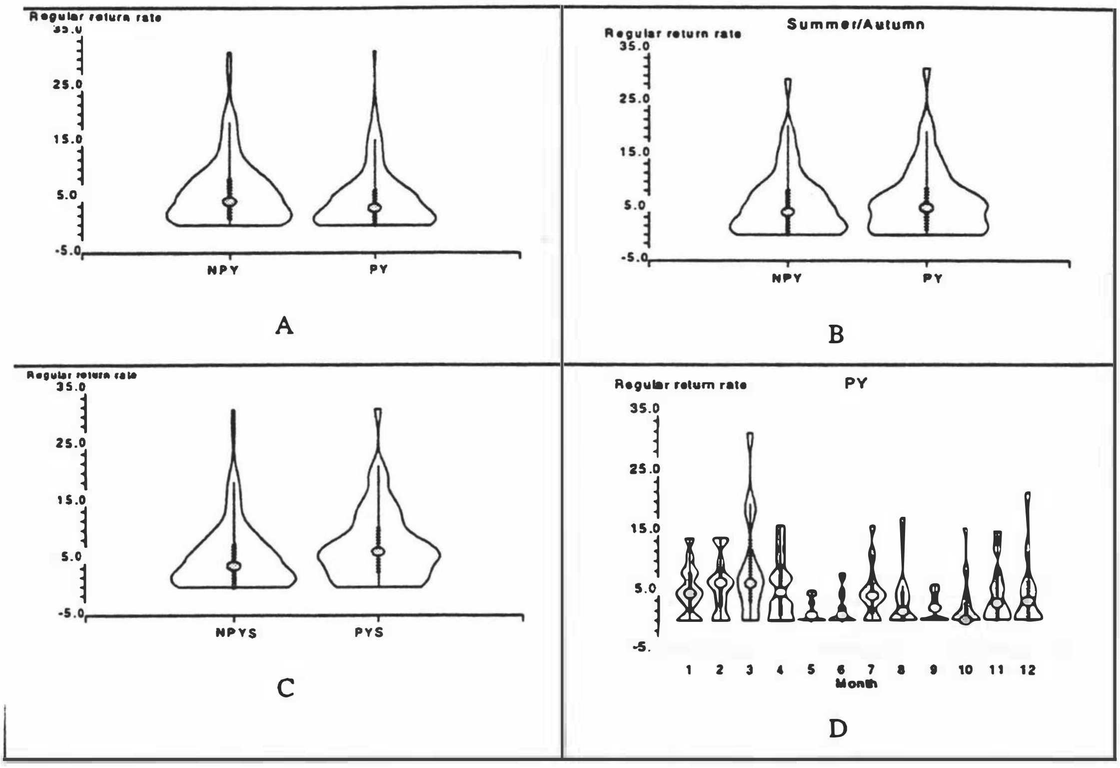


Table 2-12: Descriptive statistics for regular return rate stratified by herd status and season

Seasons	Status	N	Mean	95% CL	Median	Min-Max	SD
0 and 1	0 and 1	436	5.34	4.8-5.88	4.05	0-31.4	5.7
0	0 and 1	256	4.91	4.25-5.57	3.75	0-31.3	5.4
1	0 and 1	180	5.95	5.06-6.85	4.6	0-31.4	6.07
0 and 1	0	295	5.77	5.1-6.44	4.3	0-31.3	5.84
0 and 1	1	141	4.44	3.56-5.33	3.1	0-31.4	5.31
0	0	174	5.75	4.88-6.6	4.3	0-31.3	5.76
0	1	82	3.14	2.25-4.02	2.2	0-17.2	4.02
1	0	121	5.81	4.73-6.88	4.3	0-29.4	5.97
1	1	59	6.26	4.62-7.9	5.1	0-31.4	6.29
NPYS		376	5.05	4.49-5.62	3.8	0-31.3	5.54

seasons (0 = winter/spring, 1 = summer/autumn), status (0 = NPY, 1 = PY), season of 1 and status of 1 = PYS

Irregular return rate

Irregular return rates were similar in PY and NPY overall (p = 1) but rates for PY were significantly higher than for NPY over the summer/autumn period (p = 0.002) and rates for

PYS were higher than for NPYS ($p < 0.001$, Table 2-9 and Table 2-13, Figure 2-5). As with regular returns, the rates of irregular returns were higher over the summer/autumn period.

Figure 2-5: Violin plots presenting the distribution of irregular return rate (%) (A: PY and NPY; B: between PY and NPY in summer/autumn period; C: PYS and NPYS; D: January (1) to December (12) for PY)

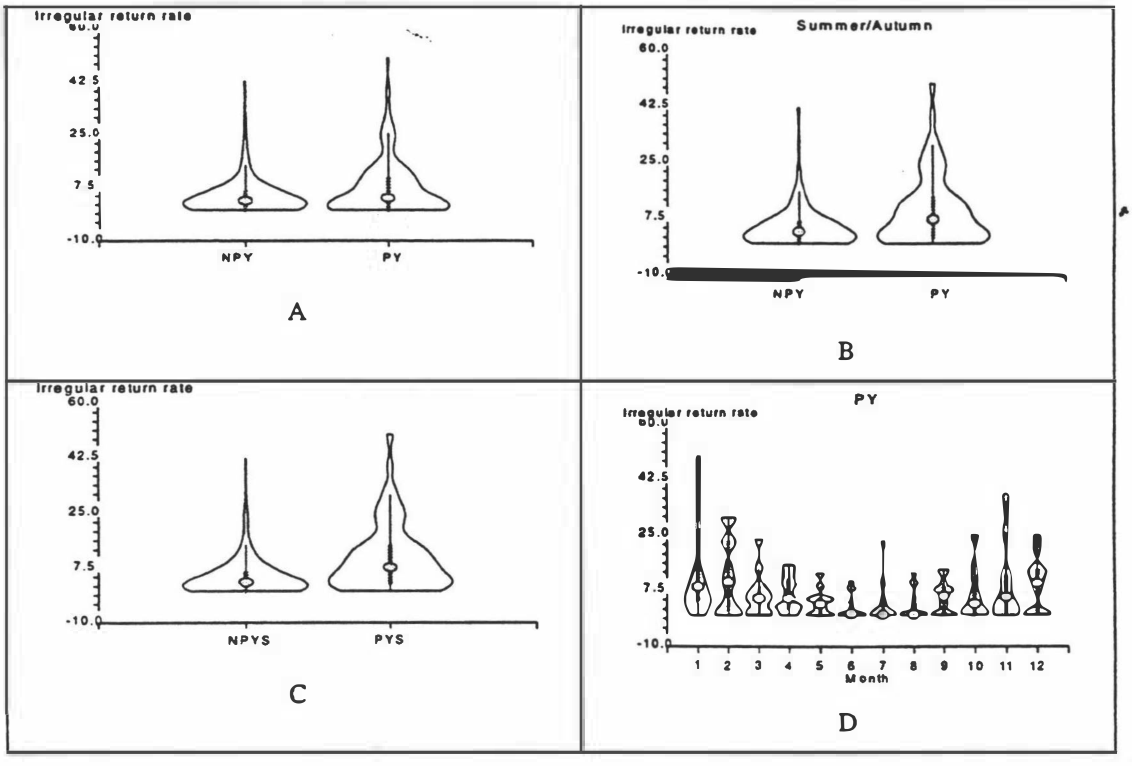


Table 2-13: Descriptive statistics for irregular return rate stratified by herd status and season

Seasons	Status	N	Mean	95% CL	Median	Min-Max	SD
0 and 1	0 and 1	436	5.17	4.51-5.83	3.25	0-50	6.99
0	0 and 1	256	4.14	3.46-4.83	2.6	0-38	5.57
1	0 and 1	180	6.64	5.4-7.87	4.5	0-50	8.41
0 and 1	0	295	4.23	3.61-4.85	3.1	0-42.3	5.44
0 and 1	1	141	7.14	5.62-8.66	4	0-50	9.15
0	0	174	3.76	3.05-4.47	2.85	0-28.6	4.73
0	1	82	4.9	3.41-6.48	2.15	0-38.1	6.98
1	0	121	4.9	3.77-6.04	3.7	0-42.3	6.28
1	1	59	10.19	7.68-13.19	7.65	0-50	10.85
NPYS		376	4.33	3.74-4.92	2.85	0-42.3	5.8

seasons (0 = winter/spring, 1 = summer/autumn), status (0 = NPY, 1 = PY), *e.g.* season of 1 and status of 1 = PYS

Abortion rate and not-in-pig rate

There were only very small and statistically non-significant differences between abortion rates and not-in-pig rates over all seasons between PY and NPY and between PYS and

NPYS, (Table 2-14 and Table 2-15, Figure 2-6 and Figure 2-7). The very low rates contributed to the medians being zero for all situations.

Figure 2-6: Violin plots presenting the distribution of abortion rate (%) (A: PY and NPY; B: between PY and NPY in summer/autumn period; C: PYS and NPYS; D: January (1) to December (12) for PY)

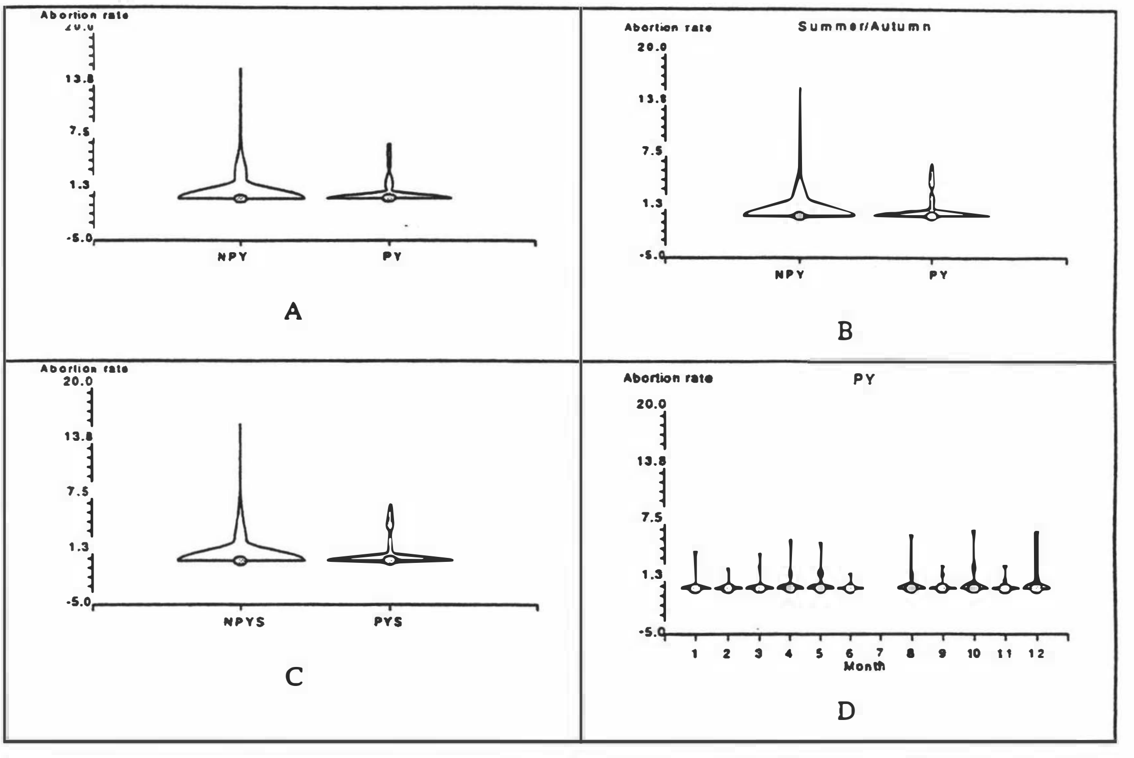


Table 2-14: Descriptive statistics for abortion rate stratified by herd status and season

Seasons	Status	N	Mean	95% CL	Median	Min-Max	SD
0 and 1	0 and 1	436	0.54	0.4-0.69	0	0-15.4	1.55
0	0 and 1	256	0.46	0.31-0.61	0	0-6.4	1.24
1	0 and 1	180	0.67	0.39-0.94	0	0-15.4	1.89
0 and 1	0	295	0.57	0.38-0.76	0	0-15.4	1.63
0 and 1	1	141	0.49	0.27-0.71	0	0-6.4	1.35
0	0	174	0.48	0.3-0.67	0	0-5.7	1.26
0	1	82	0.41	0.14-0.67	0	0-6.4	1.21
1	0	121	0.69	0.32-1.06	0	0-15.4	2.06
1	1	59	0.61	0.21-1.0	0	0-6.3	1.52
NPYS		376	0.54	0.38-0.69	0	0-15.4	1.55

seasons (0 = winter/spring, 1 = summer/autumn), status (0 = NPY, 1 = PY), *e.g.* season of 1 and status of 1 = PYS

Figure 2-7: Violin plots presenting the distribution of abortion rate (%) (A: PY and NPY; B: between PY and NPY in summer/autumn period; C: PYS and NPYS; D: January (1) to December (12) for PY)

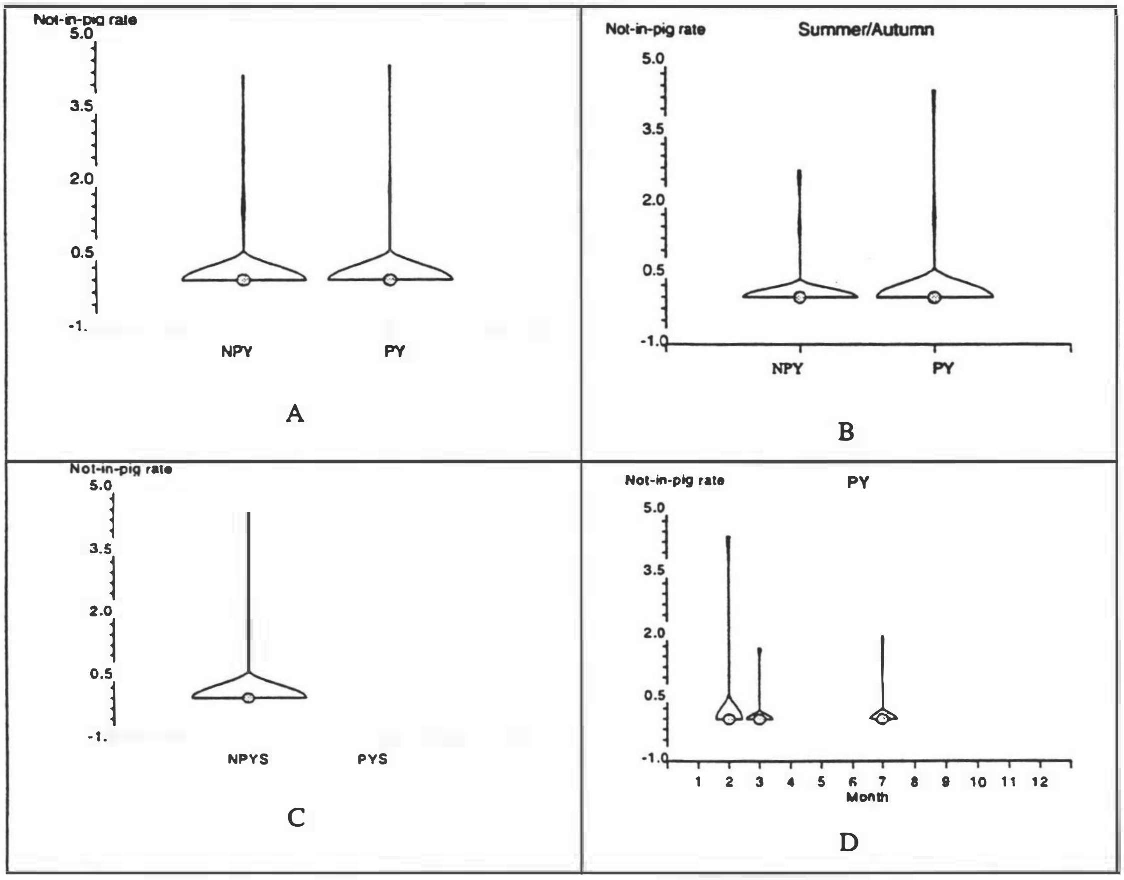


Table 2-15: Descriptive statistics for not-in-pig rate stratified by herd status and seasons

Seasons	Status	N	Mean	95% CL	Median	Min-Max	SD
0 and 1	0 and 1	436	0.08	0.03-0.12	0	0-4.4	0.45
0	0 and 1	256	0.07	0.02-0.12	0	0-4.2	0.41
1	0 and 1	180	0.09	0.02-0.17	0	0-4.4	0.5
0 and 1	0	295	0.09	0.03-0.14	0	0-4.2	0.46
0 and 1	1	141	0.06	-0.01-0.13	0	0-4.4	0.43
0	0	174	0.09	0.01-0.16	0	0-4.2	0.47
0	1	82	0.02	-0.02-0.07	0	0-2	0.22
1	0	121	0.09	0.009-0.17	0	0.2.7	0.44
1	1	59	0.1	-0.6-0.26	0	0-4.4	0.61
NPYS		376	0.09	0.04-0.14	0	0-4.4	0.48

seasons (0 = winter/spring, 1 = summer/autumn), status (0 = NPY, 1 = PY), season of 1 and status of 1 = PYS

Associations between weaning to first service interval and non-productive sow days per parity (NPD/parity), season of the year and summer/autumn infertility farm-year status

Weaning to first service interval

The p-value for the comparison of medians between PY and NPY group and their various combinations with season of the year categories are shown in Table 2-16. Statistically significant differences were detected between the weaning to first service intervals of PY and NPY in winter/spring and NPY in summer/autumn. The means of the NPY are higher than those of PY in all comparisons (Table 2-17), with substantially shorter mean intervals for sows qualifying or having intervals <19 days for "all sows" and "parity 1 sows", occurring in PY in the summer/autumn months (Figure 2-8 to Figure 2-10).

Table 2-16: P-value calculated from Mann-Whitney U test comparisons of medians of weaning to first service interval between problem and non-problem herds, between seasons, and between PYS and NPYS

Parameter	A	B	C	D	E
wean to 1st service interval	0.0002	0.0003	<0.001	<0.001	0.0002
wean to 1st service interval (<19 days)	0.0001	0.007	<0.001	<0.001	<0.001
wean to 1st service interval (parity 1)	0.62	0.29	<0.001	<0.001	<0.001
wean to 1st service interval (<19 d, parity 1)	0.87	0.067	<0.001	<0.001	<0.001
NPD/parity (parity >0)	0.12	0.094	<0.001	0.14	0.014

A = PY in summer/autumn *vs* PY in winter/spring

B = NPY in summer/autumn *vs* NPY in winter/spring

C = PY *vs* NPY in winter/spring

D = PY *vs* NPY in summer/autumn

E = PYS *vs* NPYS

Shaded cells indicate p-values < 0.05

Table 2-17: Descriptive statistics for length (days) of weaning to first service intervals stratified by season and farm status

Parameter	*Season*	*Status*	*N*	*Mean*	*95% CL*	*Median*	*Min-Max*	*SD*
Weaning to 1st service interval	0 and 1	0 and 1	11893	6.59	6.43-6.74	5	1-189	8.6
	0	0 and 1	6960	6.81	6.59-7.03	5	1-189	9.25
	1	0 and 1	4932	6.28	6.06-6.49	5	1-189	7.59
	0 and 1	0	7945	6.74	6.56-6.93	5	1-179	8.37
	0 and 1	1	3947	6.28	6-6.56	5	1-189	9.04
	0	0	4671	7.004	6.74-7.27	5	1-179	9.36
	0	1	2289	6.41	6.04-6.78	5	2-189	9
	1	0	3274	6.37	6.14-6.6	5	1-86	6.71
	1	1	1657	6.1	5.66-6.54	5	1-189	9.1
	NPYS		10236	6.67	6.5-6.6	5	1-189	8.52
Weaning to 1st service interval (<19)	0 and 1	0 and 1	11327	5.11	5.08-5.14	5	1-18	1.84
	0	0 and 1	6598	5.14	5.09-5.18	5	1-18	1.77
	1	0 and 1	4728	5.07	5.02-5.13	5	1-18	1.94
	0 and 1	0	7537	5.2	5.16-5.24	5	1-18	1.91
	0 and 1	1	3789	4.93	4.88-4.98	5	1-18	1.68
	0	0	4403	5.22	5.17-5.28	5	1-18	1.87
	0	1	2195	4.96	4.89-5.02	5	2-18	1.55
	1	0	3134	5.19	5.1-5.24	5	1-18	1.97
	1	1	1593	4.89	4.8-4.98	4	1-18	1.85
	NPYS		9734	5.15	5.11-5.18	5	1-18	1.84
Weaning to 1st service interval (parity 1)	0 and 1	0 and 1	2947	8.93	8.51-9.35	5	1-159	11.52
	0	0 and 1	1778	9.57	8.97-10.18	5	1-159	12.98
	1	0 and 1	1169	7.95	7.45-8.45	5	1-82	8.74
	0 and 1	0	1834	9.56	8.99-10.12	5	1-159	12.26
	0 and 1	1	1113	7.89	7.3-8.48	5	1-96	10.09
	0	0	1112	10.38	9.56-11.2	5	1-159	13.89
	0	1	666	8.23	7.38-9.08	5	2-96	11.2
	1	0	722	8.29	7.63-8.96	5	1-82	9.07
	1	1	447	7.39	6.63-8.15	5	1-59	8.16
	NPYS		2500	9.2	8.73-9.68	5	1-159	12
Weaning to 1st service interval (<19 and parity =1)	0 and 1	0 and 1	2643	5.73	5.64-5.82	5	1-18	2.43
	0	0 and 1	1560	5.68	5.56-5.8	5	1-18	2.34
	1	0 and 1	1083	5.81	5.65-5.96	5	1-18	2.55
	0 and 1	0	1617	5.98	5.85-6.11	5	1-18	2.64
	0 and 1	1	1026	5.34	5.21-5.46	5	1-18	2.01
	0	0	949	5.91	5.75-6.07	5	1-18	2.57
	0	1	611	5.32	5.17-5.47	5	2-18	1.88
	1	0	668	6.08	5.87-6.29	5	1-18	2.72
	1	1	415	5.36	5.15-5.57	5	1-18	2.18
	NPYS		2228	5.8	5.7-5.9	5	1-18	2.47

season : 0 = winter/spring, 1 = summer/autumn; status : 0 = PY, 1 = NPY, *e.g.* season of 1 and status of 1 = PYS, N = number pigs, 95% CL = 95% confidence limits, Min-Max = minimum-maximum, SD. = standard deviation

Figure 2-8: Box and Whisker plots of weaning to first service interval for PY and NPY stratified by season and month of the year

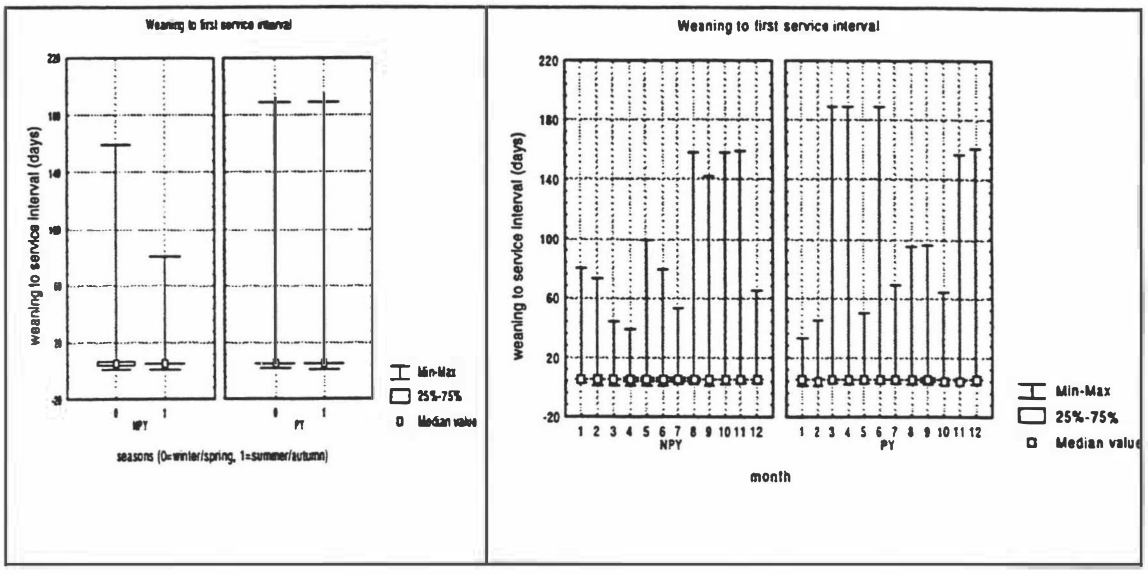


Figure 2-9: Box and Whisker plots of weaning to first service interval (< 19 days) stratified by season and month of the year

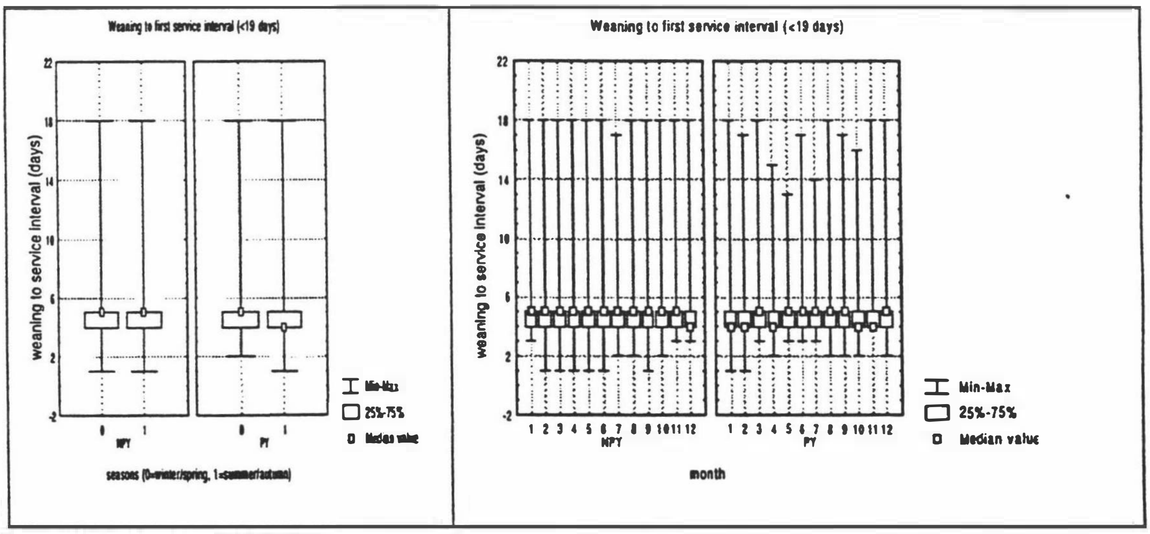


Figure 2-10: Box and Whisker plots of weaning to first service interval (parity 1) for PY and NPY stratified by season and month of the year

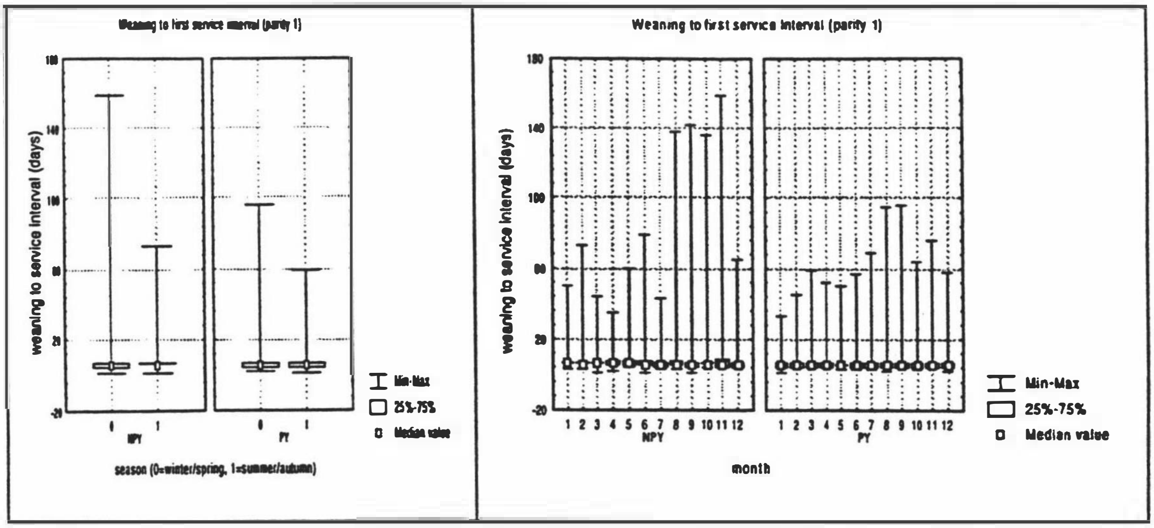
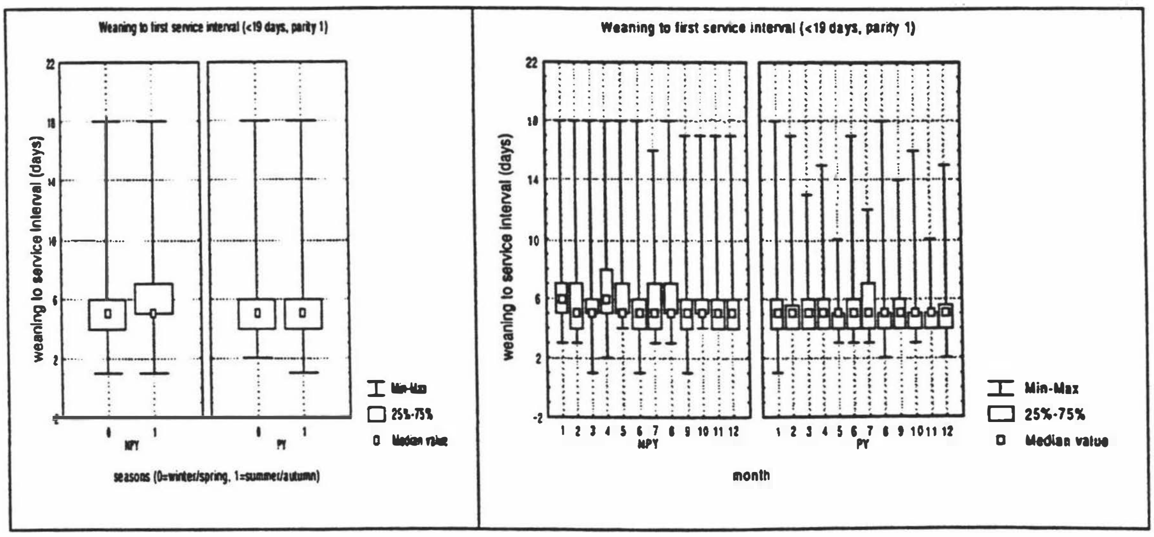


Figure 2-11: Box and Whisker plots of weaning to first service interval (<19 days, parity 1) for PY and NPY stratified by season and month of the year



Non-productive sow days per parity (NPD/parity)

Statistically significant differences were detected between the NPD/parity of the PY and NPY groups in winter/spring, and between PYS and NPYS (Table 2-16). The means of NPD/parity of PY were higher than for NPY (Table 2-18). Figure 2-12 illustrates the NPD/parity of PY and NPY stratified by seasons or months.

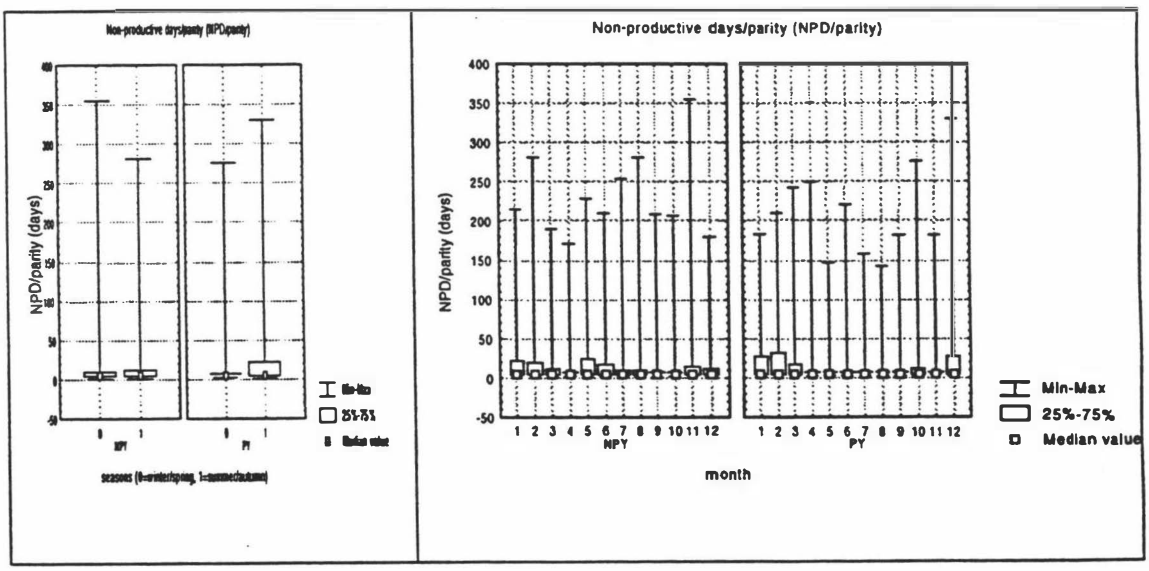
Table 2-18: Descriptive statistics for non-productive sow days per parity (NPD/parity)

Parameter	*Seasons*	*Status*	*N*	*Mean*	*95% CL*	*Median*	*Min-Max*	*SD*

Parameter	*Seasons*	*Status*	*N*	*Mean*	*95% CL*	*Median*	*Min-Max*	*SD*
NPD/parity	0 and 1	0 and 1	11891	18.57	17.98-19.16	5	1-355	32.74
	0	0 and 1	6960	18.08	17.33-18.84	5	1-355	32.31
	1	0 and 1	4930	19.24	18.31-20.17	5	1-330	33.31
	0 and 1	0	7943	17.87	17.18-18.57	5	1-355	31.44
	0 and 1	1	3947	19.97	18.88-21.07	5	1-330	35.17
	0	0	4671	17.87	16.95-18.79	5	1-355	32.05
	0	1	2289	18.52	17.18-19.87	5	2-276	32.84
	1	0	3272	17.88	16.83-18.93	5	1-281	30.55
	1	1	1657	21.93	20.1-23.77	5	1-330	38.04
	NPYS		10234	18.03	17.41-18.64	5	1-355	31.76

season : 0 = winter/spring, 1 = summer/autumn; status : 0 = PY, 1 = NPY, *e.g.* season of 1 and status of 1 = PYS, N = number pigs, 95% CL = 95% confidence limits, Min-Max = minimum-maximum, SD. = standard deviation

Figure 2-12: Box and Whisker plots of non-productive sow days (NPD) for PY and NPY stratified by season and month of the year



Comparisons of the total number of pigs born, number of pigs born alive, number of stillborn and mummies for litters in problem and non-problem farms overall, and in summer-autumn and winter-spring

Total number of pigs born and number of pigs born alive per litter

Results of two way ANOVA indicate that the main effects, season (winter/spring and summer/autumn) and farm status (PY or NPY) were significantly associated with the number of total pigs born and those born alive per litter, whereas there was no significant interaction between season and farm status (Table 2-19, Figure 2-13, Figure 2-14). The numbers of pigs born and pigs born alive per litter were higher in winter/spring than in summer/autumn and higher in non-problem farms than in problem farms (Table 2-20). The results of more detailed comparisons are presented in Table 2-21 and Table 2-22, which show statistically significant differences (p-value <=0.05) in multiple comparisons for the interaction terms season and problem farm status. The average number of pigs born and pigs born alive during winter/spring for the NPY group was 11.76 and 10.85 whereas the means in summer/autumn for the group PY were 11.54 and 10.58 (Table 2-20).

Results of two-way ANOVA comparison of season, farm status (PY/NPY) and the interaction term between seasons and status of PY or NPY for the parameters numbers of pigs born and the number born alive per litter are presented in Table 2-19.

Table 2-19: Results of two-way ANOVA (comparison) for the effect of season, farm status (PY/NPY), and the interaction between season and status of PY or NPY on the number of pigs born and born alive per litter

	Total born		Born alive	
	F ratio	p-values	F ratio	p-values
summer/autumn *vs* winter/spring	3.81	0.051	8.81	0.051
PY *vs* NPY	5.65	0.018	15.38	<0.001

shaded cells indicate p-value < 0.05

Table 2-20: Descriptive statistics for number of pigs born and number of pigs born alive per litter for different combinations of season and farm status

Parameter	*Seasons*	*Status*	*N*	*Mean*	*95% CL*	*Median*	*Min-Max*	*SD*
Total pigs born	0 and 1	0 and 1	17137	11.7	11.7-11.8	12	0-29	3.0
	0	0 and 1	9920	11.7	11.7-11.8	12	0-25	3.0
	1	0 and 1	7217	11.7	11.6-11.7	12	0-29	3.1
	0 and 1	0	11082	11.7	11.7-11.8	12	0-29	3.1
	0 and 1	1	6055	11.6	11.6-11.7	12	0-22	3.0
	0	0	6334	11.8	11.7-11.8	12	0-25	3.0
	0	1	3586	11.7	11.6-11.8	12	0-22	2.9
	1	0	4748	11.7	11.6-11.8	12	0-29	3.1
	1	1	2469	11.5	11.4-11.7	12	1-22	3.0
	NPYS		14668	11.74	11.7-11.8	12	0-29	3.03
Pigs born alive	0 and 1	0 and 1	17137	10.8	10.7-10.8	11	0-21	2.9
	0	0 and 1	9920	10.8	10.7-10.9	11	0-21	2.9
	1	0 and 1	7217	10.7	10.7-10.8	11	0-21	2.9
	0 and 1	0	11082	10.8	10.8-10.9	11	0-21	2.9
	0 and 1	1	6055	10.7	10.6-10.7	11	0-20	2.8
	0	0	6334	10.9	10.8-10.9	11	0-21	2.9
	0	1	3586	10.7	10.6-10.8	11	0-19	2.8
	1	0	4748	10.8	10.7-10.9	11	0-21	2.9
	1	1	2469	10.6	10.5-10.7	11	0-20	2.8
	NPYS		14668	10.8	10.8-10.9	11	0-21	2.9

season : 0 = winter/spring, 1 = summer/autumn; status : 0 = PY, 1 = NPY, *e.g.* season of 1 and status of 1 = PYS, N = number of pigs born, 95% CL = 95% confidence limits, Min-Max = minimum-maximum, SD. = standard deviation

Figure 2-13: Box and Whisker plots of number pigs born per litter for PY and NPY stratified by season and month of the year

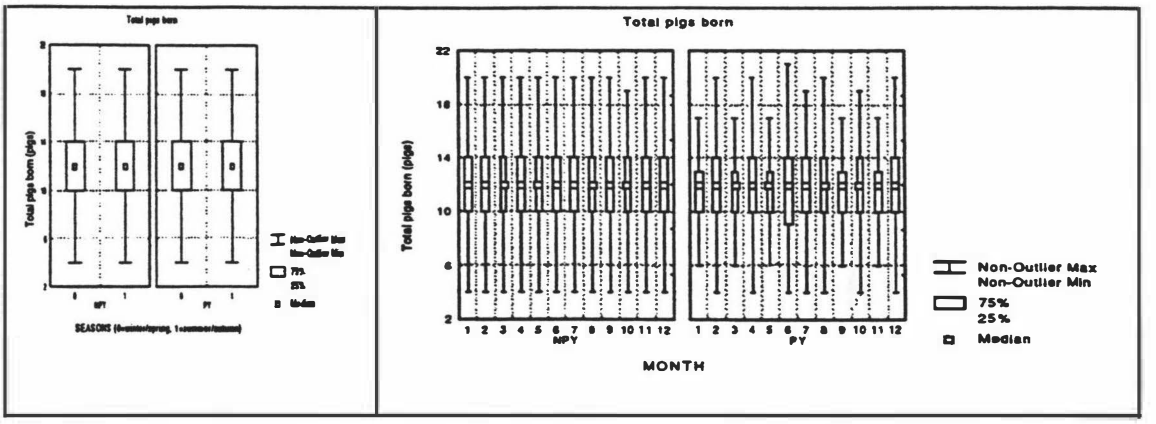


Figure 2-14: Box and Whisker plots of number of pigs born alive per litter for PY and NPY stratified by season and month of the year

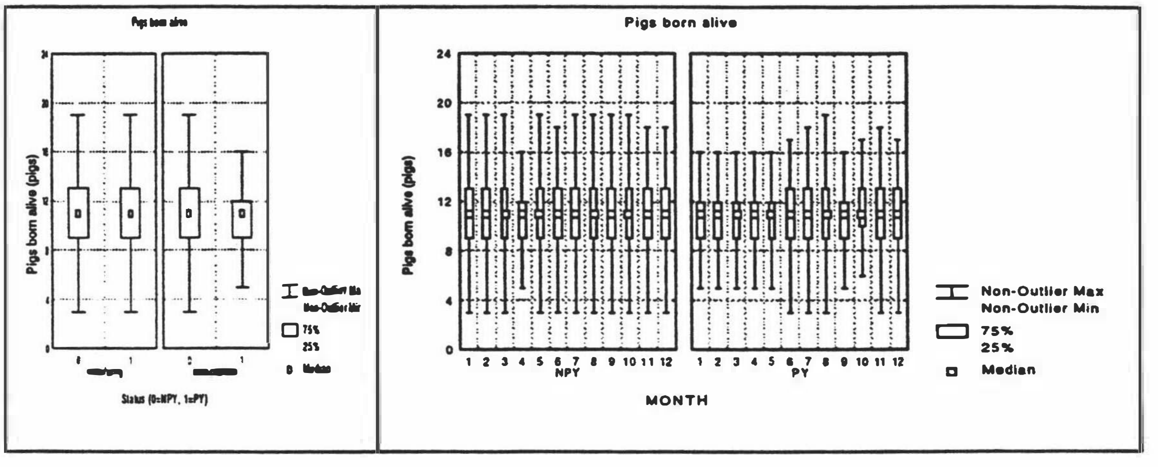


Table 2-21: P-values obtained from two-way ANOVA comparisons of total number of pigs born per litter between different season and farm status (PY or NPY) categories

TOTAL PIGS BORN	winter/spring X NPY	winter/spring X PY	summer/autumn X NPY	summer/autumn PY
winter/spring X NPY		0.82	0.93	0.02
winter/spring X PY	0.82		0.99	0.19
summer/autumn X NPY	0.93	0.99		0.08
summer/autumn X PY	0.02	0.19	0.08	

shaded cells indicates p-value < 0.05

Table 2-22: P-values obtained from two-way ANOVA comparisons of number of pigs born alive per litter between different season and farm status (PY or NPY) categories

PIGS BORN ALIVE	winter/spring X NPY	winter/spring X PY	summer/autumn X NPY	summer/autumn X PY
winter/spring X NPY		0.08	0.79	<0.01
winter/spring X PY	0.08		0.47	0.03
summer/autumn X NPY	0.79	0.47		0.1
summer/autumn X PY	<0.01	0.03	0.1	

shaded cells indicates p-value < 0.05

Stillborn and mummies

Number of stillborn piglets

The Mann-Whitney U test demonstrated statistically significant differences between the number of stillborn piglets per litter in problem and non-problem farms in each of the two seasons, summer/autumn and winter/spring ($p = 0.04$ and $p < 0.01$ respectively) with problem farms having higher rates than non-problem farms. There were no statistically significant differences between the rates in either problem farms in summer/autumn and winter/spring or non-problem farms in summer/autumn and winter/spring ($p = 0.93$ and 0.16 respectively).

Table 2-23: Descriptive statistics for number of stillborn per litter

Parameter	*Seasons*	*Status*	*N*	*Mean*	*95% CL*	*Median*	*Min-Max*	*SD*
Stillborn	0 and 1	0 and 1	17137	0.8	0.8-0.8	0	0-15	1.3
	0	0 and 1	9920	0.8	0.8-0.8	0	0-15	1.4
	1	0 and 1	7217	0.8	0.8-0.8	0	0-13	1.3
	0 and 1	0	11082	0.8	0.8-0.8	0	0-14	1.3
	0 and 1	1	6055	0.8	0.8-0.9	0	0-15	1.4
	0	0	6334	0.8	0.8-0.8	0	0-14	1.3
	0	1	3586	0.8	0.8-0.9	0	0-15	1.4
	1	0	4748	0.8	0.7-0.8	0	0-13	1.4
	1	1	2469	0.8	0.8-0.9	0	0-13	1.3
	NPYS		14668	0.8	0.78-0.82	0	0-15	1.4

season : 0 = winter/spring, 1 = summer/autumn; status : 0 = PY, 1 = NPY, *e.g.* season of 1 and status of 1 = PYS, N = number of litters, 95% CL = 95% confidence limits, Min-Max = minimum-maximum, SD. = standard deviation

Mummies

No statistically significant differences were detected by the Mann-Whitney U test when the number of mummies per litter in problem and non-problem farms in each of the two seasons were compared, nor were there any significant differences from comparisons between problem farms in both seasons and non-problem farms in both seasons. The descriptive statistics for mummies over the whole range of stratification according to season and farm status are presented in Table 2-24.

Table 2-24: Descriptive statistics for number of mummies per litter

Parameter	*Seasons*	*Status*	*N*	*Mean*	*95% CL*	*Median*	*Min-Max*	*SD*
Mummies	0 and 1	0 and 1	17137	0.1	0.1-0.1	0	0-18	0.5
	0	0 and 1	9920	0.1	0.1-0.1	0	0-10	0.5
	1	0 and 1	7217	0.1	0.1-0.2	0	0-18	0.6
	0 and 1	0	11082	0.1	0.1-0.1	0	0-18	0.5
	0 and 1	1	6055	0.2	0.1-0.2	0	0-10	0.5
	0	0	6334	0.1	0.1-0.1	0	0-5	0.4
	0	1	3586	0.2	0.1-0.2	0	0-10	0.6
	1	0	4748	0.1	0.1-0.2	0	0-18	0.6
	1	1	2469	0.2	0.1-0.2	0	0-9	0.5
	NPYS		14668	0.13	0.63-0.14	0	0-18	0.5

season : 0 = winter/spring, 1 = summer/autumn; status : 0 = PY, 1 = NPY, season of 1 and status of 1 = PYS, N = number pigs, 95% CL = 95% confidence limits, Min-Max = minimum-maximum, SD. = standard deviation

Discussion

Summer/autumn infertility, as defined for the purpose of this study, was not a regular event, but occurred sporadically in the study set of 20 farms with records for multiple years.

Farms were designated as problem farms or non-problem farms within each year using set criteria, and the procedure introduced some loss of independence in the observations for the 3 farms which had dual classifications through their history. It was hoped that this deficiency was somewhat compensated for by the number of farms (20) in the study and the number of farm years (37).

The analyses showed that farrowing rates on problem farms were lower in summer/autumn than in winter/spring of the same year which was used as the criterion defining problem farm-years. The analyses showed that for the affected summer/autumn periods, regular return rates and irregular return rates were higher than during winter/spring. No differences were found when negative pregnancy test rates, abortion rates and not-in-pig rates were similarly compared.

A finding of higher weaning to first service intervals in the winter/spring period compared to summer/autumn was unexpected and is contrary to findings from studies by Wrathall (1987), Love (1981), Hennessy (1987a) and Leman (1992). Because weaning to first service intervals of > 19 days may have included cases of extended anoestrus or silent oestrus, further analyses were carried out on weaning to first service intervals of < 19 days.

The results from this stratum were similar to those for the overall analysis, and only after further stratification to parity 1 sows and intervals of < 19 days, was there some evidence, albeit not at a high level of statistical significance, of the weaning to first service intervals being higher in that group of sows in summer/autumn than in winter/spring. This finding was also somewhat surprising as it too was contrary to previous reports (Hurtgen *et al.*, 1980; Hurtgen and Leman, 1980; Love, 1980) where parity 1 sows and weaning to first service intervals were examined in relation to summer/autumn infertility and no difference had been found.

The number of non-productive days per parity was higher in problem farms in summer/autumn than in winter/spring and higher than in non-problem farms over both seasons. The higher non-productive days per parity in summer/autumn was not a consequence of long weaning to first service intervals but was due to the extended lengths of the "service to detected open" period and the "detected open to removal" period. The effect of entry to first service intervals was not examined in relation to non-productive days per parity as this period varies greatly (Leman, 1992) and is influenced by management factors poorly related or unrelated to the focus of this study.

In this study, the examination of non-productive days per parity was restricted to parities > 1 (calculated from the weaning to weaning interval) as the mating to removal interval showed wide variation for gilts among the study farms and is strongly influenced by factors such as the value of gilts and the market price of culls.

Between-season differences were detected for both the numbers of pigs born and the numbers born alive per litter but the differences were very small and were not evident when problem and non-problem farms were compared by themselves and in combination with seasons.

Although Hennessy (1987a) linked reduced litter size with summer/autumn infertility, Love (1980) suggested that any reductions in litter size should not be considered as indicators of the syndrome but rather as a reflection of other factors, such as management practices and increased stress.

This descriptive and analytical study provides an insight into reproductive performance in New Zealand pig herds and indicates that summer/autumn infertility is not a major health and production problem for the herds and years considered in this study. The contrast between New Zealand and Australia, where summer/autumn infertility is seen as a serious production-limiting problem is interesting and suggests that some of the common Australian management procedures, such as lower feeding level for dry sows, together with climatic factors, may be influential in producing the syndrome. Further investigation of those and issues of a similar nature is warranted.

CHAPTER 3

NUTRITIONAL INFLUENCES ON SEASONAL VARIATION IN FERTILITY

Chapter 3: Nutritional influences on seasonal variation in fertility

Literature review

Introduction

Along with genotype and housing, nutrition ranks highly as an important determinant of health and production. Nutrition of gilts during rearing affects subsequent reproductive performance not only in the short-term, but also in the long term if there are carry over effects (den Hartog, 1984).

Pregnant sows require sufficient energy and amino acids to replace obligatory losses, provide body support functions, and properly develop the products of conception (Verstegen *et al.*, 1987; Pettigrew and Tokach, 1991, Reese *et al.*, 1995). In addition, and in particular for young sows, they often need to build their own body tissues, and to replace tissues damaged while supporting milk production in the just-completed lactation. The total nutrient needs of pregnant sows are considerably less than those of lactating sows, except during the last few days of pregnancy. Because the nutrient needs of one phase of reproduction (pregnancy or lactation) are affected by the nutritional status during preceding phases, feeding strategies need to take into account lifetime reproductive performance, rather than that of only a single pregnancy (Pettigrew and Tokach, 1991).

During pregnancy, food intake should be the minimum necessary to obtain satisfactory birth weights and a suitable rate of weight gain for the sow (Devendra and Fuller, 1979). Gilts begin their reproductive life with more limited body reserves than sows because they are still growing. Their needs differ from those of mature sows but they are generally fed similarly. Modern management tends to consider nutritional responses much more precisely than was hitherto the case. The main aim of modern strategies is to maintain body condition during lactation, which implies a high level of feeding during lactation (the period of maximum production), preceded by carefully controlled and limited weight gain during pregnancy (Williams and Close, 1985).

Dourmad (1991) showed that there is a positive relationship between body weight gain during pregnancy and weight loss during lactation. From the point of view of energetic efficiency it is preferable to produce milk from feed than from body reserves (Kirkwood and Thacker, 1988).

Excessive feed intake

A higher feed intake results when pregnant sows are fed *ad libitum* and as a consequence they lay down more body fat. Animals fed in this manner tend to lose more body fat during lactation and have more reproductive failures (Verstegen *et al.*, 1989).

Sows overfed during pregnancy will voluntarily consume less feed and lose more weight during the subsequent lactation than sows fed restricted amounts designed to support only moderate weight gain during pregnancy (Tubbs, 1988; Reese *et al.*, 1995). It also appears that excessive energy intake during pregnancy may disrupt mammary development (Tubbs, 1988; Pettigrew and Tokach, 1991; Reese *et al.*, 1995) and adversely affect lactation due to excessive fat infiltration of the alveoli (Tubbs, 1988). Consequently it is important to ensure that sows are not overly fat at farrowing (Pettigrew and Tokach, 1991). Udder hypoplasia may be prevented by early selection of replacement females (81.8-100 kg), with feeding limited to a gestation-type of ration from the time of selection until just prior to breeding (Tubbs, 1988). A level of above 3.2 kg/day in the sow produces excessive fat and causes problems at farrowing, which results in reduced pigs born alive (Smith, 1980). Excessively fat sows tend to have more problems at farrowing, become more easily exhausted, and their higher susceptibility to heat and environmental stress predisposes them to lactation failure (Tubbs, 1988; Dourmad *et al.*, 1994) and locomotion problems (Dourmad *et al.*, 1994). Excessive feed and/or calorie intakes have been associated with constipation, increased intestinal transit time and increased intestinal absorption of endotoxins which possibly contribute to lactation failure (Tubbs, 1992). When sows were fed either 1.82 kg per day or 2.77 kg per day during gestation, sows on the higher level gained more weight during gestation, lost more weight during lactation, had a higher incidence of lactation disorders, and were culled earlier than those fed the lower level (Thieu, 1975). Another study showed that increasing the feed intake by 1.36 kg after day 90 of gestation improved sow weight gain from weaning to breeding and increased litter weaning weights by 2.77 kg (Cromwell *et al.*, 1989). Good judgment is necessary to reach a balance between feeding which optimizes pig birth weights, and overfeeding, with its associated problems during late gestation (Tubbs, 1992)

Undernutrition

Sows can endure wide variations in macronutrient supply both before and during pregnancy without affecting embryo survival or final litter size, although with prolonged severe nutritional deficiencies sows may become anoestrous, or if pregnant, terminate the pregnancy. Embryo survival and final litter size appear normal in those sows which successfully carry a litter to term (Kirkwood and Thacker, 1988).

Undernutrition has to be very severe to threaten the viability of embryos (Devendra and Fuller, 1979; Lindsay *et al.*, 1993; Reese *et al.*, 1995). It appears that once an ovum is fertilized, the mother is committed to giving a high priority to partitioning her supply of nutrients, both ingested and endogenous, to her foetus(es) (Lindsay *et al.*, 1993). Litter size is unaffected unless sows are fed well below maintenance (Verstegen *et al.*, 1987). Underfeeding during pregnancy leads to lower body fat reserves at farrowing or at weaning, and in most cases return to oestrus will be delayed and conception rates lower. Undernutrition exacerbates other disorders which form part of the disease complex which leads to the thin sow syndrome (Dourmad *et al.*, 1994).

The changes in fat deposition are more extreme than those of protein deposition. At low levels of feed intake, body fat is used for both maternal maintenance and synthesis of reproductive tissue in late gestation. Thus anabolic and catabolic processes occur simultaneously at about the same rates. Although the site from which fat was mobilized was not determined, results from experiments at comparable levels of feeding suggest that a reduced lipogenic activity of the subcutaneous adipose tissue occurred during pregnancy to give a considerable reduction in backfat thickness during the first 2 parities (Close *et al.*, 1985).

In sheep, severe underfeeding in early pregnancy reduces placental size, whether measured at 90 days or near term, yet small placentae seem to compensate functionally to some degree for their size and support the development of normal-sized lambs at birth provided pregnant ewes are well fed in late pregnancy (Lindsay *et al.*, 1993).

For pigs, feeding below 1.5 kg of breeder meal or its equivalent per day will adversely affect both litter size at birth and the subsequent survival rate of the progeny (Smith, 1980).

Weight gain during gestation

Nutritionists have for a long time argued that sows should gain 10-15 kg (Brook, 1982) or 12-15 kg (Cutler *et al.*, 1981) or 25 kg (NRC, 1988) or 22.7-31.8 kg (Connor and Tubbs, 1992) liveweight per reproductive cycle in order to sustain performance. Although there is some disagreement about how much they should gain, in situations where facilities do not permit weighing, it should be assumed that sows are gaining 15 kg/cycle, and the sows' feed allowance should be adjusted accordingly at the start of each successive pregnancy (Brooks, 1982). This rate of gain will allow for skeletal growth and maintenance of adequate fat reserves (Cutler *et al.*, 1981). In a study involving 3000 sows, Hillyer (1980) quoted by Brooks (1982) measured the effect on litter size of body weight losses and gains between successive matings. His data summarized in Table 3-1 shows that weight gains of 1-10 kg between successive matings was associated with optimal litter size at subsequent farrowings.

Table 3-1: Sow weight changes between successive matings stratified at 10 kg intervals and average litter size at the subsequent farrowing for each stratum (Hillyer 1980)

Sow weight change over previous cycle (kg)*	Litter size at subsequent farrowing*
< -10	9.6
-9 to 0	9.7
1 to 10	10.4
11 to 20	10.1
21 to 30	10.0
31 to 40	10.1
>50	9.6

*Data was recorded over 3 successive litters and the weight change reported was between the first and second weaning, with litter size reported from the subsequent farrowing (Brooks, 1982).

Gilts should gain 50-55 kg (Tubbs, 1992) or 40.9-45.5 kg (Connor and Tubbs, 1992) during gestation. Dourmad *et al.* (1994) recommended 33.2 MJ DE/day (31.87 MJ ME/day) during gestation for gilts mated early at a low bodyweight and 22.9 MJ DE (28.7 MJ ME/day) for gilts mated later at heavier weights and with more body fat reserves (Dourmad *et al.*, 1994). In the last 3 to 4 weeks of gestation, gilt feed levels may be increased by up to 25% (0.45 to 0.68 kg feed/day) to increase pig birth weights, but overfeeding above that level should be avoided (Tubbs, 1992). Smith (1980) recommended a total bodyweight gain of sows of about 45 kg, a level with which Vestegen *et al.* (1989) concur. Allowing for the bodyweight of the litter and products of conception, this converts to an actual sow bodyweight gain of around 30 kg (Smith, 1980). Vestegen *et al.* (1989) proposed a litter weight gain of 20 kg and a maternal gain of 25 kg with an overall gain of 45 kg during gestation. This target is influenced by bodyweight and condition at the end of the previous reproductive cycle. Furthermore, if there is a need to increase birthweights for piglet survival, this will also increase sow bodyweight gain during gestation. Further complicating factors are environment (ambient temperature and housing system), health status and system of feeding (pasture, group or individual), which all need to be considered in the overall context, together with nutritional status (Smith, 1980).

Connor and Tubbs (1992) recommended target weight gains of 40-45 kg during pregnancy for sows in normal condition. About 20 kg of this weight gain is for the litter and other intra-uterine contents. The remaining 20-25 kg is for maternal weight gain of which 15 kg may be for growth to full maturity, which is usually achieved by the 4th or 5th parity. (see

Table 3-1). Table 3-2 shows the relative weights of the products of pregnancy and weight changes of sows/gilts during pregnancy and lactation accompanying an assumed growth and development pattern over 5 parities.

Table 3-2: Relative weights of the products of pregnancy and weight changes of sows during pregnancy and lactation accompanying an assumed growth and development pattern over 5 parities (partly after Whittemore, 1980)

	Parity				
	1	2	3	4	5
Weight at conception (kg)	110	125	140	155	170
Weight at parturition (kg)	155	170	185	195	210
Weight of litter (kg)	15	15	15	15	15
Weight of placenta and uterine fluids (kg)	5	5	5	5	5
Weight gain of sow itself (kg)	25	25	25	20	20
Weight loss during lactation (kg)	10	10	10	5	-

Sows in parities 0, 1, and 2 require higher daily intakes of feed per unit of body weight because in addition to gestating a litter, they are still growing.

Energy

Maintenance energy

A sow requires an extra 3 MJ digestible energy (DE)/day (250 g feed/day) intake for every 30 kg increase in her live weight to cater for increased energy requirements of maintenance (King, 1990). Pregnant sows should be fed to achieve a body condition score of 3.0 immediately before farrowing and feed allowances should be adjusted accordingly if there is much deviation from this target score. In practice, daily feeding rates are commonly adjusted by 0.23-0.37 kg/day in accordance with sow condition scores (Reese *et al.*, 1995).

Maintenance energy is equivalent to about 4.184 MJ metabolisable energy (ME)/kg.bodyweight$^{.75}$ in primiparous pregnant sows and similar values pertain in multiparous sows (Noblet *et al.*, 1990).

Total energy requirements in pregnant sows

Daily energy requirements during pregnancy correspond to the sum of requirements for maintenance, uterine growth and maternal gain. More than 75% of the energy intake of pregnant sows is used to meet maintenance requirements. Therefore, it is important to estimate this component precisely. Unfavorable climatic conditions or heavy animals can increase this maintenance component to the point where it equals 90% of the total energy requirement. The requirement for uterine growth represents only about 5% of total energy needs, although the daily requirement increases as pregnancy progresses (Noblet *et al.*, 1990).

Close *et al.* (1985) calculated an efficiency of 0.72 for total energy gain for pregnant sows but there is still some uncertainty about the composition of this maternal gain. The Agricultural Research Council (ARC, 1981) assumed this to be 0.0987 MJ/g. In a study by Noblet and Close (1980), primiparous animals gained about 25 kg more during pregnancy when 2.5 kg of feed (30 MJ of ME/day) was supplied. A sow which has a gain in her own body (not including the uterus and foetal weight gain) of 220 g per day throughout pregnancy, will need an average 7.6 MJ of ME for her maternal gain per day (Verstegen *et al.*, 1987). Table 3-3 shows the mean daily feed requirements for pregnancy with an assumed gain of 2.5 kg in grams of feed per day and MJ of ME per day compartmentalised for the requirements of the dam and the products of pregnancy.

Table 3-3: Mean feed requirement for a pregnant sow (gain 25 kg) in MJ of ME per day and in g of feed per day (from Verstegen et al., 1987)

Weight at mating (kg)	120	140	160
Mean weight (kg) during pregnancy	145	165	185
ME for conceptus MJ/day	0.74	0.74	0.74
ME for maternal gain MJ/day	7.6	7.6	7.6
ME for gain total MJ/day	8.34	8.34	8.34
ME for maintenance MJ/day	18.6	20.5	22.3
Total MJ/day	26.94	28.84	30.64
Feed for gain g/day	700	700	700
Feed for maintenance g/day	1550	1708	1850
Total g/day	2250	2408	2550

Table 3-3 clearly shows that pregnancy does not markedly influence the estimation of the total daily requirements of ME. In relation to the total daily requirements of ME, that are required for the reproductive tissue weight increases from approximately 3% to 15% of body weight at days 50-110 of gestation. Throughout gestation the energy retained in the reproductive tissue represents no more than 10% of the total requirement. This is equivalent to a 3 kg increase in the maternal body weight of the sow (Close *et al.,* 1985).

Feeding 45.2 MJ of ME resulted in more net sow weight gain per reproductive cycle, when compared with sows receiving 12.6 MJ, 18.8 MJ, 25.1 MJ, or 31.4 MJ of ME, but there was no change in reproductive performance. However, birthweight of pigs reflects sow energy levels, and sow weight change was greater for sows receiving higher energy. The greatest increase in sow weight occurred between the 31.4- and 45.2- ME treatment groups. Fewer sows receiving 31.4 MJ of ME completed 3 reproductive cycles than those from groups receiving the lower energy levels. A linear response between sow gestation weight gain and ME levels from 16.7 MJ to 29.3 MJ was observed, the number of live pigs born decreased linearly with increasing gestation energy levels, and there was a tendency for sows gaining more during gestation to gain less or lose more weight during lactation. Although gestation energy supply levels did not influence the number of pigs weaned, it had an effect on pig and litter weaning weights, with pig and litter weaning weights peaking for litters from sows receiving 25.1 MJ of ME. The 25.1 ME level supported adequate gains and reproductive performance, with less extreme changes in weight during gestation and lactation. Sow backfat was greater for sows receiving the more extreme levels of 37.7 MJ of ME after one parity, and remained greater over 4 parities (Libal, 1991).

The National Research Council (NRC) indicates that the energy need for optimum weight gain in pregnant sows is 5.2 MJ of metabolizable energy (ME) (Reese *et al.*, 1995). Table 3-4 shows the effect of 3 levels of energy intake during gestation on voluntary feed intake in lactation and the percentage of sows coming in oestrus within 10 days of weaning.

Table 3-4: The effect of energy intake during gestation on voluntary feed intake during lactation and percentage of sows in oestrus within 10 days of weaning

	Energy supply in gestation (DE, MJ/day)		
	24.0	29.8	35.8
No. sows	16	16	16
Voluntary feed intake in lactation (kg/day)	4.9	4.7	4.3
Sows in oestrus within 10 days (%)	53	80	80

Early pregnancy energy requirements

This period is not only critical for conception but extreme changes during this period can cause early embryonic death. Under practical feeding situations, where energy intakes are usually within the range of 20-30 MJ DE/day, embryonic survival is unlikely to be noticeably affected by energy effects (Tubbs 1995c).

High energy feed : detrimental effects

High feed levels during early pregnancy have been shown to increase embryo mortality. Although embryo survival was significantly depressed by high energy intakes, the numbers of embryos was not, indicating that highly fed gilts also had an elevated ovulation rate. These effects were reported in gilts, which respond to flushing with increased ovulation rates (Kirkwood and Thacker, 1988).

The studies of Heap *et al.* (1967) and Toplis *et al.* (1983) were summarized by Kirkwood and Thacker, 1988) as shown in Table 3-5. There was no marked difference between high and low feeding levels during early pregnancy for reproductive performance of multiparous sows although the high feed level (4 kg/day) greatly exceeded the levels commonly used in commercial practice.

Table 3-5: The influence of feeding level during early pregnancy on reproductive performance of multiparous sows.

	Feeding level (kg/day)	
	2.0	4.0
Ovulation rate	21.0	21.8
No. embryos	15.8	15.5
Embryo survival (%)	75.2	71.1

From Heap *et al.* (1967) and Toplis *et al.* (1983)

High energy feed: advantageous effects

Experiments with multiparous sows have generally failed to show any detrimental effect of high energy intakes during the first 10-30 days of pregnancy on embryo survival. In contrast, the results of a recent experiment with gilts has shown that a reduction in feeding level for 10 days after mating improves embryonic survival (Kirkwood and Thacker, 1988; Tubbs, 1995c).

While it appears that for sows in particular, limited feed intake during the first 10-14 days after mating may not be as critical as was once thought, recent research now suggests that maintaining a relatively high feed intake during the immediate post-breeding period may ameliorate some of the adverse effects that decreasing photoperiod has on fertility in the late summer and early fall (Tubbs, 1995c).

Mid-pregnancy energy requirements

This period of pregnancy has received less attention than early and late stages. Tubbs (1995a) recommends moderately high feed intake during the first 2-4 weeks after mating, depending on the animal's body condition. If necessary, intake can then be adjusted in mid-gestation based on current body condition and the desired body condition for farrowing. He classes high feed intake as 3.6 kg/day, moderately high intake as 2.7 kg/day, and intermediate intake as between 2.7-3.6 kg/day. Noblet *et al.* (1985) reported that between day 50 and 110 of gestation, the ME requirement for reproduction in gilts increased from 3 to 12% of the maternal intake. The ARC (1981) committee assumed that foetal gain was 20% less efficient than gain in growing animals (Verstegen *et al.*, 1987).

Late pregnancy energy requirements

Late pregnancy is a period of rapid foetal growth with the most rapid phase occurring in the last 10 days of pregnancy (King, 1990). Most foetal weight increase occurs during the last 2-3 weeks of gestation (Reese *et al.*, 1995). The metabolizable energy requirement for uterine and mammary tissue gain is about 4.18 MJ during the last week of pregnancy (Noblet *et al.*, 1985a). At this time, sows are heavier and their maintenance energy requirements are higher (23.4 MJ and 24.3 MJ per day, for 30 and 40 mg maternal gain, respectively). Hence, sows fed 24.7 MJ ME per day will mobilize energy reserves during late pregnancy whereas maternal energy balance will be about zero for those fed 28.9 MJ ME per day. The large increase in energy requirements during late pregnancy needs to be balanced by feeding more energy during that period so as to increase maternal protein deposition while avoiding mobilization of body reserves. Energy recommendations should consider the high body weight loss during lactation that is associated with inadequate voluntary feed intake and high requirements for milk production.

The daily requirement for pregnancy ranges from about 25.4 MJ to more than 41.8 MJ (Noblet *et al.*, 1990). Noblet *et al.* (1985) reported that at comparable litter sizes the total weight of the foetuses in late gestation was 16% higher when metabolizable energy during pregnancy was 30 MJ rather than 20 MJ. His data also suggested that a high feeding level before parturition may increase the duration of parturition, resulting in a higher number of piglets born dead. When this hypothesis was tested by reducing feed intake during the last days of gestation or by the use of a laxative, no attributable effect was observed in the equivocal results (Table 3-6).

Table 3-6: The effects of laxative, and reduced feeding levels intake in the last few days of gestation on the percentage of stillborn piglets

	Feeding level			
	Constant		Reduced	
Laxative	yes	no	yes	no
No. of sows	93	385	247	444
Stillborn piglets (%)	8.6	9.4	9.1	8.6

After Kemp *et al.* (1991) and den Hartog (1984)

In some circumstances, adding fat to sow diets improves pig survival, but improved survival from feeding fat or oil is unlikely when the average birthweight of piglets is more than 1.3-1.4 kg and pre-weaning survival is more than 85-90% (King, 1990).

It is logical to give additional feed in late gestation as the rate of foetal weight gain increases during this period. A recent study (Reese *et al.*, 1995) showed that the provision of an additional 1.4 kg of feed/day during the last 24 days of gestation increased the number of pigs weaned/litter, pig birth weight and litter weaning weight.

Sows that are underfed and thin (condition score 2.5 or less) at day 90 of pregnancy are excellent candidates for extra feed. Sows that are overfed and fat (condition score 3.5 or greater) at day 90 of gestation may experience farrowing difficulties and consume less feed during lactation when extra feed is provided during late pregnancy. Thus, for sows that have a condition score of 3.5 or greater at day 90 of gestation, it is probably best to maintain a constant feeding rate until farrowing (Reese *et al.*, 1995).

Traditional practice has been to greatly increase feed intake in late gestation with the aim of improving litter birth weights but recent research has shown that this practice is detrimental to feed intake during lactation. Sows that are overfed may be unable to eat enough initially to keep up with the demands of lactation. If sound feeding practices have been followed during early gestation to mid-gestation, excessive feeding during late gestation is unnecessary. Moderate increases in feed should have little influence on lactation intake (Tubbs, 1995c).

Fat supplementation

Feeding supplemental fat to sows during late gestation has generally resulted in improved baby pig survival to weaning. The greatest response is observed when two conditions are met:

- sows are provided with more than 1 kg of added fat in the 14 days before farrowing.
- average pig preweaning survival rate in the herd (total pigs at weaning/total pigs born alive) is less than 80%. Under these conditions, survival rates increased on average by 2.7%. In practice, e.g. feeding 2.2 kg/day of a lactation diet with 3% added fat for 14 days before farrowing would supply the recommended amount of fat (Reese *et al.*, 1995).

In a study involving 168 first parity sows, feeding supplemental fat to provide about 50% more daily intake of digestible energy than a control diet increased the proportion of sows in oestrus within 7 days post-weaning and improved the pregnancy rates of first-parity sows which had high lactation weight loss. Supplemental fat also had a beneficial effect on ovulation rate, the number of normal embryos, foetal survival and foetal weight, whereas the effect of feeding supplemental lysine was only apparent for foetal weight. Feeding supplemental fat or lysine (i.e. the control diet supplemented with lysine to provide approximately 50% more daily intake of lysine) than the control diet only improved ovulation rates in 2nd parity sows with high lactation weight loss (>14 kg). The results indicate that feeding supplemental fat or lysine can improve the postweaning reproductive performance of sows which have high weight and fat losses during lactation (Grandhi, 1992).

Protein requirements

The gut capacity (i.e. *ad libitum* dry matter appetite) for a pregnant sow is around 4.5 kg of dry feed each day. Sow needs are usually only 2-3 kg at the most, which then leaves around 2.5 kg of 'unfilled' gut space. However, sows need a high proportion of their diet in a concentrated form and the high-fibre part of the diet should be seen as a top-up ingredient. The aim should be to get the protein needs fulfilled before any food gets into the large intestine where fibre broken down by bacteria can then contribute very economical energy in the form of volatile fatty acids (Beynon, 1990).

For every 1 % of fibre above maximum needs, the digestibility of feed energy falls by about 4 %. Protein digestion is affected in a similar way. In pregnant sows, increased intakes of fibrous materials, such as straw, leads to a more contented animal because the gut capacity (dry matter appetite) of a pregnant sow is more fully satisfied (Beynon, 1990).

Reproductive characteristics such as litter size, birth weight, and probably also breeding regularity and fertility, show little response above approximately 140 g crude protein/day (CP/day) during pregnancy (ARC, 1981). The ARC report (1981) suggests that extra protein is required to maintain sow body condition for subsequent reproduction, and considers that the protein needs of pregnant sows of 140 kg liveweight gaining 30 kg maternal liveweight during pregnancy can be met by a daily intake of 180 g CP provided the diet meets the specific amino acid requirements. Protein intakes may be as low as 140 - 180 g CP/day during pregnancy in sows fed all-cereal diets (containing approximately 7-10 % CP) fortified with minerals and vitamins. Feeding all-cereal diets generally produces some loss in litter performance, and the inclusion of low levels of protein supplements in all-cereal diets to supply essential amino acids is necessary to ensure that the reproductive performance of sows and their litters is not adversely affected (King, 1990).

Different genotypes have different potentials for lean growth, which is fueled by lysine and protein levels in the diet. Where a high protein diet is fed in gestation to levels where it can no longer be utilized for lean tissue growth, then any excess is de-aminated, which causes a further drain on net energy levels. Each 1 % excess crude protein consumed above requirements will need 0.13 MJ DE to de-aminate it. The saving in net energy produced by restricting lean tissue gain allows the developing foetus to increase its rate of gain and produces heavier litter birthweights There is also some indication that the variation of individual birthweights within the litter is reduced. If for example, a sow was fed 2.5 kg of a 16% protein diet and this was sufficient to satisfy her genetic potential for lean tissue gain, maintenance and conceptus growth, her protein requirements would be 400 g per day. If she was fed 3.5 kg per day then the excess protein would amount to 160 g or 40% of requirements. This would require 5.2 MJ DE to de-aminate it, equivalent to about 0.4 kg of feed. The extra feed being given for conditioning is, therefore, inefficient in terms of energy utilization. A 16% crude protein diet produced a 16% mortality of all pigs born at 1 kg or less whereas the 12.9% crude protein diet gave 5.3% mortality. Theoretically, any increase in the net energy available to the sow should also influence the glycogen reserves in the newborn piglet, giving beneficial effects in the activity and early suckling behavior of the piglet (Baker, 1994).

A severely restricted protein intake (0.5% protein in the diet) during the first 63 days of gestation decreased the size of the conceptus and foetal liver weight but foetal brain weights were unaffected (Schoknecht *et al.*, 1992).

Baker *et al.* (1970) demonstrated reduced growth rates of pigs during a 21-day suckling period when an 8.7% protein diet was fed throughout gestation, despite the provision of a 16% protein diet during lactation. Providing a 16% protein diet during the first one third of gestation did not improve performance, but when supplied during the last third of gestation, pig performance was equal to that of pigs from sows receiving the high-protein diet throughout gestation. Gilt and sow litters responded similarly. Pig gains to 21 days were greatest at the highest daily gestation protein level. The lower level of protein during gestation was adequate to support reproduction but was not compatible with maximum pig gains (Libal, 1991).

Maternal weights remained constant between 70 and 105 days post-coitum with the low protein diet, but daily weight gain increased slightly when the higher protein diet was fed. Maternal weight differences between the 2 dietary gestation protein treatments therefore became more pronounced as pregnancy progressed. These weights indicate that the dam's maternal body tissue accretion was higher during the first two trimesters when foetal demands were low. This suggests that during the last trimester, much of the dam's dietary nutrient supply was diverted to conceptus development or conceptus metabolism rather than to maternal tissue deposition. Because foetal growth and therefore total nutrient demand is exponential as pregnancy proceeds, the rate of maternal body tissue accretion would be expected to decline as pregnancy progresses, particularly when a nutritionally inadequate diet is provided (Shields *et al.*, 1985).

For pregnant animals, protein deposition was highest during mid-pregnancy and was relatively independent of the level of feeding during mid- and late pregnancy. There was little difference in protein deposition between pregnant and non-pregnant animals at a high feed intake level. At a low feed intake level, pregnant animals generally had a higher protein deposition than their non-pregnant litter sisters and this was entirely associated with accretion in reproductive tissue (Close *et al.*, 1985).

Pregnant gilts retained significantly more protein (~1kg) than non-pregnant gilts, due to a higher retention (1.9 kg) in the reproductive organs and a lower retention (0.9 kg) in the maternal body.

Amino acid requirements

The lysine requirements of sows during pregnancy have received more attention than the requirements for other essential amino acids. ARC (1981) suggests that a daily intake of 8-10 g lysine is adequate for the pregnant sow. The concept of an ideal protein based on optimum balance of essential amino acids has been suggested as a basis for meeting the amino acid requirements of grower pigs (ARC, 1981).

For gestation, the amino acids required for the synthesis of the proteins of the foetus and other products of conception constitute a major component of total requirements. The needs increase rapidly as pregnancy progresses, typically reaching a maximum of 60-90 g/day (Noblet *et al.*, 1985). In addition to the amino acids deposited in the products of conception, there are also increases in maternal tissue protein in pregnancy. Close *et al.* (1985) found the highest rate of nitrogen retention by pregnant sows at mid-gestation. This maximum rate, (0.28 g $kg^{-0.75}day^{-1}$), is of a similar magnitude to their daily nitrogen requirement for maintenance, emphasizing that in relation to maintenance, the demands of pregnancy are very modest compared with the needs for rapid growth. Although similar in total amount, the patterns of amino acids required for maintenance and for tissue accretion in pregnancy are very different (Fuller, 1994).

In growing and gestating pigs the amino acids needed for the synthesis of new tissue protein constitute the largest single component of total requirements. The relative proportions of amino acids required are closely related to and broadly agree with the composition of whole-body protein of normally growing pigs.

Specific deficiencies of individual amino acids produce small but significant changes in whole-body amino acid composition. Recently, it has been shown that in growing pigs fed a lysine-deficient diet, there are significant changes in whole-body amino acid composition, with reductions in the concentrations of several amino acids, including lysine.

Recommendations by Devendra and Fuller (1979) for percentages of crude protein and amino acids needed by pregnant sows are presented in Table 3-7.

Table 3-7: Recommended levels of percentage of crude protein and amino acids for pregnancy in sows

CRUDE PROTEIN (%) OF DIET	15
AMINO ACIDS (%) OF CP	
Lysine	0.49
Methionine+Cystine	0.40
Tryptophan	0.08
Histidine	0.19
Tyrosine + Phenylalanine	0.60
Threonine	0.42
Leucine	0.50
Isoleucine	0.43
Valine	0.53

The number, weight and composition of piglets born per litter is maximized when the sow is given a daily allowance of 140-180 g crude protein during pregnancy, subject to this meeting the requirements for amino acids. Estimates of requirements for lysine vary from 0.4-0.65% of the diet, but most experiments suggest levels of 0.4-0.5%. The requirements for methionine plus cystine are considered to be less than 0.3% of the diet.

The average weight gain of sows allowed 299±10.5 g of crude protein per day was 8.3 kg more than those allowed 164±24 g per day. It can be calculated that this extra gain may be offset by reducing daily feed intake by 1.7 MJ DE/sow daily. This strategy would support the overall aim of gaining 30 kg gross weight during pregnancy (O'Grady, 1980).

Environment

Ambient Temperature

When environmental temperatures fall below the sow's lower critical temperature (LCT)[1.] maintenance energy requirements increase (Reese *et al.*, 1995). An extra 3 MJ DE/day (250 g feed/day) is required for each 5 °C below the LCT (King, 1990). In practice, pregnant sows, are often given only small quantities of food (2 kg per day or less), and in these circumstances the LCT may be as high as 20 °C. At very high temperatures, 30 °C and above, pregnant sows, particularly those in late pregnancy, can be stressed by heat and in severe heat stress are liable to abort (Devendra and Fuller, 1979). Table 3-8 presents estimated LCTs for gestating sows weighting 150-220.5 kg in 3 different housing situations.

Table 3-8: Estimated lower critical temperatures (LCTs) for gestating sows weighing 150-220.5 kg housed individually or in groups with no bedding or in groups with bedding

Housing situation [a]	LCT, °C
Individual - no bedding	18.33
Group - no bedding	15.56
Group - dry bedding	12.78

[a] Draft-free conditions, dry floors, and in normal condition. (Reese *et al.*, 1995).

Generally, sows in gestation crates need an extra 0.27 kg of feed/day for each 5.6 °C drop in temperature below 18.3 °C. Thus, at 12.8 °C a 181.8 kg sow would need 1.9 kg of feed daily for maintenance (the total feed requirement would be 2.3 kg/day). Group-housed sows without access to bedding have a lower critical temperature of about 15.6 °C, and they would not need extra feed for maintenance until the temperature drops below about 15.6 °C. For each 5.6 °C drop in temperature below 15.6 °C group-housed sows without access to bedding need an extra 0.14 kg of feed/day for maintenance. Group-housed sows with access to dry bedding usually do not need extra feed for maintenance until the temperature drops below about 12.8 °C. Dry bedding has the effect of decreasing the lower critical temperature. As an example, a 181.8 kg sow lying on a wet floor in a gestation crate would

1 The environmental temperature range within which pigs do not have to make special efforts to maintain body temperatures is called the **thermo-neutral zone**. The point at which the environmental temperature falls below this range is called the **lower critical temperature** and at and below that point an increase in metabolic rate is necessary to maintain body temperatures.

have a lower critical temperature of 21.1 °C, which would reduce with dry bedding. Backfat serves as insulation to reduce heat loss from the body and energy needs are affected by the amount of backfat. A thin sow will lose more body heat to her surroundings than will a sow of similar weight with more backfat. Thus thin sows require slightly more feed (0.11 kg/day to meet maintenance energy needs) than do sows in better condition at the same body weight (Reese *et al.*, 1995).

For dry sows fed a pregnancy ration of about 1.8 kg daily, the type of housing and grouping again has a marked impact on environmental temperature requirements. Temperatures could be about 10 °C less for newly weaned sows fed 4 kg per day. Dry sows group-housed, but individually fed 1.8 kg per day need a temperature around 14 °C when bedded on straw. The same animals housed in stalls with concrete slats would require 22 °C (Smith, 1980).

If sows are housed in individual gestation crates and consume 1.8 kg of feed/day, the lower critical temperature is 17 °C. An increase in the incidence of abortion is common if temperature drop below this level (Connor and Tubbs, 1992).

For individually housed sows weighing between 150 and 220 kg, the lower critical temperature (LCT) varies between 18-23 °C, and the preferred value is 20-21 °C. The value is high because the usual metabolizable energy intakes of pregnant sows are close to the maintenance levels.

Housing

Live weight increases in individually-housed sows were slightly lower at ambient temperatures of 8 °C and 11 °C than at 17 °C and 20 °C, and with group-housing changes in live weight at these temperatures were small. The metabolizable energy intake of individually-housed sows was slightly lower than that of group-housed sows. The heat production increased below 14 °C for both individual and group-housed animals. The heat production in the individual-housing system was higher than the heat production in the group-housing system. Similarly, the increase in heat production when temperatures were decreased was higher in the individually housed sows than in group-housed sows. The heat production in group housing was similar at temperatures between 14 °C and 20 °C. Below 14 °C the heat production of the group-housed sows increased, whereas in individually-housed sows heat production increased below an ambient temperature of 20 °C. (Geuyen *et al.*, 1984).

Feed recommendations for sows during the gestation period are similar to those for gestating gilts. Although group-housed sows have been fed every 2nd or 3rd day with no apparent ill effects, except for a possible increase in fighting at feeding time, this practice is seldom recommended for sows and is not recommended for gilts because they need daily intakes of protein. Sows do not suffer the same deleterious effects on embryo survival that gilts do when fed high planes of nutrition immediately after mating (Tubbs, 1992).

A commonly held perception is that individual housing or tethering of the sows may reduce their activity and thus their maintenance requirement. However, measurements made in thermoneutral and cold conditions did not show reduced activity in individually tethered sows compared with group housed animals (Geuyen *et al.*, 1984). Activity accounted for about 15% of total metabolic rate in both individual and group housed sows. This does not rule out a conclusion that housing affects the thermoneutral maintenance requirement. Cronin *et al.* (1986) noticed that tethered sows which showed a high level of stereotyped activity (e.g. chain-chewing) had considerably increased activity-related heat production compared with unaffected control animals. Their data indicate that the variation in metabolic rate between sows showing chain-chewing and controls was clearly associated with variation in activity. The differences may be as high as about 20% of maintenance requirement (Verstegen *et al.*, 1987).

In standard confinement group settings, fighting is more common when groups contain more than 6 to 10 animals per pen and the fighting may cause variations in sow body size. In small groups of less than 9 sows a relatively tranquil social order is fostered, while in groupings larger than 25, similarly structured subgroups can also develop. In contrast, in groupings of between 9 and 25, sows have difficulty in developing a social order and there is constant fighting and stress. (Connor and Tubbs 1992). Apart from fighting and resulting stress, overcrowding should be avoided for sanitation and health reasons.

It is recommended practice to feed sows according to body condition (i.e. maintain at a body condition score of 2.5 to 3.5) after the initial 10- to 14-day post-breeding period. However, under conditions of large group housing, sows may need an additional 0.45 to 0.90 kg of feed daily to prevent those at the bottom of the social structure from becoming too thin. Unfortunately, this practice may allow dominant sows to become overweight.

Backfat

With increases in parity, sow weights also increase, but it does not always follow that backfat in older sows also increases. Dourmad (1991) reported that backfat in sows may decrease at higher parities. Everts and Dekker (1995) compared protein and fat gain in sows. The amounts of body weight, protein and fat in sows after the third lactation were 1.49, 1.52, and 1.22 kg higher respectively than the amounts in sows just after the first lactation, indicating that while the ratio of protein and weight gain of sows was similar over 3 parities, the gain in fat was lower.

It is well established that sows which receive high intakes during pregnancy (>2.3 kg/day) have reduced feed intake in the subsequent lactation (Baker *et al.*, 1969). Furthermore, once body fat exceeds about one third of body weight (equivalent to about 28 mm backfat at parity 2), voluntary feed intake decreases (Williams and Mullan, 1989). Feeding strategies during pregnancy should be aimed at controlling weight gains, such that the sow gains the minimum weight commensurate with productivity. Usually, maternal body weight gains of 25-35 kg (corresponding to 45-55 kg total gain) during pregnancy are sufficient. The nutrient requirements are now well understood and accepted for sows during pregnancy (ARC, 1981). Field studies have commonly shown that gilts which are mated at an older age are heavier, have greater fat reserves, have less non-productive-sow days and are retained in the herd for longer periods (King *et al.*, 1984). On the other hand there is evidence that excess body weight and fatness of gilts may adversely affect long-term reproductive performance (Den Hartog and van Kempen, 1980, King *et al.*, 1993).

The estimate of fat loss of 140 g per day at term referred to an animal maintained within thermal neutrality. If conditions vary then both the period during which mobilization occurs and the extent of mobilization will be changed. Working on the basis that each 1 °C decrease in temperature increases ME needs by 12 MJ/kg$^{-0.75}$ bodyweight/day, it can be calculated that at an environmental temperature of 13 °C, i.e. 5 °C below the sow's LCT the sow would be in energy equilibrium at approximately day 70 of gestation, and by day 110 would be losing some 240 g fat/day. That is equivalent to a loss of 4.8 kg throughout gestation and represents up to 20% of the animal's body fat reserves (ARC, 1981) and this is before the inevitable loss which subsequently occurs during lactation. Since there appears to be a direct relation between reproductive efficiency and fat content of the body (Frisch, 1976), repeated and prolonged application of these treatments would be expected to result in severely emaciated sows with a high incidence of infertility. A condition such as this, the 'thin sow syndrome', has been reported by MacLean (1968) and induced experimentally by Hovell and MacPherson (1977) (Close *et al.*, 1985).

Dietary treatments that increase piglet glycogen or fat stores during late gestation are beneficial for improving neonatal survival (Britt, 1986). Severe restriction of energy or protein intake during mid or late gestation reduces piglet birth weight, but not embryo survival rate (Pond, 1973; Shield *et al.*, 1985; Pond *et al.*, 1986). The effect of prolonged starvation during either the middle third or last third of gestation closely parallels the effects observed during dietary energy restriction (Anderson *et al.*, 1979; Hard and Anderson, 1979). It is suggested that feed levels of pregnant sows after the first 2-4 weeks of gestation have little effect on litter size. Energy metabolism during late gestation and lactation in relation to backfat thickness was studied in multiparous sows (Hulten *et al.*, 1993). The sows were divided into 2 groups - high(H) and low (L) - according to their backfat thickness 9 days before parturition and both groups were fed the same diet (11.9 MJ/kg BW, 14.5% CP). During gestation feed intake was 2.2 kg/day, while during lactation it was 3.0 kg/day plus 0.4 kg per piglet nursed. Sow weight loss was greatest during the first week of lactation. This loss was most evident in the H-group, amounting to 14.0 kg during the first week of lactation ($P < 0.05$) and a total of 16.6 kg during the first 3 weeks. Corresponding values for the L-group were 4.2 and 6.5 kg, respectively. Backfat thickness decreased in both groups in the 9 days before farrowing and up to the 21st day of lactation, but the decrease was greatest in the H-group ($P<0.05$). In both groups the concentrations of free fatty acids were low on day 9 prior to parturition, while those of triglycerides were high, indicating anabolism. During the first week of lactation, the concentrations of free fatty acids increased in the H-group but not in the L-group and the concentrations of urea nitrogen were higher in the H-group. These differences, together with the greater loss of weight observed in the H-group, indicate that catabolism of maternal fat and protein depots was more pronounced in the H-group than in the L-group during this time (Einarsson and Rojkittikhun, 1993).

Feed levels

In one study by Tubbs (1988) which compared the effects of feed levels of 1.8 kg/day and 2.7 kg/day) during gestation on incidence of lactation failure, sows fed high levels of feed gained more weight during lactation than those fed at the lower level. The cumulative incidence of lactation failure was higher for sows on high feed levels, and the high level sows were culled earlier than sows on the low level. Energy deficiency during gestation especially during the last trimester and immediately prepartum, tends to affect lactation performance. An insufficient energy intake during lactation is more likely to affect subsequent reproductive performance by increasing the weaning-to-oestrus interval and by decreasing conception rate. Thus in order to optimize milk production and pig performance, it is recommended that:

- feed is limited during gestation (1.82-2.32 kg/head/day),
- feed intake is increased by 25-50% during the last trimester
- high-producing sows are fed ad libitum during lactation (Tubbs 1988).

In a study which reported results apparently at variance with Tubbs' (1988) study, Vermedahl *et al.* (1969) fed 1.36 and 2.27 kg respectively to 2 groups of gilts and found that gilts fed at the lesser level of feed intake during pregnancy lost significantly less weight (3.9 vs 15.6 kg) during lactation than gilts receiving the greater quantity of feed during gestation.

Restriction of feed intake to one third of normal during the first two thirds of gestation resulted in reduced weight gain and fat accretion in the offspring during young adulthood. Hard and Anderson (1982) observed that the offspring of dams which had experienced severe nutrient deprivation during the middle and last thirds of gestation, exhibited no detrimental effects on reproduction and reached puberty at an earlier age. Pond *et al.* (1986) reported that feeding primiparous gilts one third of their energy requirement to day 84 or day 108 resulted in reduced foetal weight and no evidence of pregnancy anabolism. They were able to attribute the greater weight gain of pregnant animals over non-pregnant animals to an increase of uterine and mammary tissue. The effects of gestation feed levels on lactation feed intake and gestation and lactation weight change are shown in Table 3-9.

Table 3-9: Effect of daily gestation feed intake levels on lactation feed intake and gestation and lactation weight change (after Baker et al., 1969)

Daily feed intake in gestation	0.9	1.4	1.9	2.4	3.0
Lactation feed intake (kg)	89.4	90.3	90.5	81.1	71.7
Gestation weight gain (kg)	5.9	30.3	51.2	62.8	74.4
Lactation weight gain (kg)	6.1	0.9	-4.4	-7.6	-8.5

Adam *et al.* (1971) fed 2 levels of feed to 48 sows allocated according to mating weight and measured backfat ultrasonically over 3 reproductive cycles and found that the high level of feeding increased both live litter weights and numbers in parity 1. Increases in average piglet birth weight due to high level feeding were 0.09, 0.14 and 0.18 kg in parities 1, 2 and 3, respectively, and no difficulty in rearing the pigs was experienced.

Feed requirements for sows during pregnancy vary from 2.3-2.6 kg per day per animal on average, depending on the weight at mating. It is not clear, however, whether a sow should be fed the same amount throughout pregnancy (de Wilde, 1980a,b) or an amount which varies with the stage of pregnancy, although Verstegen *et al.* (1987) consider the latter feeding strategy to be the optimal one. They calculated that for practical purposes, sows require about 1% of body weight as maintenance plus about 700 g a day to meet the mean requirements during pregnancy, with a proviso that environmental conditions do not alter maintenance requirements.

Dutt and Chaney (1968) and Dyck and Strain (1980) demonstrated a benefit when daily feed intake was reduced from the day of mating to day 10 of pregnancy to 1.25 or 1.5 kg. A high level of feeding during rearing is associated with increased ovulation rates at the first, second or third oestrus, but with reduced embryo survival during early gestation (den Hartog and van Kempen, 1980; den Hartog, 1984). High energy feeding during the pre-mating period is also associated with reduced embryo survival during early gestation in gilts. Gilts with high energy intakes also had an increased ovulation rate, and this *per se*, may lead to increased embryo mortality. Toplis *et al.* (1983), however, failed to confirm an effect of high energy intake on early embryo survival and suggested that since the various nutritional regimens in earlier reported studies were usually implemented at or very soon after mating, an increase in ovulation rate may have occurred and increased ovulation rates could then be associated with increased embryo mortality (Einarsson and Rojkittikhun, 1993).

With regard to the most desirable pattern of feeding through pregnancy, some workers have suggested high levels in early pregnancy, lower levels in mid-pregnancy, and an increase in feed intake towards the end of pregnancy. On the other hand, studies at the Rowett Research Institute and other centres have demonstrated that provided the same total amount of feed is given, it does not matter how this is distributed over the different phases of pregnancy. Keeping a constant level of feeding throughout produces results as good as those from any departure from that programme and, of course simplifies feeding management. It is desirable to feed pregnant sows according to their body condition so that both under and over-feeding are avoided and all sows conform to the target body condition set for farrowing. Thus, individual feeding for most of pregnancy is very desirable (English *et al.*, 1982).

Connor and Tubbs (1992) recommended that sows (especially young sows) should be fed daily at maintenance feed level until day 90 of gestation, at which stage body condition should be carefully assessed and feed adjusted according to condition score. Sows in acceptable body condition should be held on maintenance or slightly increased amounts of feed (0.45-0.9 kg) per day to support foetal growth and achieve birth weights of more than 1.36 kg, and to minimize birth weight variability. Sows below an acceptable body condition should receive corresponding increases in the amount of daily feed (>0.9 kg).

Love (1993) reported considerably higher pregnancy rates at 7 week after mating (43-63 VS 67-87%) in sows receiving high level of feed (3.2 kg/day of 13.6 MJ/kg diet) during the first 4 weeks of pregnancy, than in sows fed a lower level (1.6 kg/day for the first 2 weeks and 1.9 kg/day after 2 weeks). He recommended not less than 3-3.5 kg/day of a 12.5 MJ/kg diet for group-housed sows and approximately 2.7 kg/day for individually housed sows for the first 4 weeks of pregnancy.

Effects of nutrition on hormone levels

The relationships of maternal nutrition and progesterone secretion to prenatal foetal loss and neonatal survival and growth were investigated in domesticated pigs that normally experience 40% foetal loss (Anderson, 1975). Yorkshire pigs were subjected to prolonged starvation (40 days; 0 kcal/day; water only), in either the middle third or last third of pregnancy and then gradually adjusted to a full diet and allowed to advance to parturition (controls received a full diet 29.4 MJ/day throughout gestation). Pregnancies were maintained in 74% of the pigs starved during either middle or late gestation compared with 100% retention in controls. In dams starved from days 30-70, progesterone levels remained about the same as controls, but were maintained at lower levels during readjustment between days 72 and 99. Progesterone levels in dams starved days 50-90 and controls were similar from days 50 to 130. At parturition, litter size in starved dams (9.4) was similar to full-diet controls (8.0) although birth weight and neonatal growth of piglets were reduced markedly from dams starved in middle or late pregnancy. These results indicate that severe maternal nutrient deprivation during the middle or last third of gestation has little effect on ovarian progesterone secretion and is not a major limitation to foetal survival in this litter-bearing species. Maternal nutrient deprivation imposes a significant detrimental effect, however, on birth weight and neonatal growth to 80 days of age (Hard and Anderson, 1979). Kirkwood and Thacker (1988) conclude that dietary manipulations during pregnancy are unlikely to significantly influence embryo survival in sows except where deficiencies are sufficiently severe to induce total embryo loss.

Inadequate nutrition inhibits secretion of luteinizing (LH) from the pituitary (ewe studies). In sheep, undernutrition markedly decreased secretion of LH, but growth hormone (GH) was increased (Foster *et al.*, 1989; Kile *et al.*, 1991) and prolactin was either not affected (Foster *et al.*, 1989) or reduced (Rhind *et al.*, 1984a, 1985, 1986; Rhind and McNeilly, 1986). Thus, undernutrition seems to differentially affect secretion of pituitary trophic hormones (Dunn and Moss, 1992). In Large White x Landrace gilts (4 controls, 5 on restricted feed), restricted feed gilts received about 50% of the *ad libitum* intake (1.8 kg/day). The ration contained 12.0 MJ/kg, 14.5% CP and 0.66% lysine. LH pulse frequency was reduced by this moderate feed restriction and this effect may have implications for the successful management of pregnancy. It may be of greater importance during the seasonal infertility period of the year, when LH secretion may be further suppressed by seasonal effects (Lindsay *et al.*, 1993).

In contrast, a high level of feeding appears to have a large effect on progesterone. Hughs and Pearce (1989) suggested that a high feed intake during early gestation may result in a suboptimal uterine specific protein secretion, which has a negative effect on embryonic survival. Their hypothesized sequence of events is:

High plane feeding in early gestation

⇓

Rapid live weight/body condition gain

⇓

Increased hepatic blood flow

⇓

Increased metabolic clearance of progesterone

⇓

Decreased plasma progesterone concentrations

⇓

Suboptimal uterine specific protein secretion

⇓

Reduced embryo survival rate

Pharazyn *et al.* (1991) found no effect with two levels of energy and protein from 3-15 days of gestation on plasma progesterone. However, embryo survival was correlated with plasma progesterone concentrations on day 3 of pregnancy which indicated that changes in circulating progesterone in the immediate post-ovulatory period may be of greater importance in determining embryo survival than progesterone concentrations later in gestation. Parr *et al.* (1993) showed that high feed levels after mating reduce peripheral progesterone concentrations and increase embryonic mortality.

Peltoniemi *et al.* (1994) fed 4 Landrace X Large White gilts *ad libitum* (3.6 kg/day) and 5 gilts with restricted diet (1.8 kg/day) of 13 MJ/kg feed, and found LH pulse frequency to be reduced by feed restriction, a finding which may have implications for successful management of pregnancy. This effect may be of greater importance during the seasonal infertility period, when LH secretion may be further suppressed by the season of the year. The effect of feed levels in early gestation on embryo survival and plasma progesterone levels is shown in Table 3-10.

Table 3-10: The effect of gestation feed levels on plasma progesterone levels and embryo survival in sows (from Dyck *et al.*, 1980)

Feed level (kg/day)	Embryo survival (%)	Mean plasma progesterone (ng/ml)
1.50	82.8	16.7
2.25	78.6	13.8
3.00	71.9	11.8

Summary of literature review

Pregnant sows require sufficient energy and amino acids to replace obligatory losses, provide body support functions, and properly develop the products of conception (Verstegen *et al.*, 1987). Sows overfed during pregnancy will voluntarily consume less feed and lose more weight during the subsequent lactation than sows fed restricted amounts designed to support only moderate weight gains during pregnancy (Tubbs, 1988). Underfeeding during pregnancy leads to lower body fat reserves at farrowing or at weaning, and in most cases return to oestrus will be delayed and conception rates will be lower (Dourmad *et al.*, 1994).

It is logical to give additional feed in late gestation as the rate of foetal weight gain increases during this period. Addition of 1.4 kg of feed/day during the last 24 days of gestation increased the number of pigs weaned/litter, pig birth weight and litter weaning weight (Reese *et al.*, 1995). Sows that are underfed and thin (condition score 2.5 or less) at day 90 of pregnancy are excellent candidates for extra feed (Reese *et al.*, 1995). Feeding supplemental fat (1kg) to sows during late gestation (14 days before farrowing) has its greatest response when average pig pre-weaning survival rate in the herd is less than 80% (Reese *et al.*, 1995). Daily intake of 8-10 g lysine is adequate for a pregnant sow (ARC, 1981). Specific deficiencies of individual amino acids produce small but significant changes in whole-body amino acid composition.

Gilts should gain 50-55 kg (Tubbs, 1992) or 40.9-45.5 kg (Connor and Tubbs, 1992) during gestation. Casting *et al.* (1983) recommended 33.2 MJ DE/day during gestation for gilts mated early at a low body weight and 22.9 MJ DE for gilts mated later at heavier weights and with more body fat reserves (Dourmad *et al.*, 1994).

A sow requires an extra 3 MJ DE/day for every 30 kg increase in the live weight of the sow to cater for the increased energy requirement over maintenance (King, 1990). More than 75% of the energy intake of pregnant sows used to meet maintenance requirements. Under practical feeding situations, where energy intakes are usually within the range of 20-30 MJ DE/day, embryonic survival is unlikely to be noticeably affected by energy effects (Tubbs, 1995c).

While it appears that for sows in particular, limited feed intake during the first 10-14 days after mating may not be as critical as was once thought, recent research now suggests that maintaining a relatively high feed intake during the immediate post-breeding period may ameliorate some of the adverse effects that decreasing photoperiod has on fertility in the late summer and early autumn. Love (1993) recommends 3-3.5 kg/day of a 12.5 MJ/kg diet for group-housed sows and approximately 2.7 kg/day for individually housed sows for the first 4 weeks of pregnancy during summer and autumn. Verstegen *et al.* (1987) recommended adjustments in mid-gestation based on current body condition and the desired body condition for farrowing. Sows that are overfed may be unable to eat enough initially to keep up with the demands of lactation. If sound feeding practices have been followed during early gestation through to mid-gestation, excessive feeding during late gestation will be unnecessary.

In pregnant sows, increased intakes of fibrous materials, such as straw, lead to a more contented animal because the gut capacity of a pregnant sow is around 4 ½ kg of dry feed each day (Beynon, 1990).

The ARC (1981) suggest that extra protein is required to maintain sow body condition for subsequent reproduction, and consider that the protein needs of pregnant sows of 140 kg liveweight gaining 30 kg maternal liveweight during pregnancy can be met by a daily intake of 180 g crude protein provided the diet meets the amino acid requirements. Different genotypes have different potentials for lean growth, which is promoted by lysine and protein levels in the diet. Where a high protein diet is fed in gestation to levels where it can no longer be utilized for lean tissue growth then any excess is de-aminated, which causes a further drain on net energy levels (Baker, 1994). The concept of an ideal protein based on optimum balance of essential amino acids has been suggested as a basis for meeting the amino acid requirements of grower pigs (ARC, 1981). Estimates of requirements for lysine vary from 0.4-0.65% of the diet. The requirements for methionine plus cystine are considered to be less than 0.3% of the diet (O' Grady, 1980).

An extra 3 MJ DE/day is required for each 5 °C below the LCT (King, 1990). In group-housed systems with small groups of less than 9 sows, a relatively tranquil social order is fostered, while in groupings larger than 25, similarly structured subgroups can also develop. In contrast, in groups containing between 9 and 25, sows have difficulty in developing a social order and there is a constant fighting and stress (Connor and Tubbs, 1992).

Severe maternal nutrient deprivation during the middle or last third of gestation has little effect on ovarian progesterone secretion and is not a major limitation to foetal survival in this litter-bearing species. Maternal nutrient deprivation imposes a significant detrimental effect, however, on birth weight and neonatal growth to 80 days of age (Hard and Anderson, 1979). Undernutrition seems to differentially affect secretion of pituitary trophic hormone (Dunn and Moss, 1992). LH pulse frequency was reduced by this moderate feed restriction and this effect may have implications for the successful management of pregnancy. It may be of greater importance during the seasonal infertility period of the year, when LH secretion may be further suppressed by seasonal effects (Lindsay *et al.*, 1993).

High feed intake during early gestation may result in a sub-optimal uterine specific protein secretion, which has a negative effect on embryonic survival. Embryo survival was correlated with plasma progesterone concentrations on day 3 of pregnancy, which indicated that changes in circulating progesterone in the immediate post-ovulatory period may be of greater importance in determining embryo survival than progesterone concentrations later in gestation.

Dry sow feeding trial

Introduction

Research conducted in Australia (Love, 1994; Klupiec, 1994) has given encouraging signs of reducing summer/autumn infertility by feeding extra feed to sows during the first month after mating. It is important that this initial trial be repeated in other locations to see if the results hold up in different environments. If the problem can be dealt with in this way, it would be a very cost-effective solution to a problem which affects most New Zealand pig farmers in some or all years.

Materials and methods

Sample size

The field trial was designed to assess the effect on treatment of reproductive performance in gilts and/or sows. Power analysis was conducted to determine the required sample sizes using NCSS-PASS version 1 (Kaysville, Utah). A sample size of more than 300 animals per group was required to detect a difference in farrowing rate of 3% between treatment and control groups with a power of 0.80 and a p-value of 0.05.

Selection of farms

Ten commercial pig farms were included in the trial so that sufficient animals were available. Farms selected had a history of some degree of summer/autumn infertility problem based on the manager's information, and willingness to provide feed and information.

Methods

Housing system

Farms with 2 different types of group housing, and farms using an individual stall housing system were all involved in this trial. Five farms with the group housing system were keeping the pigs outdoors, and one farm used group housing in a building open sided on two sides and exposed to natural light. All of the farms using individual stall housing kept their pigs indoors.

Timing of studies

The trial was conducted between 1 December 1994 and 30 April 1995. Farms were visited in November 1994 to ascertain cooperation. All weaned sows were allocated as a "week group" to treatment or control group by week of weaning to match a farm's management system. Animals weaned in the first week of December were put into either groups by farmers' decisions, animals weaned in the subsequent weeks were alternately put into each group.

Levels of feed

For the sows on farms with the stall housing system, 2 levels of feed were used: 2.5 kg for the controls and 3 kg for the treatments (12.5 MJ/kg of feed). Two separate clinical trials were conducted with the sows kept in a group housing system: one comparing a medium treatment level against of a lower control feed quantity (2.5 kg versus 3.5 kg of 12.5 MJ/kg of feed), and the other one comparing a high treatment feed quantity against an intermediate control level (3.5 kg versus 4.5 kg of 12.5 MJ/kg of feed). Numbers of animals and levels of feed used are presented in Table 3-11.

Table 3-11: Numbers of control and treatment animals in each stall and group housing system study group and the levels of feeding applied to each group

Type of Housing	Location	Levels of feed (kg)*		Farms	No. Animals	Total Animals by Island and Housing	Total Animals by Housing Type
		control	treatment				
Stalled	North Island	2.5	3	A	661	997	1354
				B	336		
	South Island	2.5	3	C	19	357	
				D	237		
				E	101		
Grouped	South Island	2.5	3.5	F	261	428	538
				G	81		
				H	86		
		3.5	4.5	I	59	210	
				J	151		
Total				10 farms	1992	1992	1992

*12.5 MJ/kg of feed

Farms were visited four times during the period of the trial. To reduce the possibility that the animals could have been exposed to zearalenone during the course of the trials, feed was collected during each visit and kept in a freezer at < 0 ^{0}C. All feed sample were quantitatively analyzed in March 1995 using a quantitative zearalenone testing kit based on direct competitive enzyme-linked immunosorbent assay (Veratox®, Neogen Corporation, Lansing, MI). All feed samples were negative for zearalenone.

Data collection

Data were sent from farms to the Department of Veterinary Clinical Sciences, Massey University on a monthly basis. Data recorded include pigs' identification numbers, service dates, return dates, abort dates, farrow dates, numbers of pigs born alive, number of stillborns, and numbers of mummies. Data were stored using the database management software Access for Windows version 2 (Microsoft Corporation, Redmond, U.S.A).

Unit of analysis

The parameter "adjusted non-productive days" (adjusted NPD) represents mean number of days between weaning and subsequent farrowing or other outcome (culling, death, etc.) when the sow is not pregnant, with the adjusted weaning to first service interval of 6. Analyses for adjusted non-productive days (adjusted NPD) were based on the actual number of the adjusted NPD from each sow. Analyses for total pigs born, pigs born alive, stillborn, and mummies were based on the actual number of pigs for each sow in such events. Breeding outcomes (farrow, return, abort, pseudopregnancy) were analyzed on an individual sow basis.

Data were analyzed for the whole period of the trial (December - April), and in each individual month of the trial using the following comparisons:

- Control vs treatment group of grouped housing higher feed level farms (3.5 vs 4.5 kg of feed)
- Control vs treatment group of grouped housing lower feed level farms (2.5 vs 3.5 kg of feed)
- Control vs treatment group of stall housing farms in North Island (2.5 vs 3 kg of feed)
- Control vs treatment group of stall housing farms in South Island
- Control vs treatment group of stall housing farms in both islands

Other comparisons were performed only when graphical results suggested the information was of interest.

Statistical analysis

Data were analyzed using the statistical program Statistica® for Windows version 5 (StatSoft Inc, Tulsa, Oklahoma) and EpiTable (USD, Inc., Georgia). The data analyses were based on a comparison of means between treatment and control groups within the various feeding and housing system categories for individual months as well as for the whole trial period. *Student's t-test* was used if the assumptions for the technique were met, as was the case for total pigs born and pigs born alive. As parity is an important confounding variable for most of these reproductive parameters, additional analyses using analysis of covariance (ANCOVA) using parity as a covariate were conducted for the parameters where the conditions for the use of this feeding technique were met.

The Mann-Whitney U test and Kruskal-Wallis test ANOVA were used in the analysis of parameters where the assumptions for Student's t-test or ANCOVA were violated. This was the case for adjusted non-productive sow days (NPD), average number of stillborn piglets and average number of mummies. The *Chi-Squared* test was used to compare the outcome of mating, expressed as proportions between the control and treatment groups. The association between farrowing rate and the independent variables housing system, location (North or South Island), farm (10 farms), levels of feed, and parity of the sows was analysed using logistic regression.

Results

Data were available for gilts and sows mated between December 1994 and April 1995. 1992 sows were included in the analysis. Of these, 638 sows were kept in grouped housing, of which 428 sows were included in the lower feed level trial and 210 sows in the higher level feed trial. 1354 sows were in individual stall housing, of which 997 sows were in the North Island and 357 sows were from Canterbury, South Island. All sows in stall housing were included in the lower feed level trial.

Table 3-12: Number of animals included in the analysis by housing type, treatment group and month

Housing Type	Feed Category	Farm	Treatment	Month					Total
				Dec	Jan	Feb	Mar	Apr	
Group	Group Higher	I	Control	37	0	0	0	0	37
			Treatment	22	0	0	0	0	22
		I total		59	0	0	0	0	59
		J	Control	8	24	19	16	12	79
			Treatment	0	22	19	17	14	72
		J total		8	46	38	33	26	151
	Group Higher	Control		45	24	19	16	12	116
		Treatment		22	22	19	17	14	94
	Group higher total			67	46	38	33	26	210
	Group Lower	F	Control	24	28	30	32	25	139
			Treatment	24	24	23	24	27	122
		F total		48	52	53	56	52	261
		G	Control	9	11	8	8	4	40
			Treatment	9	11	8	7	6	41
		G total		18	22	16	15	10	81
		H	Control	10	14	12	12	0	52
			Treatment	12	8	4	14	0	38
		H total		22	22	16	26	0	90
	Group Lower	Control		43	53	50	52	29	227
		Treatment		45	43	35	45	33	201
	Group lower total			88	96	85	97	62	428
Group total				155	142	123	130	88	638
Stall	Stall North	A	Control	63	86	65	62	63	339
			Treatment	68	61	67	63	63	322
		A total		131	147	132	125	126	661
		B	Control	32	38	29	31	28	158
			Treatment	35	48	28	39	28	178
		B total		67	86	57	70	56	336
	Stall North	Control		95	124	94	93	91	497
		Treatment		103	109	95	102	91	500
	Stall north total			198	233	189	195	182	997
	Stall South	C	Control	1	2	2	1	3	9
			Treatment	3	1	2	1	3	10
		C total		4	3	4	2	6	19
		D	Control	26	31	20	21	21	119
			Treatment	21	22	23	25	27	118
		D total		47	53	43	46	48	237
		E	Control	10	8	7	8	11	44
			Treatment	13	18	10	9	7	57
		E total		23	26	17	17	18	101
	Stall South	Control		37	41	29	30	35	172
		Treatment		37	41	35	35	37	185
	Stall south total			74	82	64	65	72	357
	Stall Both	Control		132	165	123	123	126	669
		Treatment		140	150	130	137	128	685
Stall total				272	315	253	260	254	1354

Adjusted non-productive sow days (Adjusted NPD)

In the grouped housed higher fed sows, adjusted NPD can be seen to be less in February and March than in the other months (Figure 3-2). But the difference was not significant when compared with the average adjusted NPD of the control group for February and March or both February and March, versus other months during trial period (p = 0.337, 0.56 and 0.337, respectively). No statistically significant difference was detected in comparisons between the control and treatment group in any subgroups (Table 3-14). Table 3-13, Figure 3-1 and Figure 3-2 present descriptive data for the adjusted NPD.

Table 3-13: Means (95% confidence limits) and medians of adjusted non-productive sow days (NPD+6) stratified by housing/feeding system and month

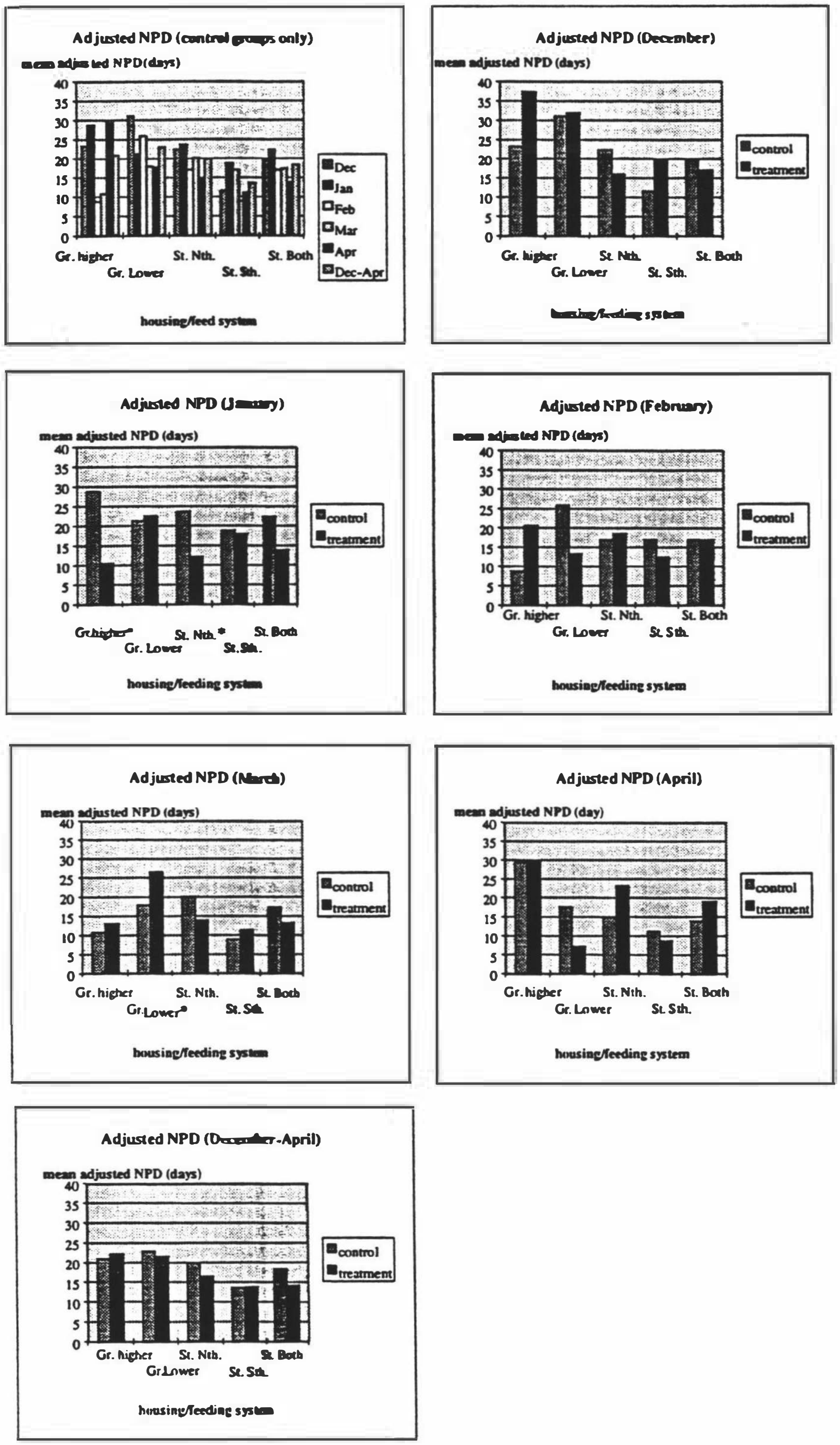
Adjusted NPD			Month					
			Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group higher feed	control	mean (95% CL)	20.9 (15.4-26.4)	23.2 (14.2-32.1)	28.8 (14.2-43.4)	8.7 (4.7-12.8)	10.8 (3.02-18.6)	29.3 (0.2-58.4)
		median	6	6	6	6	6	6
	treatment	mean (95% CL)	22.1 (14.7-29.5)	37.3 (16.8-57.8)	10.6 (5.8-15.3)	20.5 (2.96-38.1)	13.06 (-1.9-28)	29.6 (3.8-55.5)
		median	6	6	6	6	6	6
Group lower feed	control	mean (95% CL)	22.9 (18.3-27.6)	31.9 (18.3-43.9)	21.3 (12.1-30.6)	25.8 (15.03-36.5)	17.96 (9.3-26.7)	17.7 (5.8-29.7)
		median	6	6	6	6	6	6
	treatment	mean (95% CL)	21.5 (16.9-26.03)	31.9 (18.7-45.1)	22.5 (12.2-32.8)	13.3 (6.3-20.3)	26.7 (16-37.4)	7.3 (5.5-9.2)
		median	6	6	6	6	6	6
Stall North	control	mean (95% CL)	19.9 (16.9-22.8)	22.4 (15.5-29.3)	23.6 (16.8-30.4)	16.95 (10.9-22.96)	20.1 (12.7-27.5)	14.9 (9-20.7)
		median	6	6	6	6	6	6
	treatment	mean (95% CL)	16.5 (13.9-19.2)	15.99 (9.9-22.1)	12.1 (8.01-12.3)	18.5 (11.8-25.1)	13.9 (9.1-18.6)	23.3 (15.1-31.6)
		median	6	6	6	6	6	6
Stall South	control	mean (95% CL)	13.7 (10-17.3)	11.6 (5.6-17.7)	18.7 (8.2-29.2)	17 (7.4-26.6)	8.9 (4.3-13.5)	11.1 (2.9-19.4)
		median	6	6	6	6	6	6
	treatment	mean (95% CL)	14.2 (10.6-17.7)	19.6 (9.9-29.3)	17.95 (7.9-28.03)	12.5 (4.6-20.3)	11.3 (4.4-18.2)	8.8 (6-11.5)
		median	6	6	6	6	6	6
Stall Both	control	mean (95% CL)	18.3 (15.9-20.7)	19.5 (14.2-24.8)	22.4 (16.7-28.1)	16.96 (11.9-22.02)	17.4 (11.6-23.1)	13.8 (9.04-18.6)
		median	6	6	6	6	6	6
	treatment	mean (95% CL)	15.9 (13.7-18.04)	16.95 (11.8-22.1)	13.7 (9.7-17.8)	16.9 (11.6-22.1)	13.2 (9.3-17.1)	19.1 (13.1-25.1)
		median	6	6	6	6	6	6

Table 3-14: P-values of comparisons of adjusted NPD between control and treatment groups in different categories using Mann-Whitney U test

	Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group / higher feed level	0.404	0.198	0.056	0.639	0.773	0.918
Group / lower feed level	0.948	0.812	0.718	0.292	0.064	0.421
Stall / North	0.368	0.342	0.107	0.973	0.691	0.289
Stall / South	0.669	0.405	0.767	0.509	0.885	0.744
Stall / Both	0.557	0.697	0.21	0.776	0.787	0.296

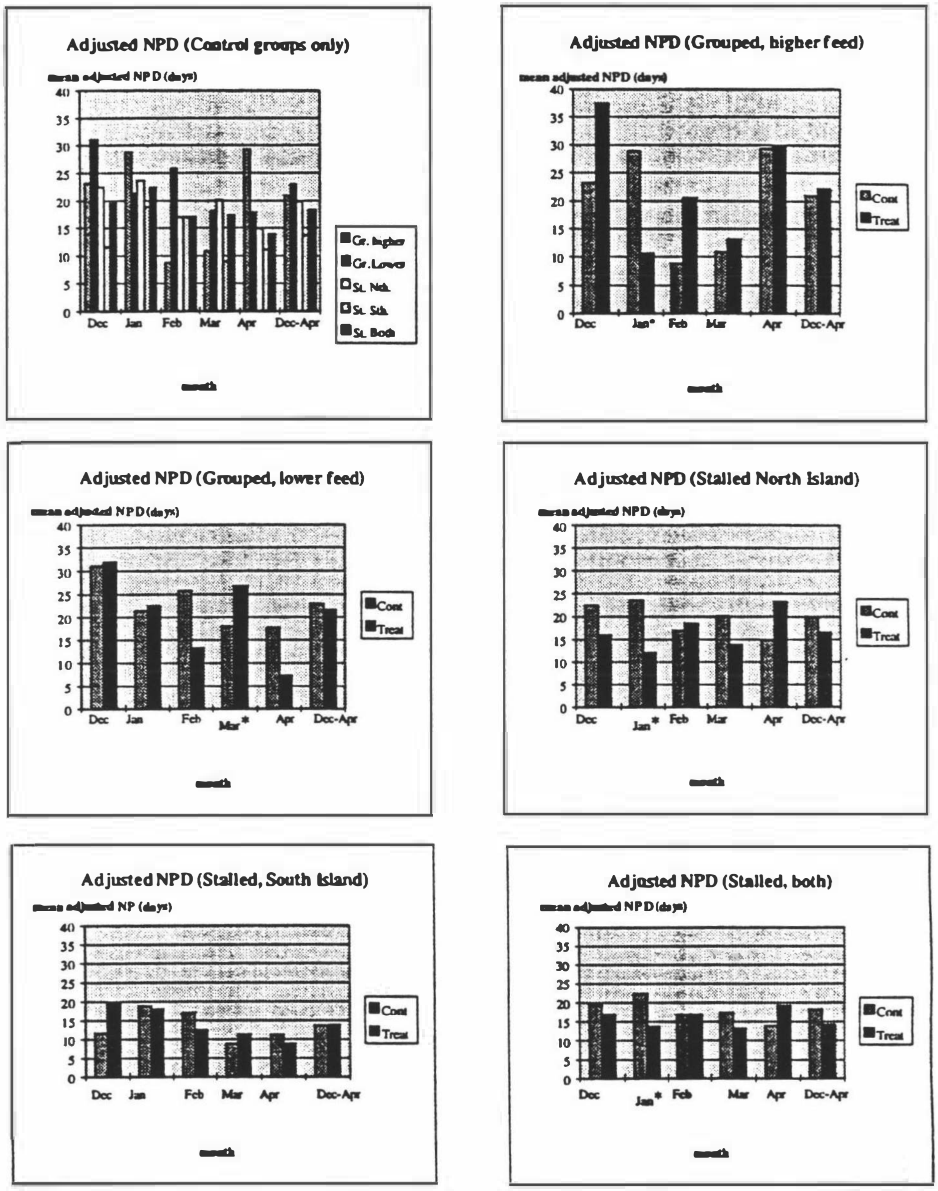
Group / higher feed = group housed pigs, higher feed level; Group / lower feed = group housed pigs, lower feed level; Stall / North = stall housed pigs in North Island; Stall / South = stall housed pigs in South Island

Figure 3-1: Barcharts showing the average of adjusted NPD by housing/feeding system and treatment status stratified by month



Gr. higher = grouped higher feed farms; Gr. lower = grouped lower feed farms; St. North = stalled feeding farms in North Island; St. South = stalled feeding farms in South Island; St. Both = stalled feeding farms in both islands

Figure 3-2: Barcharts showing the average adjusted NPD by month and treatment status stratified by housing/feeding system



Total pigs born

No statistically significant difference was detected between control and treatment groups for total pigs born when Student's t-test and ANCOVA (parity as the covariate) were performed. Table 3-16 presents descriptive statistics for the total pigs born (see also Figure 3-3 and Figure 3-4).

Table 3-15: Mean (95% confidence limits) and median of total pigs born/sow stratified by housing/feeding system and month

Total pigs born			Month					
			Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group / higher feed	control	mean (95% CL)	11.3 (10.6-12.1)	11.2 (10-12.5)	11.8 (9.6-13.9)	10.4 (8.2-12.6)	12.2 (10.3-14.2)	11.4 (8.9-13.9)
		median	11	11	11	10	12.5	11.5
	treatment	mean (95% CL)	11.01 (10.2-11.9)	12.5 (10.1-14.8)	10.1 (8.2-11.9)	10 (7.7-12.3)	10.9 (9.04-12.7)	13 (11.7-14.3)
		median	12	12.5	10.5	10	11	13.5
Group / lower feed	control	mean (95% CL)	13.4 (13-14)	13.9 (12.3-15.5)	12.3 (11.3-13.4)	13.6 (12.7-14.5)	14.3 (13.4-15.3)	13.3 (12-14.7)
		median	13	14	12.5	14	13	13
	treatment	mean (95% CL)	13.4 (12.8-14)	13.4 (11.9-14.9)	12.7 (11.6-13.8)	13.2 (11.7-14.7)	14.6 (13.2-16)	13.3 (12-14.5)
		median	13	14	12	13	15	13
Stall / North	control	mean (95% CL)	12.5 (12.1-12.8)	12.3 (11.5-13.1)	12.8 (12.2-13.4)	12.3 (11.5-13.1)	12.4 (11.7-13.1)	12.8 (12.2-13.4)
		median	13	13	13	12	13	13
	treatment	mean (95% CL)	12.5 (12.2-12.7)	12.3 (11.2-12.9)	12.4 (11.8-13.1)	12.3 (11.7-12.9)	12.58 (12-13.2)	11.8 (11-12.6)
		median	13	13	12	13	12.5	12
Stall / South	control	mean (95% CL)	11.7 (11.3-12.1)	12.1 (11.2-13.1)	11.5 (10.5-12.4)	11.2 (10.2-12.2)	11.9 (10.9-12.9)	11.8 (11-12.6)
		median	12	12	12	11	12	11
	treatment	mean (95% CL)	11.4 (11-11.9)	11.5 (10.1-12.8)	11.1 (9.9-12.3)	12.1 (11.1-13.1)	11.3 (10.3-12.3	11.3 (10.3-12.6)
		median	11	12	11	12	11	12
Stall / Both	control	mean (95% CL)	12.2 (12-12.5)	12.3 (11.6-12.9)	12.4 (11.9-12.9)	12.1 (11.4-12.7)	12.3 (11.7-10.3)	12.2 (11.7-12.7)
		median	12	13	13	12	11	12
	treatment	mean (95% CL)	12.2 (12-12.4)	12.1 (11.5-12.6)	12.1 (11.5-12.7)	12.3 (11.8-12.8)	12.2 (11.7-12.8)	12.3 (11.8-12.9)

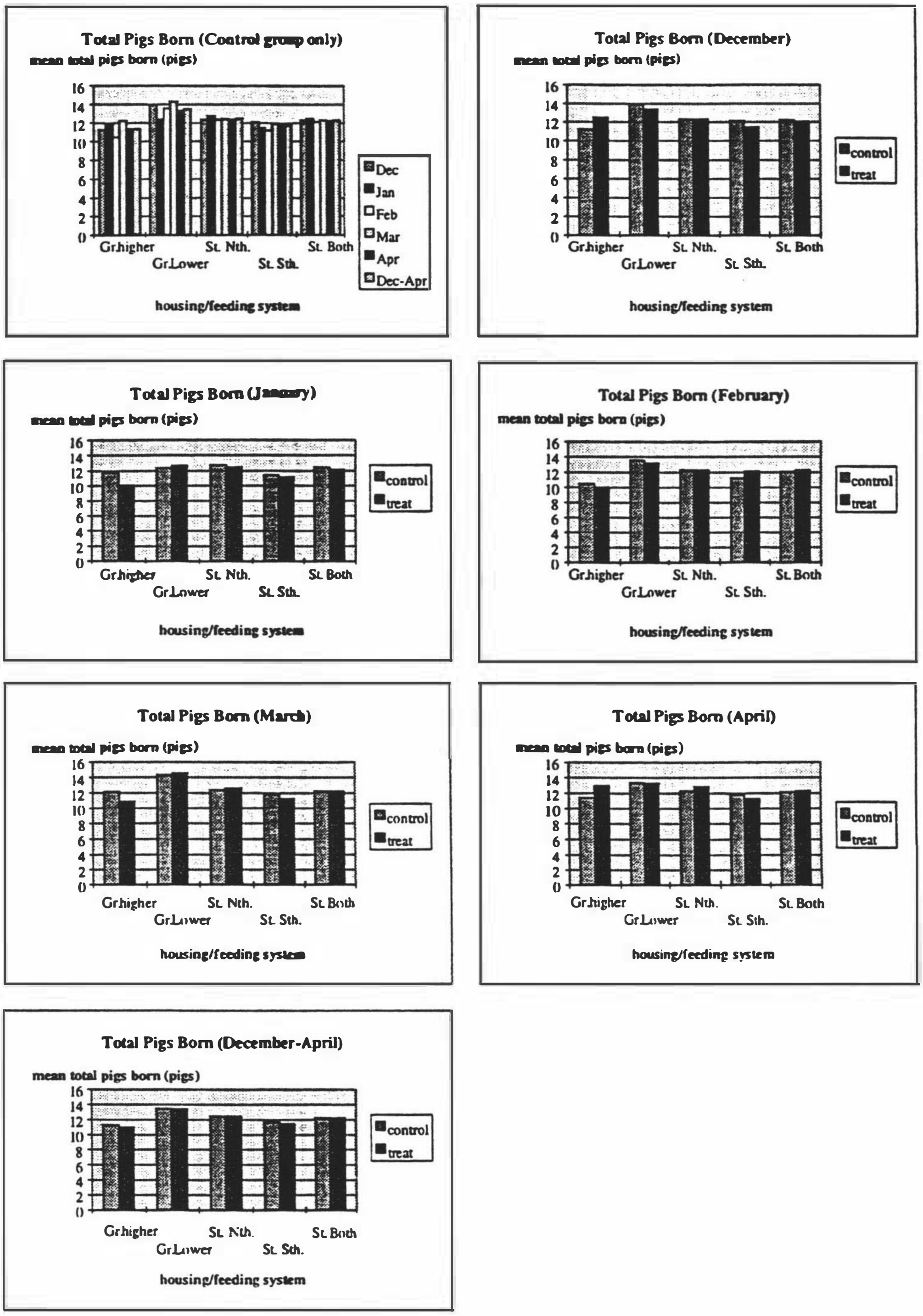
		median	12	13	12	13	12	13

Table 3-16: P-values for comparisons of total pigs born between control and treatment groups in different groupings using t-test and ANCOVA (presented in bracket)

	Dec-Apr	Dec	Jan	Feb	Mar	Apr
Gr. higher	0.583 (0.598)	0.302 (0.31)	0.204 (0.103)	0.785 (0.78)	0.293 (0.3)	0.176 (0.095)
Gr. lower	0.833 (0.859)	0.638 (0.61)	0.629 (0.55)	0.633 (0.66)	0.707 (0.69)	0.934 (0.91)
Stall North	0.833 (0.75)	0.961 (0.82)	0.46 (0.45)	0.994 (0.84)	0.695 (0.71)	0.352 (0.32)
Stall South	0.393 (0.39)	0.399 (0.62)	0.624 (0.54)	0.186 (0.2)	0.38 (0.23)	0.411 (0.46)
Stall both	0.769 (0.95)	0.667 (0.97)	0.412 (0.37)	0.619 (0.52)	0.932 (0.85)	0.738 (0.64)

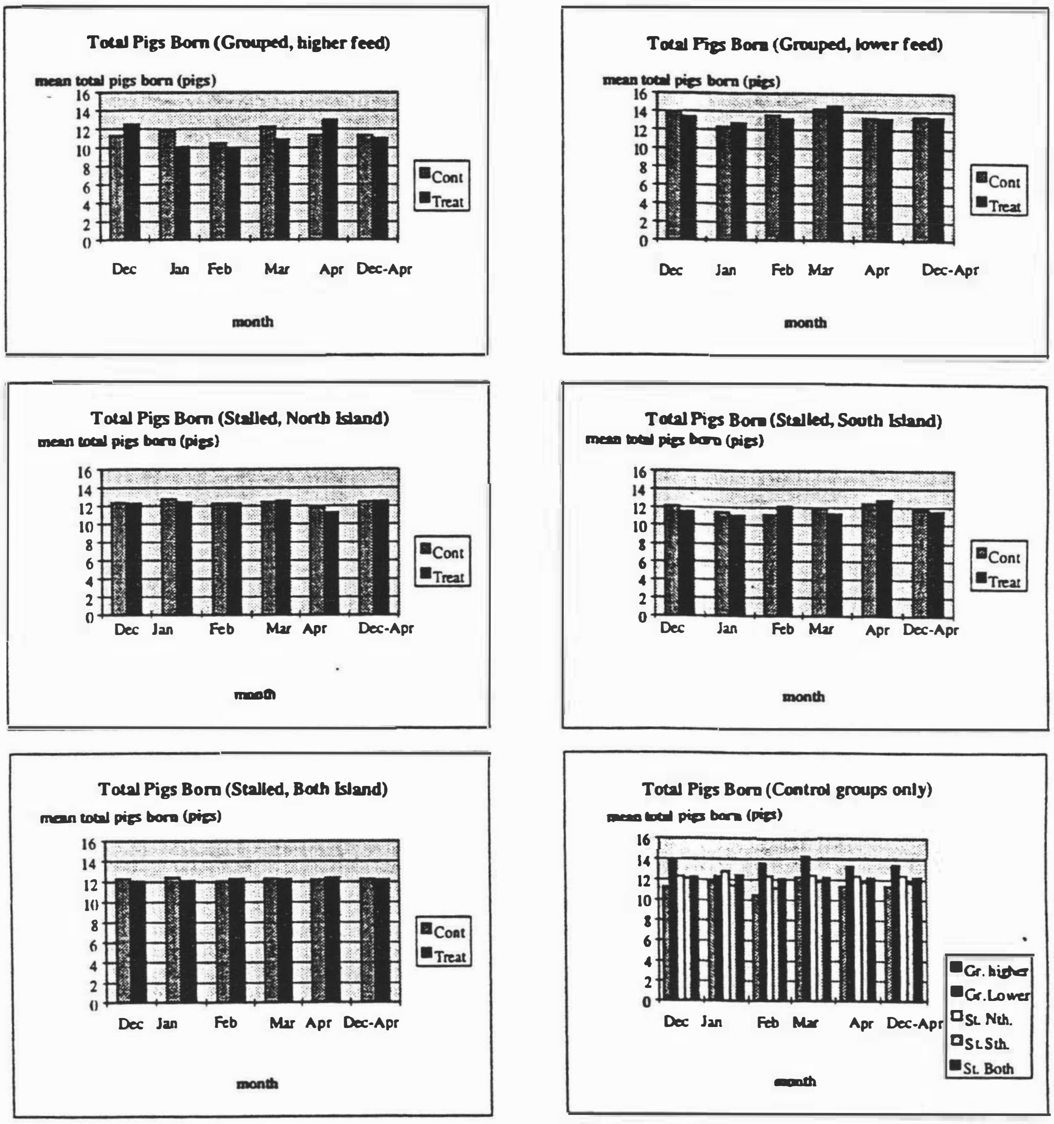
Gr. higher = grouped pigs, higher feed level, Gr. lower = grouped pigs, lower feed level, Stall North = stalled pigs in North Island, Stall South = stalled pigs in South Island

Figure 3-3: Barcharts showing means of total pigs born by months and treatment status stratified by housing/feeding system



Gr. higher = grouped higher feed farms; Gr. lower = grouped lower feed farms; St. North = stalled feeding farms in North Island; St. South = stalled feeding farms in South Island; St. Both = stalled feeding farms in both islands

Figure 3-4: Barcharts showing means of total pigs born by month and treatment status stratified by housing/feeding system



Pigs born alive

A significant difference was detected for the month of April between control and treatment groups within the grouped category higher feed (treatment sows had more pigs born alive than controls) when the Student's t-test and ANCOVA (parity as the covariate) were performed (Figure 3-6 and Table 3-18). Figure 3-5 and Figure 3-6 present graphical information of the comparison for average pigs born alive between control and treatment groups in different housing types. Compared with the feeding/housing types grouped pigs receiving a higher feed level had the lowest number of pigs born alive, whereas grouped pigs receiving a lower feed level had the highest pigs born alive.

Table 3-17: Mean (95% confidence limits) and median of number of pigs born alive stratified by feeding/housing system and month

Pigs born alive			Month					
			Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group / higher feed	control	mean (95% CL)	10.5 (9.7-11.2)	10.2 (8.96-11.5)	11.2 (9.1-13.4)	9.9 (7.9-11.9)	11.2 (9.7-12.7)	9.9a ☺ (7.8-12)
		median	11	10	11	10	11.5	10.5
	treatment	mean (95% CL)	9.8 (9-10.6)	11.2 (8.9-13.5)	8.7 (7.1-10.4)	9.1 (6.9-11.3)	9.5 (7.7-11.3)	12 (10.9-13.1)
		median	10	11.5	9	9	10	12
Group / lower feed	control	mean (95% CL)	11.98 (11.6-12.4)	12.2 (11-13.4)	10.8 (9.9-11.6)	12.4 (11.6-13.3)	12.6 (11.8-13.4)	11.9 (10.7-13)
		median	12	12	11	12.5	13	12
	treatment	mean (95% CL)	12.04 (11.5-12.6)	12.03 (10.5-13.6)	12.03 (10.9-13.1)	12.1 (10.6-13.6)	12.7 (11.6-13.7)	11.5 (10.2-12.7)
		median	12	12	12	12	13	12
Stall / North	control	mean (95% CL)	11.2 (10.9-11.4)	10.9 (10.2-11.6)	11.6 (11.04-12.2)	10.8 (10.2-11.5)	10.9 (10.2-11.6)	11.4 (10.7-12)
		median	11	11	12	11	11	11.5
	treatment	mean (95% CL)	11.1 (10.8-11.4)	10.9 (10.3-11.4)	11.1 (10.5-11.7)	11.1 (10.5-11.7)	11.1 (10.6-11.6)	11.3 (10.7-12)
		median	11	11	11	12	11	12
Stall / South	control	mean (95% CL)	11.1 (10.8-11.4)	11.2 (10.4-12.1)	11.1 (10.2-11.9)	10.4 (9.4-11.4)	10.9 (9.6-12.2)	11.2 (10.5-11.9)
		median	11	11	11	10	12	11
	treatment	mean (95% CL)	11 (10.6-11.4)	10.8 (9.5-12.1)	10.2 (9-11.4)	11.5 (10.5-12.4)	10.4 (9.6-11.3)	10.7 (9.8-11.6)
		median	11	11	10	11	10	10
Stall / Both	control	mean (95% CL)	11.1 (10.9-11.3)	11 (10.4-11.6)	11.5 (11-12)	10.7 (10.2-11.3)	10.9 (10.3-11.5)	11.3 (10.8-11.8)
		median	11	11	12	11	11	11
	treatment	mean (95% CL)	10.99 (10.8-11.2)	10.9 (10.3-11.4)	10.87 (10.4-11.4	11.2 (10.7-11.7)	10.9 (10.5-11.4)	11.1 (10.6-11.6)
		median	11	11	11	11	11	11

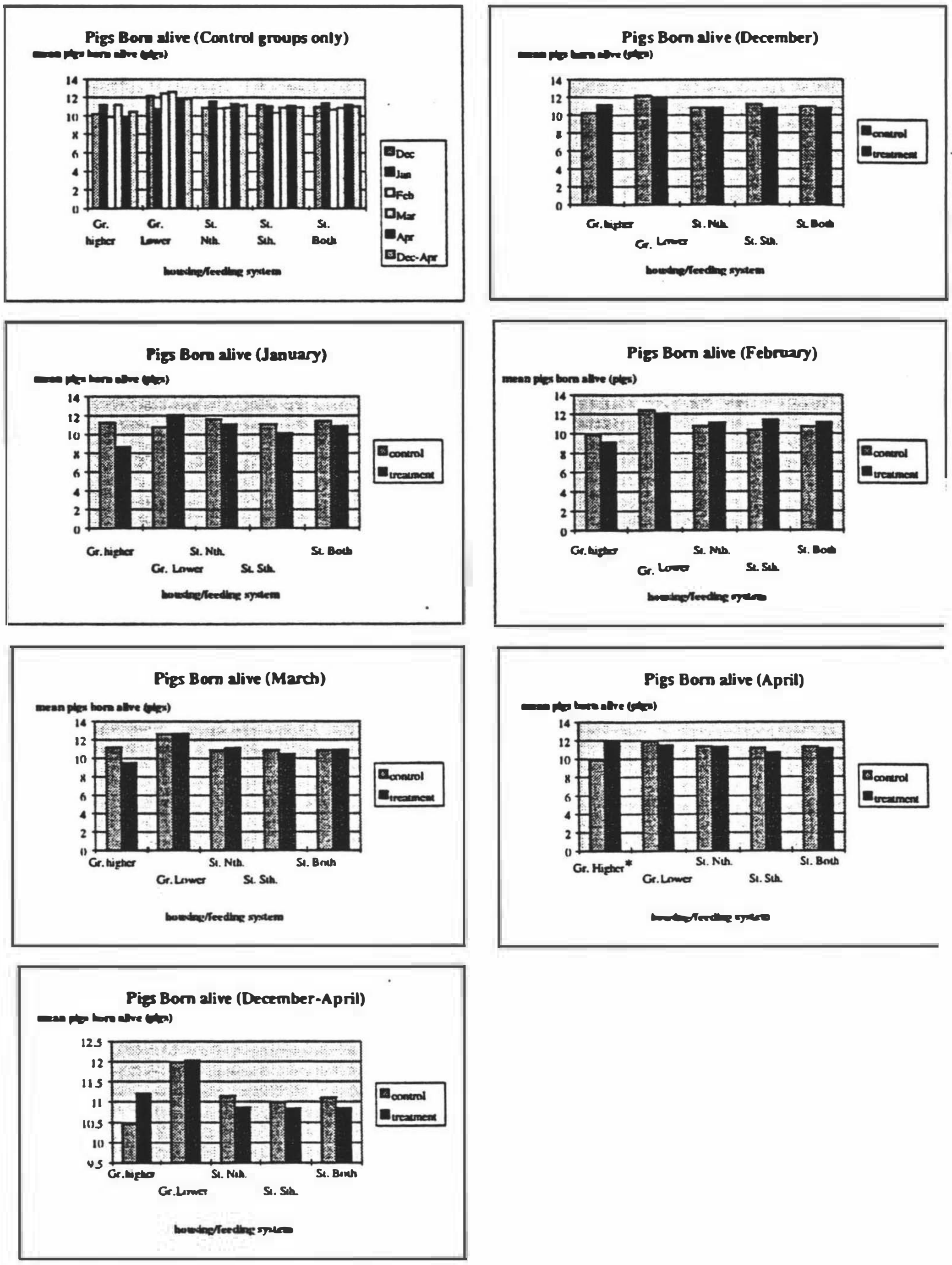
a = p-value of ANOVA 0.04 of ANCOVA 0.004 (☺); ☺ = treatment group had more pigs born alive than control group, shaded areas = detected statistically significant difference at $p<0.05$ when ANOVA and ANCOVA (parity as covariate) were performed to compare number pigs born alive between control and treatment group

Table 3-18: P-values for comparison of average number of pigs born alive between control and treatment groups in different feeding/housing system using t-test and ANCOVA (presented in bracket)

	Dec-Apr	Dec	Jan	Feb	Mar	Apr
Gr. higher	0.253 (0.29)	0.436 (0.44)	0.056 (0.015)	0.596 (0.58)	0.133 (0.143)	0.041 (0.004)
Gr. lower	0.878 (0.86)	0.866 (0.66)	0.068 (0.097)	0.646 (0.55)	0.986 (0.98)	0.649 (0.56)
Stall North	0.804 (0.84)	0.948 (0.82)	0.22 (0.2)	0.516 (0.4)	0.656 (0.64)	0.97 (0.99)
Stall South	0.369 (0.36)	0.578 (0.83)	0.221 (0.18)	0.129 (0.13)	0.535 (0.48)	0.417 (0.44)
Stall both	0.5 (0.58)	0.701 (0.77)	0.098 (0.08)	0.199 (0.16)	0.956 (0.97)	0.649 (0.7)

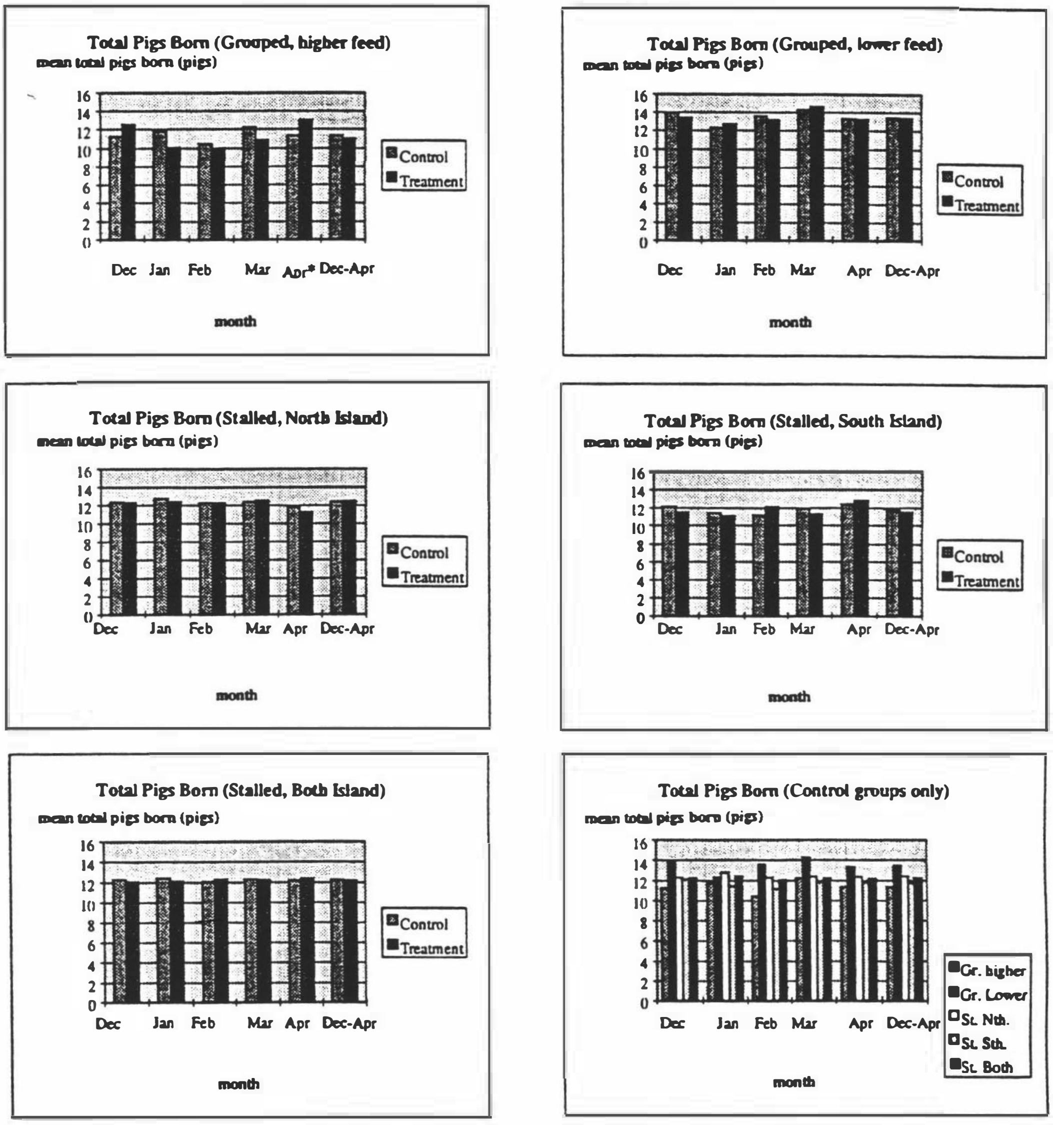
Gr. higher = grouped pigs, higher feed level, Gr. lower = grouped pigs, lower feed level, Stall North = stalled pigs in North Island, Stall South = stalled pigs in South Island

Figure 3-5: Barcharts showing means for number of pigs born alive by differen month and treatment status stratified by housing/feeding system



Gr. higher = grouped higher feed farms; Gr. lower = grouped lower feed farms; St. North = stalled feeding f in North Island; St. South = stalled feeding farms in South Island; St. Both = stalled feeding farms in islands; * = statistically significant difference (p-value < 0.05)

Figure 3-6: Barcharts showing means for number of pigs born alive by month and treament status stratified by housing/feeding system



* = statistically significant difference (p-value < 0.05) between treatment and control group

Stillborn

The only significant difference was found in grouped lower feed animals in January (control group had more stillborn than treatment, see Table 3-19 and Table 3-20). In the group housing system/higher feed level category, treatment pigs had more piglets stillborn than control pigs for December to March ($p = 0.05$), but in April the figure for stillborn was higher in the control group ($p = 0.689$). Stalled pigs in South Island farms had less stillborn than the other farm systems in every month ($p < 0.001$) (see Figure 3-7 and Figure 3-8).

Table 3-19: Mean (95% confidence limits) and median of stillborn piglet numbers stratified by housing/feeding system and month

Stillborn			Month					
			Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group / higher	control	mean (95% CL)	0.68 (0.4-0.95)	0.7 (0.3-1.2)	0.4 (-0.08-0.9)	0.5 (0.02-0.9)	1 (-0.09-2.1)	0.9 (-0.3-2)
		median	0	0	0	0	0	0.5
	treatment	mean (95% CL)	0.99 (0.7-1.3)	1.2 (-0.1-2.5)	1.1 (0.4-1.7)	0.8 (0.2-1.4)	1.3 (0.5-2.02)	0.5 (-0.006-1)
		median	1	1	0.5	0	1	0
Group / lower feed	control	mean (95% CL)	1.31 (1.1-1.6)	1.5 (0.8-2.3)	$1.37^{a,\oplus}$ (0.8-1.95)	1.03 (0.6-1.5)	1.4 (0.95-1.8)	1.3 (0.5-2.1)
		median	1	1	1	1	1	1
	treatment	mean (95% CL)	1.2 (0.9-1.5)	1.1 (0.6-1.7)	0.6 (0.3-0.9)	1.1 (0.6-1.6)	1.6 (0.8-2.4)	1.7 (0.9-2.5)
		median	1	1	0	1	1	1
Stall / North	control	mean (95% CL)	1.2 (1.03-1.4)	1.3 (0.8-1.8)	1.1 (0.7-1.4)	1.4 (1.04-1.7)	1.4 (1-1.7)	$0.85^{b,\oplus}$ (0.6-1.1)
		median	1	0	1	1	1	1
	treatment	mean (95% CL)	1.22 (1.1-1.4)	1.3 (0.8-1.7)	1.2 (0.8-1.5)	1.1 (0.8-1.4)	1.3 (0.98-1.6)	1.3 (0.97-1.7)
		median	1	1	1	1	1	1
Stall / South	control	mean (95% CL)	0.5 (0.4-0.7)	0.8 (0.4-1.2)	0.3 (-0.05-0.6)	0.61 (0.1-1.1)	0.78 (0.2-1.3)	0.4 (0.2-0.6)
		median	0	0	0	0	0	0
	treatment	mean (95% CL)	0.4 (0.4-0.6)	0.34 (0.1-0.6)	0.5 (0.2-0.8)	0.45 (0.09-0.8)	0.6 (0.3-0.8)	0.3 (0.1-0.5)
		median	0	0	0	0	0	0
Stall / Both	control	mean (95% CL)	11.01 (0.9-1.1)	1.1 (0.8-1.5)	0.9 (0.6-1.1)	1.2 (0.9-1.5)	1.2 (0.9-1.5)	$0.7^{c,\oplus}$ (0.5-0.9)
		median	0	0	0	1	1	0
	treatment	mean (95% CL)	1.01 (0.9-1.1)	1.03 (0.7-1.4)	0.98 (0.7-1.3)	0.9 (0.7-1.2)	1.09 0.9-1.3)	1.01 (0.7-1.3)
		median	1	0	0	1	1	1

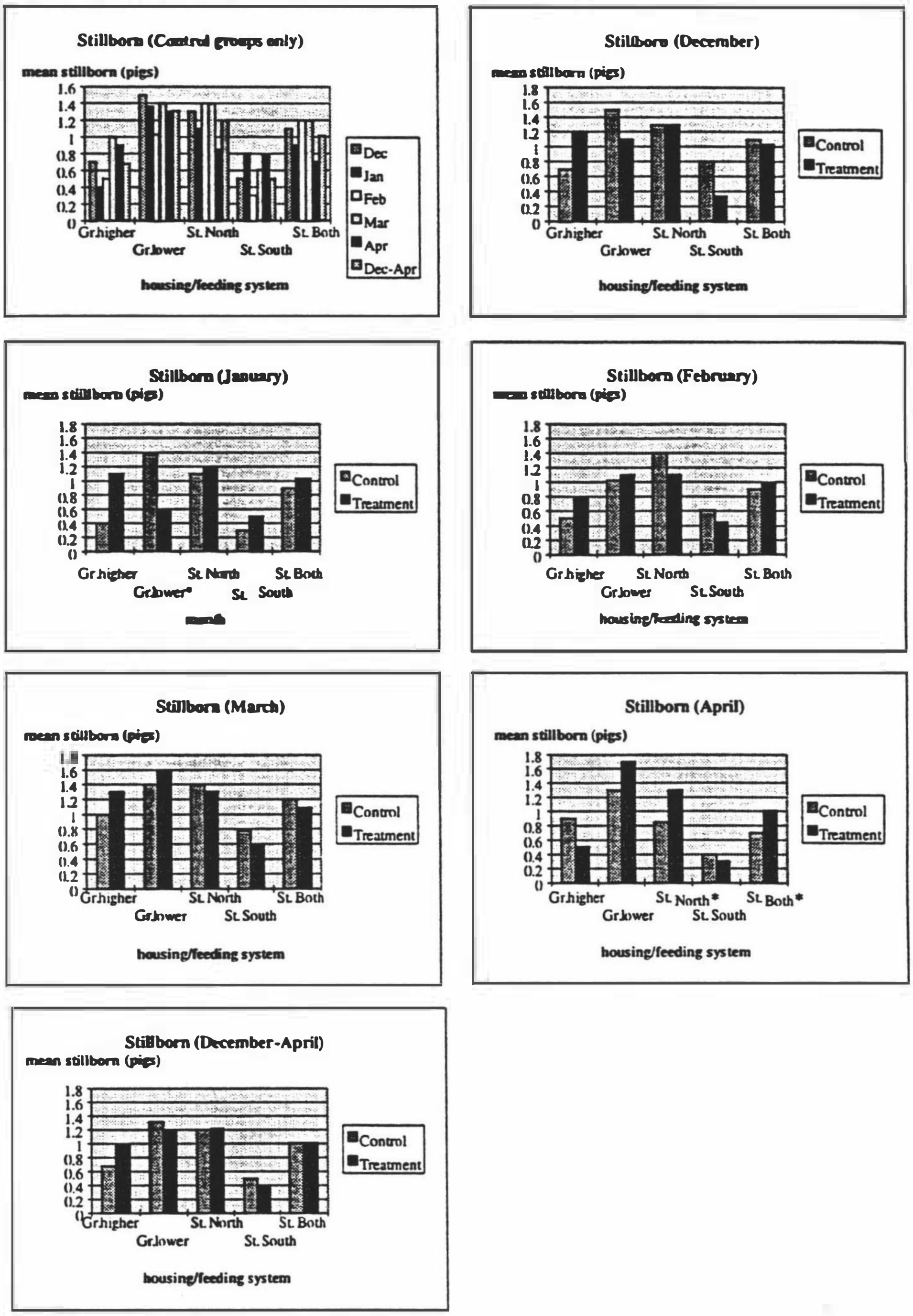
shaded areas = detected statistically significant difference at $p < 0.05$

Table 3-20: P-values for comparison of number of stillborn piglets between control and treatment groups in different feeding/housing systems using Mann-Whitney U test

	Dec-Apr	Dec	Jan	Feb	Mar	Apr
Gr. higher	0.057	0.31	0.12	0.408	0.318	0.654
Gr. lower	0.367	0.536	0.046	0.748	0.937	0.581
Stall North	0.804	0.729	0.761	0.19	0.976	0.08
Stall South	0.443	0.086	0.112	0.398	0.993	0.435
Stall both	0.918	0.778	0.694	0.115	0.895	0.322

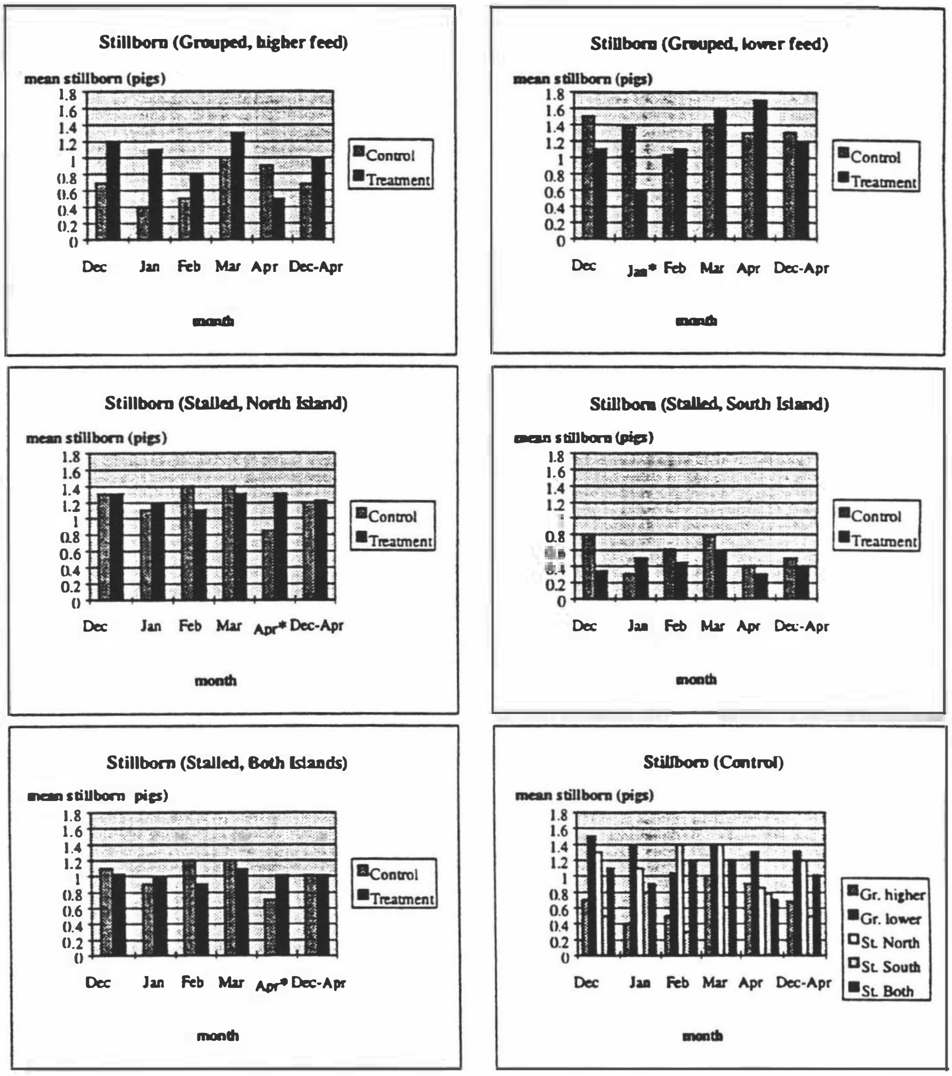
Gr. higher = grouped pigs, higher feed level, Gr. lower = grouped pigs, lower feed level, Stall North = stalled pigs in North Island, Stall South = stalled pigs in South Island, shaded area = statistically significant difference between control and treatment group at p-level <= 0.05

Figure 3-7: Barcharts showing means for number of stillborn piglets by month and treatment status stratified by housing/feeding system



Gr. higher = grouped higher feed farms; Gr. lower = grouped lower feed farms; St. North = stalled feeding farm in North Island; St. South = stalled feeding farms in South Island; St. Both = stalled feeding farms in both island

Figure 3-8: Barcharts showing means for number of stillborn piglets by month and treatment status stratified by housing/feeding system



Mummies

Significant differences were detected between control and treatment groups in the stalled South Island category, and the stalled sows from both islands. The treatment group had more mummies than the control group in both cases (Table 3-21 and Table 3-22).

The average number of mummies did not appear to vary significantly between months, but a sharp surge in April in grouped pigs on higher feed was found. The mean number of mummies was zero in March in grouped pigs on higher feed. Stalled pigs in North Island farms had the lowest mean number of mummies (see Figure 3-9 and Figure 3-10).

Table 3-21: Mean (95% confidence limits) and median for number of mummies, stratified by housing/feeding system and month

Mummies			Month					
			Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group / higher feed	control	mean (95% CL)	0.2 (0.1-0.3)	0.3 (0.1-0.5)	0.15 (-0.18-0.5)	0.06 (-0.07-0.2)	0 (0)	0.63 (-0.6-1.8)
		median	0	0	0	0	0	0
	treatment	mean (95% CL)	0.2 (0.1-0.4)	0.1 (-0.13-0.3)	0.28 (0-0.6)	0.07 (-0.08-0.2)	0 (0)	0.5 (-0.4-1.4)
		median	0	0	0	0	0	0
Group / lower feed	control	mean (95% CL)	0.2 (0.1-0.3)	0.2 (0-0.4)	0.123 (0.11-0.13)	0.12 (-0.05-0.21)	0.31 (0.06-0.6)	0.17 (0-0.33)
		median	0	0	0.13	0	0	0
	treatment	mean (95% CL)	0.2 (0.07-0.3)	0.24 (0-0.5)	0.07 (-0.03-0.2)	0 (0)	0.38 (0.02-0.8)	0.1 (-0.05-0.24)
		median	0	0	0	0	0	0
Stall / North	control	mean (95% CL)	0.1 (0.1-0.14)	0.1 (0.02-0.2)	0.06 (0.01-0.1)	0.09 (0.02-0.2)	0.12 (0-0.2)	0.16 (0.06-0.3)
		median	0	0	0	0	0	0
	treatment	mean (95% CL)	0.2 (0.1-0.2)	0.2 (0.04-0.3)	0.2 (0.07-0.3)	0.1 (0.03-0.2)	0.19 (0.08-0.3)	0.14 (0.05-0.2)
		median	0	0	0	0	0	0
Stall / South	control	mean (95% CL)	0.2 (0.1-0.3)	0.12 (-0.03-0.3)	0.14[a] (-0.06-0.4)	0.17 (-0.04-0.4)	0.22 (0.02-0.4)	0.24 (0.06-0.4)
		median	0	0	0	0	0	0
	treatment	mean (95% CL)	0.4 (0.3-0.6)	0.3 (0.03-0.5)	0.45 (0.15-0.8)	0.23 (0.04-0.4)	0.3 (0.03-0.5)	0.27 (-0.01-0.6)
		median	0	0	0	0	0	0
Stall / Both	control	mean (95% CL)	0.1 (0.1-0.16)	0.11 (0.03-0.2)	0.08[b, c] (0.02-0.15)	0.11 (0.4-0.2)	0.14 (0.04-0.2)	0.19 (0.1-0.3)
		median	0	0	0	0	0	0
	treatment	mean (95% CL)	0.2 (0.2-0.24)	0.2 (0.08-0.3)	0.24 (0.13-0.34)	0.14 (0.07-0.2)	0.22 (0.11-0.32)	0.18 (0.07-0.3)
		median	0	0	0	0	0	0

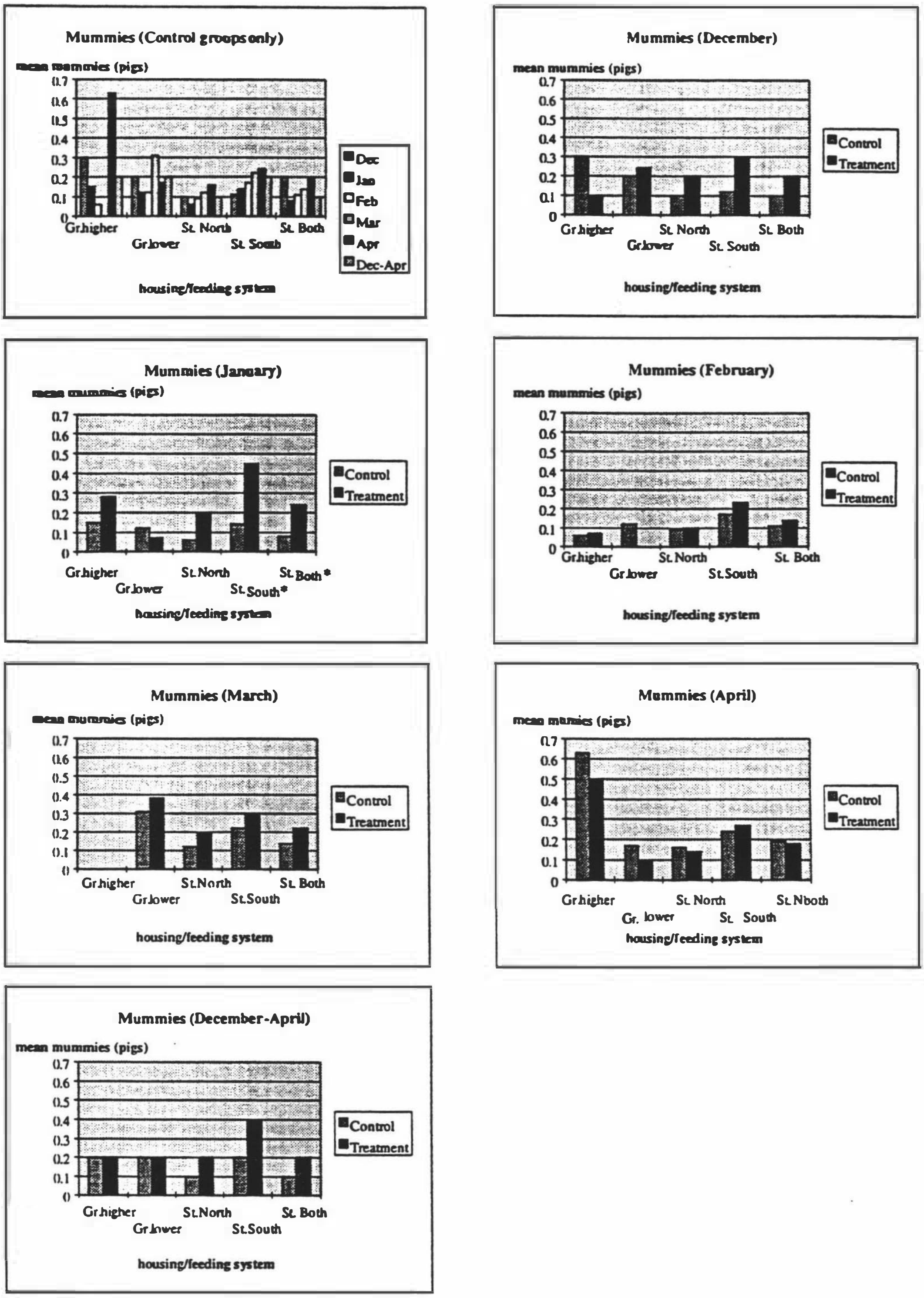
shaded areas indicate detected statistically significant difference at $p < 0.05$

Table 3-22: P-values for comparisons of number of mummies between control and treatment groups in different housing/feed categories using Mann-Whitney U test

	Dec-Apr	Dec	Jan	Feb	Mar	Apr
Gr. higher	0.745	0.427	0.332	0.928	-	0.807
Gr. lower	0.502	0.904	0.574	0.204	0.568	0.258
Stall North	0.1	0.781	0.095	0.806	0.135	0.956
Stall South	0.142	0.32	0.04	0.57	0.937	0.592
Stall both	0.446	0.296	0.01	0.524	0.216	0.718

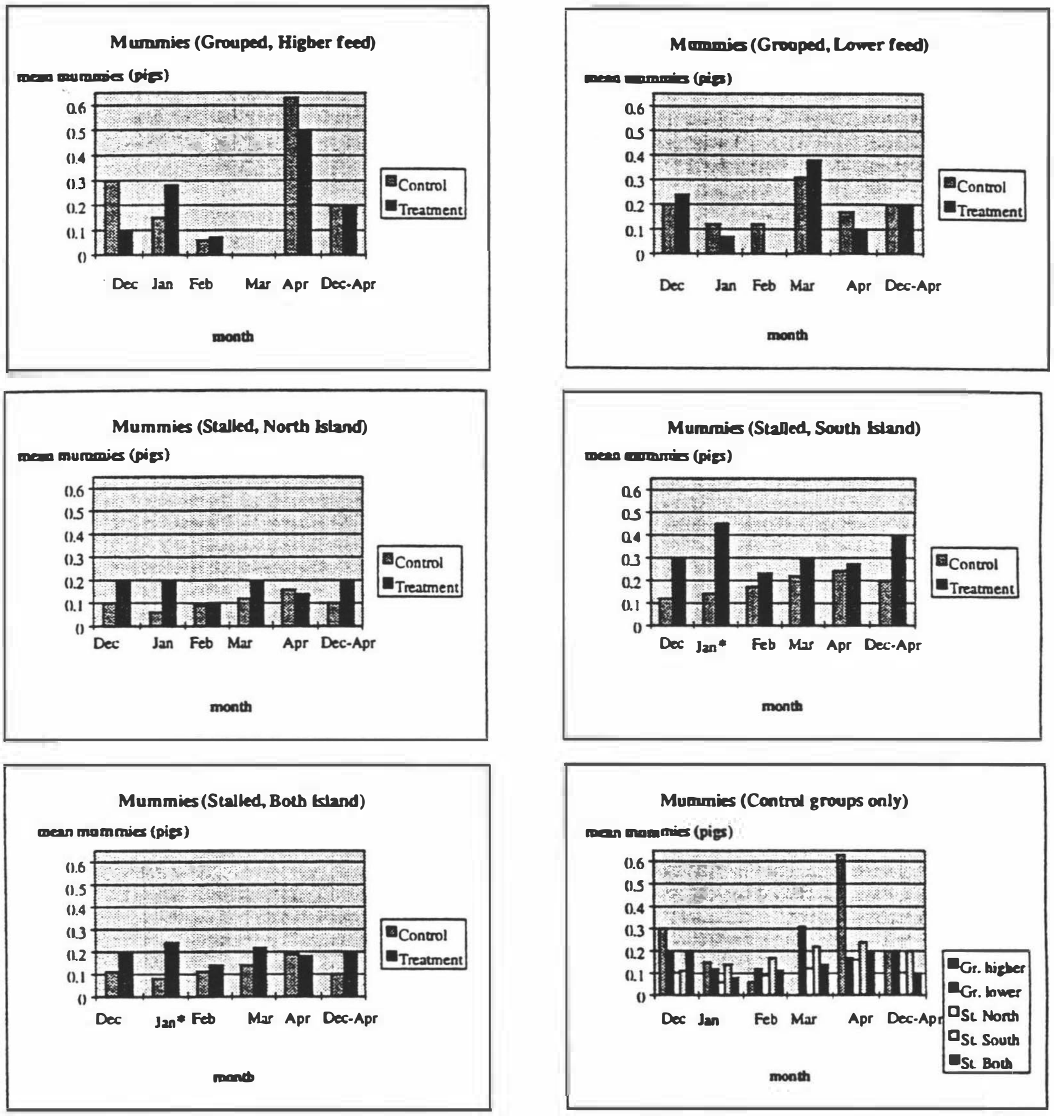
Gr. higher = grouped pigs, higher feed level, Gr. lower = grouped pigs, lower feed level, Stall North = stalled pigs in North Island, Stall South = stalled pigs in South Island, shaded areas = detected statistically significant difference at $p < 0.05$

Figure 3-9: Barcharts showing mean for number of mummies by month and treatment status, stratified by housing/feeding systems



Gr. higher = grouped higher feed farms; Gr. lower = grouped lower feed farms; St. North = stalled feeding farms in North Island; St. South = stalled feeding farms in South Island; St. Both = stalled feeding farms in both islands; * = statistically significant difference (p-value < 0.05) in the group

Figure 3-10: Barcharts showing means for number of mummies by month and treatment status stratified by different housing/feeding systems



* = statistically significant difference (p-value < 0.05) in the group

Breeding performance

In order to differentiate various reasons for reproductive failure, sows which did not become pregnant at first service were grouped according the following categories:

Events	Categories
return to oestrus 10-17 days after mating	Early return
return to oestrus 18-25 days or 38-46 days after mating	Regular return
return to oestrus 26-37 days after mating	Irregular return
return to oestrus 47-108 days after mating	Late return
"Not farrowed" at due date, pseudopregnancy, anoestrus	Not Farrowed
removed (for reproductive reason)	Removed
Abort	Abort

Table 3-23 to Table 3-28 and Figure 3-11 to Figure 3-16 present the results of a descriptive analysis of monthly numbers and percentages of breeding performance of gilts/sows based on the above categories. Because of the relatively small numbers of observations in most of the categories, it was decided not to analyze this data statistically.

Table 3-23: Count (percentage) of gilts/sows showing different reproductive outcomes, stratified by housing/feeding system for the period December-April

December-April		No. sows (%)						
System	Group	Far*	Reg*	Irreg*	Late*	NF*	Rem*	Abort
Group / higher feed	Control	81 (19.83)	16 (13.79)	5 (4.31)	10 (8.62)	3 (2.59)	0 (0)	1 (0.86)
	Treatment	69 (73.4)	14 (14.89)	1 (1.06)	3 (3.19)	5 (3.32)	2 (2.13)	0 (0)
Group / lower feed	Control	163 (71.81)	35 (15.42)	3 (1.32)	2 (0.88)	22 (9.69)	1 (0.44)	1 (0.44)
	Treatment	142 (70.3)	31 (15.84)	10 (4.95)	0 (0)	18 (8.91)	0 (0)	0 (0)
Stall / north	Control	404 (81.29)	22 (4.43)	9 (1.81)	33 (6.64)	0 (0)	26 (4.4)	3 (0.6)
	Treatment	421 (84.2)	31 (6.2)	3 (0.6)	20 (4)	0 (0)	22 (4.4)	3 (0.6)
Stall / south	Control	152 (88.37)	5 (2.91)	3 (1.74)	7 (4.07)	1 (1.58)	1 (1.58)	3 (1.74)
	Treatment	158 (85.41)	9 (4.86)	8 (4.32)	7 (3.78)	2 (1.08)	1 (0.54)	0 (0)
Stall / both	Control	556 (83.23)	27 (4.04)	11 (1.65)	40 (5.99)	1 (0.15)	27 (4.04)	6 (0.9)
	Treatment	579 (84.53)	40 (5.84)	11 (1.61)	27 (3.94)	2 (0.29)	23 (3.36)	3 (0.44)

*Far, farrowed; Reg, Regular return; Irreg, Irregular return; Late, Late return; NF, Not farrowed, Rem, Removed

Table 3-24: Count (percentage) of gilts/sows showing different reproductive outcomes, stratified by housing/feeding system in December

December		No. sows (%)						
System	Group	Far*	Reg*	Irreg*	Late*	NF*	Rem*	Abort
Group / higher feed	Control	29 (64.44)	9 (20)	1 (2.22)	6 (13.33)	0 (0)	0 (0)	0 (0)
	Treatment	10 (45.45)	7 (31.82)	1 (4.55)	2 (9.09)	0 (0)	2 (9.09)	0 (0)
Group / lower feed	Control	25 (56.82)	10 (22.73)	1 (2.27)	0 (0)	6 (13.64)	1 (2.27)	0 (0)
	Treatment	29 (64.44)	5 (11.11)	3 (7.78)	0 (0)	8 (17.78)	0 (0)	0 (0)
Stall / north	Control	71 74.74)	7 (7.37)	2 (2.11)	10 (10.53)	0 (0)	3 (3.16)	2 (2.11)
	Treatment	84 (81.55)	12 (11.65)	0 (0)	3 (2.91)	0 (0)	4 (3.88)	0 (0)
Stall / south	Control	33 (89.19)	2 (5.41)	1 (2.7)	1 (2.7)	0 (0)	0 (0)	0 (0)
	Treatment	29 (78.38)	1 (2.7)	3 (8.11)	4 (10.81)	0 (0)	0 (0)	0 (0)
Stall / both	Control	104 (78.2)	9 (6.77)	3 (2.26)	11 (8.27)	0 (0)	3 (2.26)	3 (2.26)
	Treatment	113 (78.47)	13 (9.03)	3 (2.08)	7 (4.86)	0 (0)	4 (2.78)	4 (2.78)

*Far, farrowed; Reg, Regular return; Irreg, Irregular return; Late, Late return; NF, Not farrowed, Rem, Removed

Table 3-25: Count (percentage) of gilts/sows showing different reproductive outcomes, stratified by housing/feeding system in January

January		No. sows						
System	Group	Far*	Reg*	Irreg*	Late*	NF*	Rem*	Abort
Group / higher feed	Control	13 (54.17)	3 (12.5)	3 (12.5)	3 (12.5)	1 (4.17)	0 (0)	1 (4.17)
	Treatment	18 (81.82)	4 (18.18)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Group / lower feed	Control	38 (71.7)	9 (16.98)	1 (1.89)	0 (0)	5 (9.43)	0 (0)	0 (0)
	Treatment	29 (67.44)	6 (13.95)	4 (9.3)	0 (0)	4 (9.3)	0 (0)	0 (0)
Stall / north	Control	96 (77.42)	5 (4.03)	4 (3.23)	13 (10.48)	0 (0)	5 (9.43)	1 (0.81)
	Treatment	97 (88.99)	5 (4.59)	0 (0)	2 (1.83)	0 (0)	4 (9.3)	1
Stall / south	Control	35 (85.37)	1 (2.44)	0 (0)	3 (7.32)	0 (0)	0 (0)	2 (4.88)
	Treatment	33 (80.49)	1 (2.44)	3 (7.32)	1 (2.44)	2 (4.88)	1 (2.44)	0 (0)
Stall / both	Control	131 (76.61)	6 (3.51)	4 (2.34)	16 (9.36)	6 (3.51)	5 (2.92)	3 (1.75)
	Treatment	130 (84.42)	6 (3.9)	3 (1.95)	3 (1.95)	6 (3.9)	5 (3.25)	1 (0.65)

*Far, farrowed; Reg, Regular return; Irreg, Irregular return; Late, Late return; NF, Not farrowed, Rem, Removed

Table 3-26: Count (percentage) of gilts/sows showing different reproductive outcomes, stratified by housing/feeding system in February

February		No. sows						
System	Group	Far*	Reg*	Irreg*	Late*	NF*	Rem*	Abort
Group / higher feed	Control	17 (89.47)	1 (5.26)	1 (5.26)	0 (0)	0 (0)	0 (0)	0 (0)
	Treatment	15 (78.95)	2 (10.53)	0 (0)	0 (0)	2 (10.53)	0 (0)	0 (0)
Group / lower feed	Control	34 (68)	8 (16)	1 (2)	1 (2)	6 (12)	0 (0)	0 (0)
	Treatment	27 (77.14)	7 (20)	0 (0)	0 (0)	1 (2.86)	0 (0)	0 (0)
Stall / north	Control	79 (84.04)	5 (5.32)	1 (1.06)	2 (2.13)	0 (0)	7 (7.45)	0 (0)
	Treatment	80 (84.21)	2 (2.11)	2 (2.11)	4 (4.21)	0 (0)	6 (6.32)	1 (1.05)
Stall / south	Control	23 (79.31)	1 (3.45)	2 (6.9)	2 (6.9)	0 (0)	0 (0)	1 (3.45)
	Treatment	31 (88.57)	3 (8.57)	0 (0)	1 (2.86)	0 (0)	0 (0)	0 (0)
Stall / both	Control	102 (82.93)	6 (4.88)	3 (2.44)	4 (3.25)	0 (0)	7 (5.69)	1 (0.81)
	Treatment	111 (85.38)	5 (3.85)	2 (1.54)	5 (3.85)	0 (0)	6 (4.62)	1 (0.77)

*Far, farrowed; Reg, Regular return; Irreg, Irregular return; Late, Late return; NF, Not farrowed, Rem, Removed

Table 3-27: Count (percentage) of gilts/sows showing different reproductive outcomes, stratified by housing/feeding system in March

March		No. sows (%)						
System	Group	Far*	Reg*	Irreg*	Late*	NF*	Rem*	Abort
Group / higher feed	Control	14 (87.5)	1 (6.25)	0 (0)	1 (5.26)	0 (0)	0 (0)	0 (0)
	Treatment	16 (94.12)	0 (0)	0 (0)	0 (0)	1 (5.88)	0 (0)	0 (0)
Group / lower feed	Control	42 (80.77)	6 (11.54)	0 (0)	0 (0)	4 (7.69)	0 (0)	0 (0)
	Treatment	26 (57.78)	11 (24.44)	3 (6.67)	0 (0)	5 (11.11)	0 (0)	0 (0)
Stall / north	Control	78 (83.87)	1 (1.08)	2 (2.15)	5 (5.38)	0 (0)	7 (7.53)	0 (0)
	Treatment	88 (86.27)	7 (6.86)	1 (0.98)	3 (2.94)	0 (0)	2 (1.96)	1 (0.98)
Stall / south	Control	28 (93.33)	0 (0)	0 (0)	1 (3.33)	0 (0)	1 (3.33)	0 (0)
	Treatment	32 (91.43)	1 (2.86)	1 (2.86)	1 (2.86)	0 (0)	0 (0)	0 (0)
Stall / both	Control	106 (81.54)	8 (6.15)	2 (1.54)	6 (4.62)	0 (0)	8 (6.15)	0 (0)
	Treatment	120 (92.31)	2 (1.54)	2 (1.54)	4 (2.31)	0 (0)	2 (1.54)	1 (0.77)

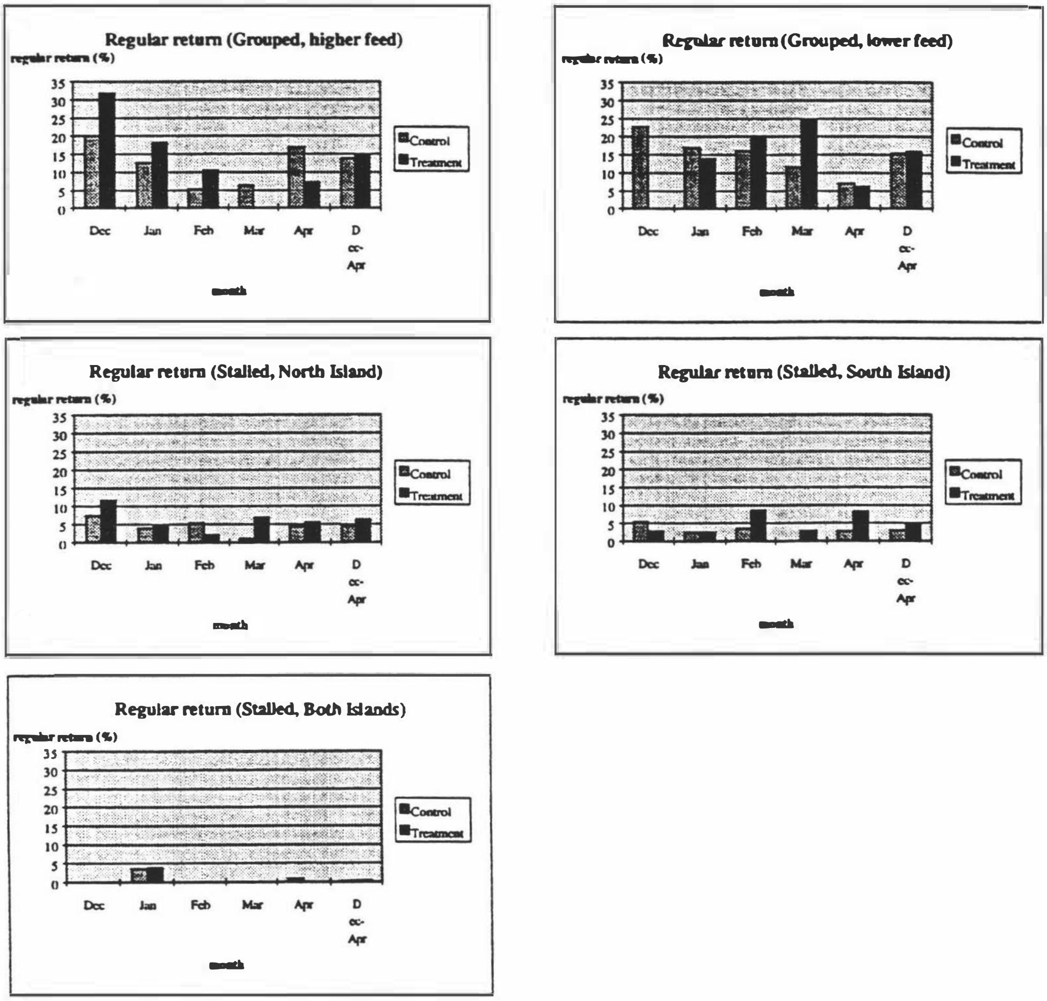
*Far, farrowed; Reg, Regular return; Irreg, Irregular return; Late, Late return; NF, Not farrowed, Rem, Removed

Table 3-28: Count (percentage) of gilts/sows showing different reproductive outcomes, stratified by housing/feeding system in April

April		No. sows						
System	Group	Far*	Reg*	Irreg*	Late*	NF*	Rem*	Abort
Group / higher feed	Control	8 (66.67)	2 (16.67)	0 (0)	0 (0)	2 (16.67)	0 (0)	0 (0)
	Treatment	10 (71.43)	1 (7.14)	0 (0)	1 (7.14)	2 (14.29)	0 (0)	0 (0)
Group / lower feed	Control	24 (82.76)	2 (6.9)	0 (0)	1 (3.45)	1 (3.45)	0 (0)	1 (3.45)
	Treatment	31 (93.94)	2 (6.06)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Stall / north	Control	80 (87.91)	4 (4.4)	0 (0)	3 (3.3)	0 (0)	4 (4.4)	0 (0)
	Treatment	72 (79.12)	5 (5.49)	0 (0)	8 (8.79)	0 (0)	6 (6.59)	0 (0)
Stall / south	Control	33 (94.29)	1 (2.86)	0 (0)	0 (0)	1 (2.86)	0 (0)	0 (0)
	Treatment	33 (89.19)	3 (8.11)	1 (2.7)	0 (0)	0 (0)	0 (0)	0 (0)
Stall / both	Control	113 (89.68)	5 (3.97)	0 (0)	3 (2.38)	1 (0.79)	4 (3.17)	0 (0)
	Treatment	105 (82.03)	8 (6.25)	1 (0.78)	8 (6.25)	0 (0)	6 (4.69)	0 (0)

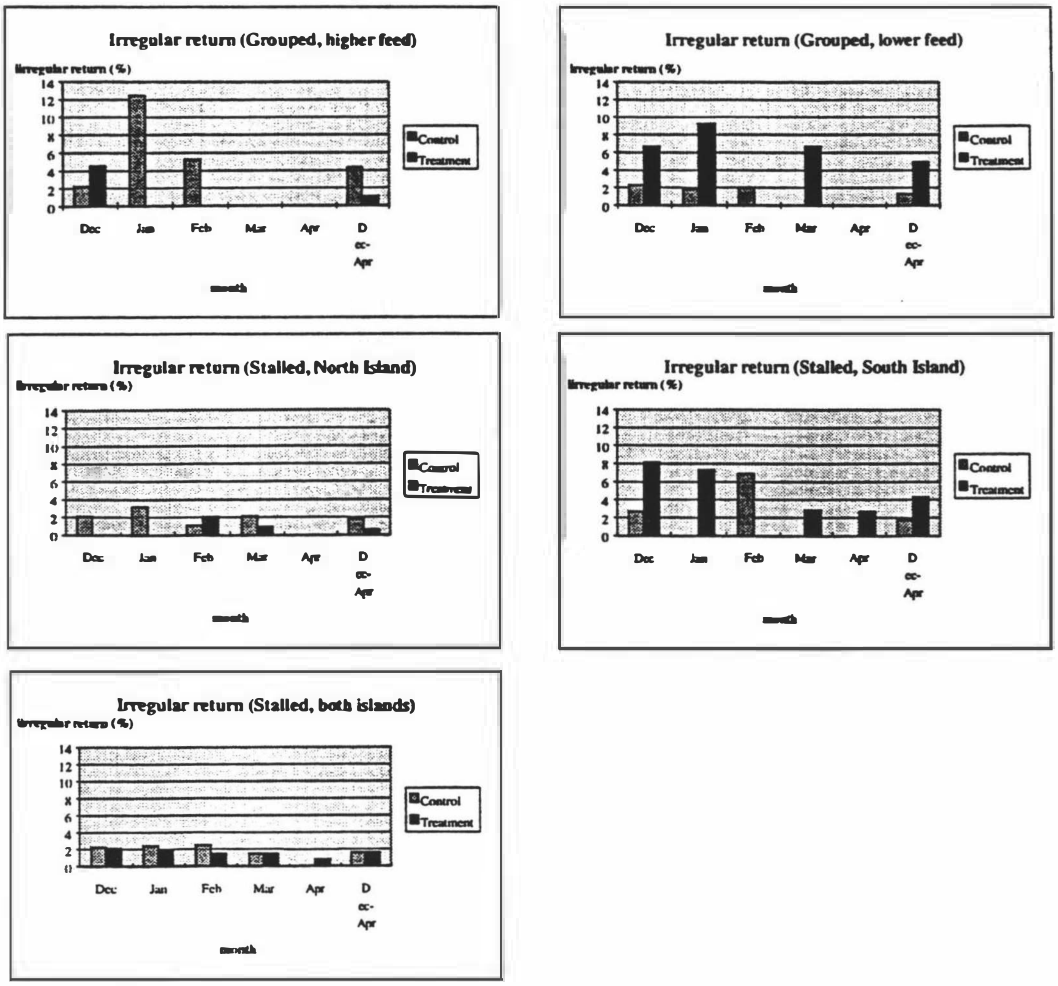
*Far, farrowed; Reg, Regular return; Irreg, Irregular return; Late, Late return; NF, Not farrowed, Rem, Removed

Figure 3-11: Barcharts showing percentages of pigs showing regular returns in different months, stratified by housing/feeding systems



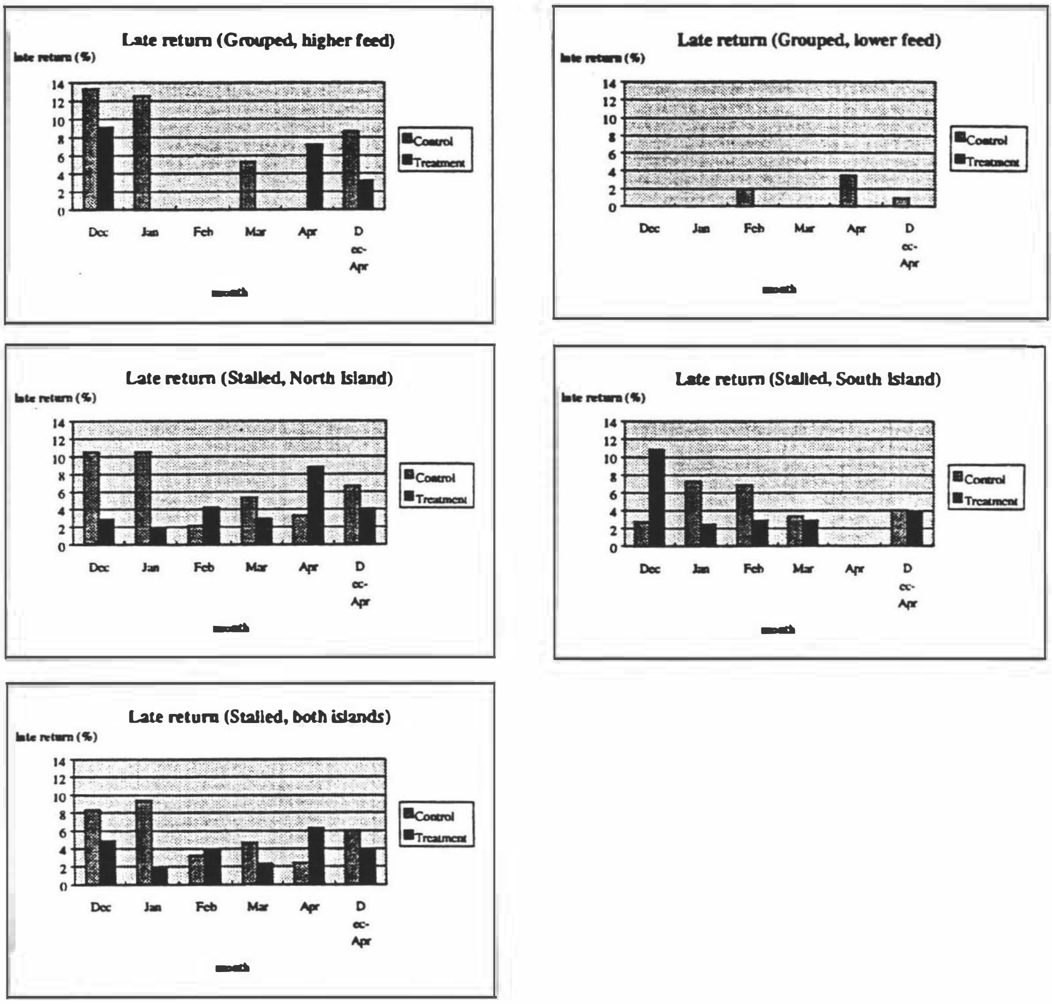
Visual examination of Figure 3-11 suggests that stall-housed pigs had lower regular return rates than group-housed pigs, and within the category of regular return rates were higher in sows feed a lower feeding level during the months of February and March.

Figure 3-12: Barcharts showing percentages of irregular returns by month and treatement status stratified by housing/feeding systems



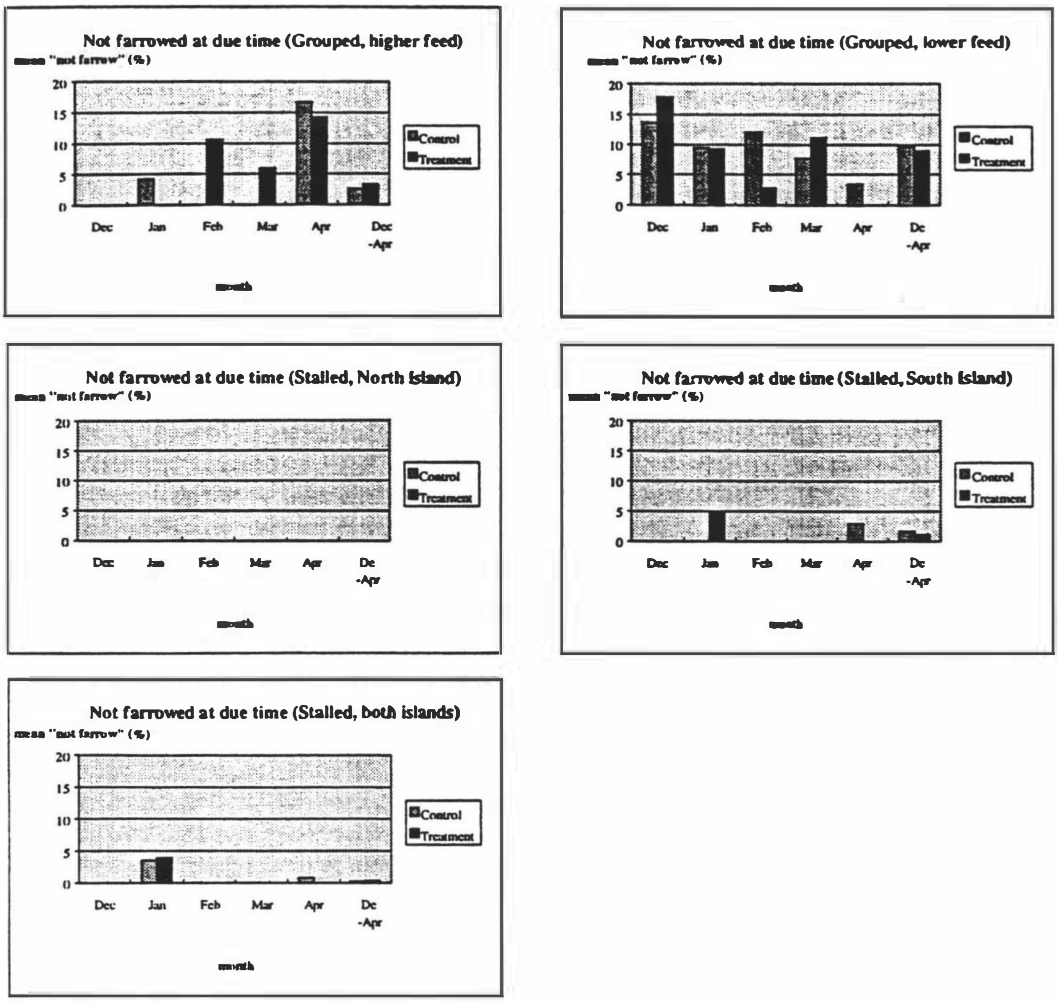
During the months January and February irregular returns rates were very high in group-housed control pigs receiving the higher level of feed, whereas treatment animals in the same herds had no irregular returns. However treatment animals from the group-housed low-feed group (which were on the same intake as the controls in the high-feed group) also showed higher irregular returns, suggesting either that irregular return was associated with intermediate feed intake, or the effect is a chance one.

Figure 3-13: Barcharts showing percentages of late return pigs by month and treatment status stratified by housing/feeding systems



Late returns do not appear to show a clear pattern which might be related to feed intake or housing system.

Figure 3-14: Barcharts showing percentages of "not farrowed at due time" pigs by month and treatment status, stratified by housing/feeding systems



Visual examination of the data suggests (see Figure 3-14) that the percentages of "not farrowed" were lower in stall-housed pigs, with zero prevalence in stall-housed pigs in North Island.

Figure 3-15: Barcharts showing percentages of pigs removed by month and treatment status, stratified by housing/feeding systems

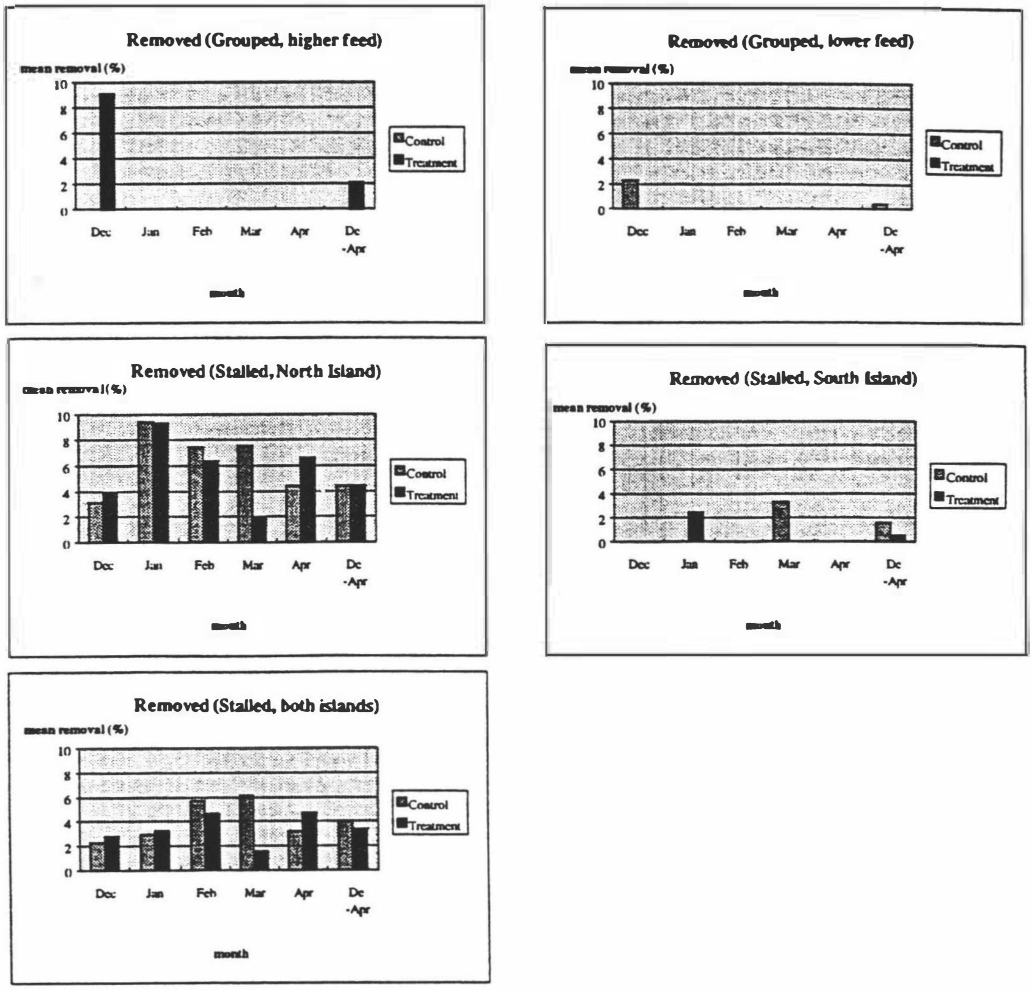


Figure 3-15 shows that pigs kept in stall housing systems in the North Island had been regularly culled for reproductive reasons, while pigs from the other goups were not.

Figure 3-16: Barcharts showing percentages of abortions by month and treatment status stratified by housing/feeding systems

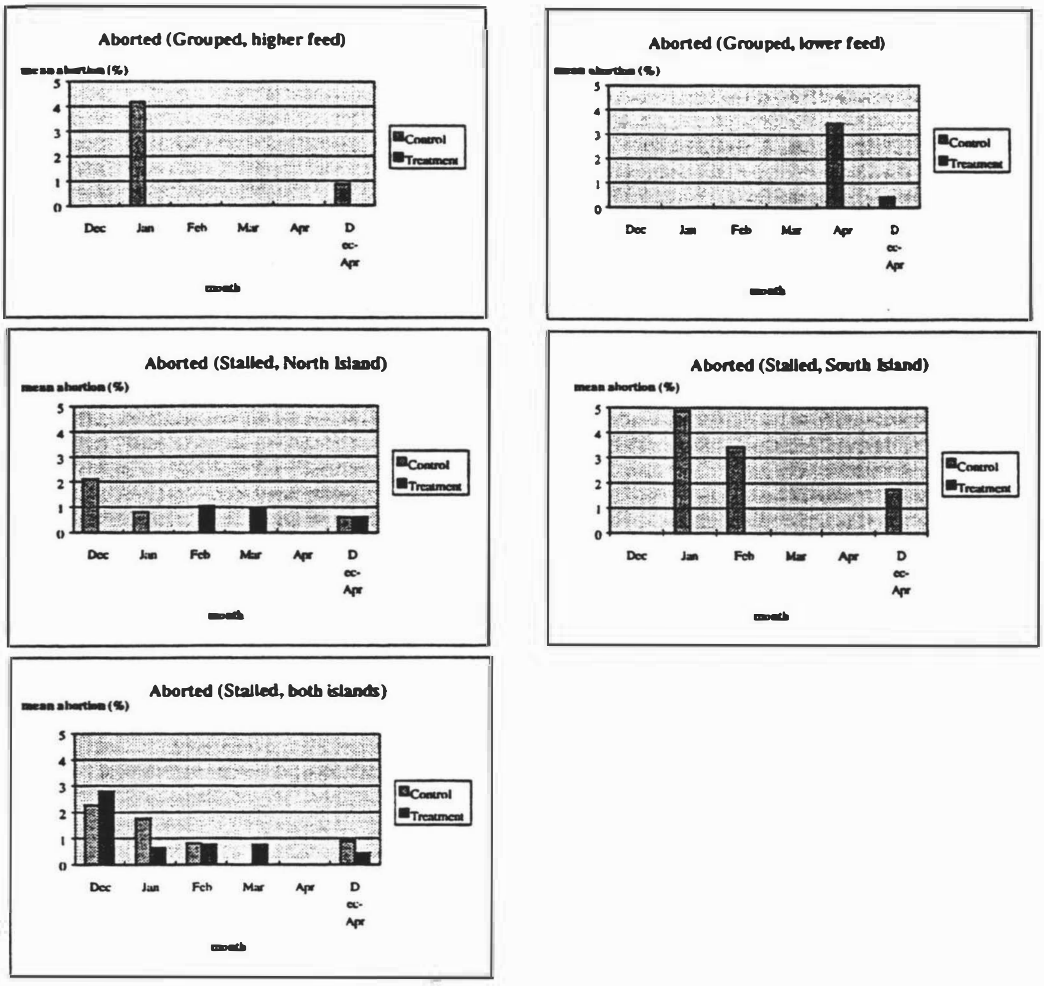


Figure 3-16 suggests that abortions were not clearly associated with either housing or feeding system.

The individual undesirable reproductive outcomes have not been analyzed statistically, because statistical power was too low with the numbers of observations available.

To increase the power of analysis the possible of reproductive outcome categories were grouped as follows:

IP = mate → implant → irregular return, late return, abortion

NP = mate → not implant → regular return

OT = mate → not farrowed at due date, removed

Far = mate → farrowed

Chi-squared analysis was used to compare percentages of the four aggregated reproductive outcome categories with controls. Statistically significant differences as indicated in Table

3-29 were found for stall-housed pigs in the North Island during January (control > treatment) and for stall-housed pigs in both islands (control > treatment); and during March statistically significant differences were detected in group-housed lower feed category, the stall-housed North Island category, and the stall-housed both islands category.

Table 3-29: Count (percentage) of farrowed, IP, NP, or OT gilts/sows stratified by housing/feeding system and month

			Dec-Apr	Dec	Jan	Feb	Mar	Apr
Gr. H	Far	Con	81 (69.83)	29 (64.44)	13 (54.17)	17 (89.47)	14 (87.5)	8 (66.67)
		Treat	60 (70.59)	10 (45.45)	18 (81.82)	15 (78.95)	16 (94.12)	10 (71.43)
	IP	Cont	16 (13.79)	7 (15.56)	7 (29.17)	1 (5.26)	1 (6.25)	0 (0)
		Treat	4 (4.71)	3 (13.64)	0 (0)	0 (0)	0 (0)	1 (7.14)
	NP	Cont	16 (13.79)	9 (20)	3 (12.5)	1 (5.26)	1 (6.25)	2 (16.67)
		Treat	14 (16.47)	7 (31.82)	4 (18.18)	2 (10.53)	0 (0)	1 (7.14)
	OT	Cont	3 (2.59)	0 (0)	1 (4.17)	0 (0)	0 (0)	2 (16.67)
		Treat	7 (8.24)	2 (9.09)	0 (0)	2 (10.53)	1 (5.88)	2 (14.29)
Gr. L	Far	Cont	163 (71.81)	25 (58.14)	38 (71.7)	34 (68)	42[d] (80.77)	24 (82.76)
		Treat	142 (70.65)	29 (64.44)	29 (67.44)	27 (77.14)	26 (57.78)	31 (93.94)
	IP	Cont	6 (2.64)	1 (2.33)	1 (1.89)	2 (4)	0 (0)	2 (6.9)
		Treat	10 (4.98)	3 (6.67)	4 (9.3)	0 (0)	3 (6.67)	0 (0)
	NP	Cont	35 (15.42)	10 (23.26)	9 (16.98)	8 (16)	6 (11.54)	2 (6.9)
		Treat	31 (15.42)	5 (11.11)	6 (13.95)	7 (20)	11 (24.44)	2 (6.06)
	OT	Cont	23 (10.13)	7 (16.28)	5 (9.43)	6 (12)	4 (7.69)	1 (3.45)
		Treat	18 (8.96)	8 (17.78)	4 (9.3)	1 (2.86)	5 (11.11)	0 (0)

Gr. H = grouped pigs, higher feed; Gr. L = grouped pigs, lower feed; St. N = stalled pigs, North Island farms; St. S = stalled pigs, South Island farms; St. B = stalled pigs, both islands; d = χ^2 7.88, p-value of 0.049

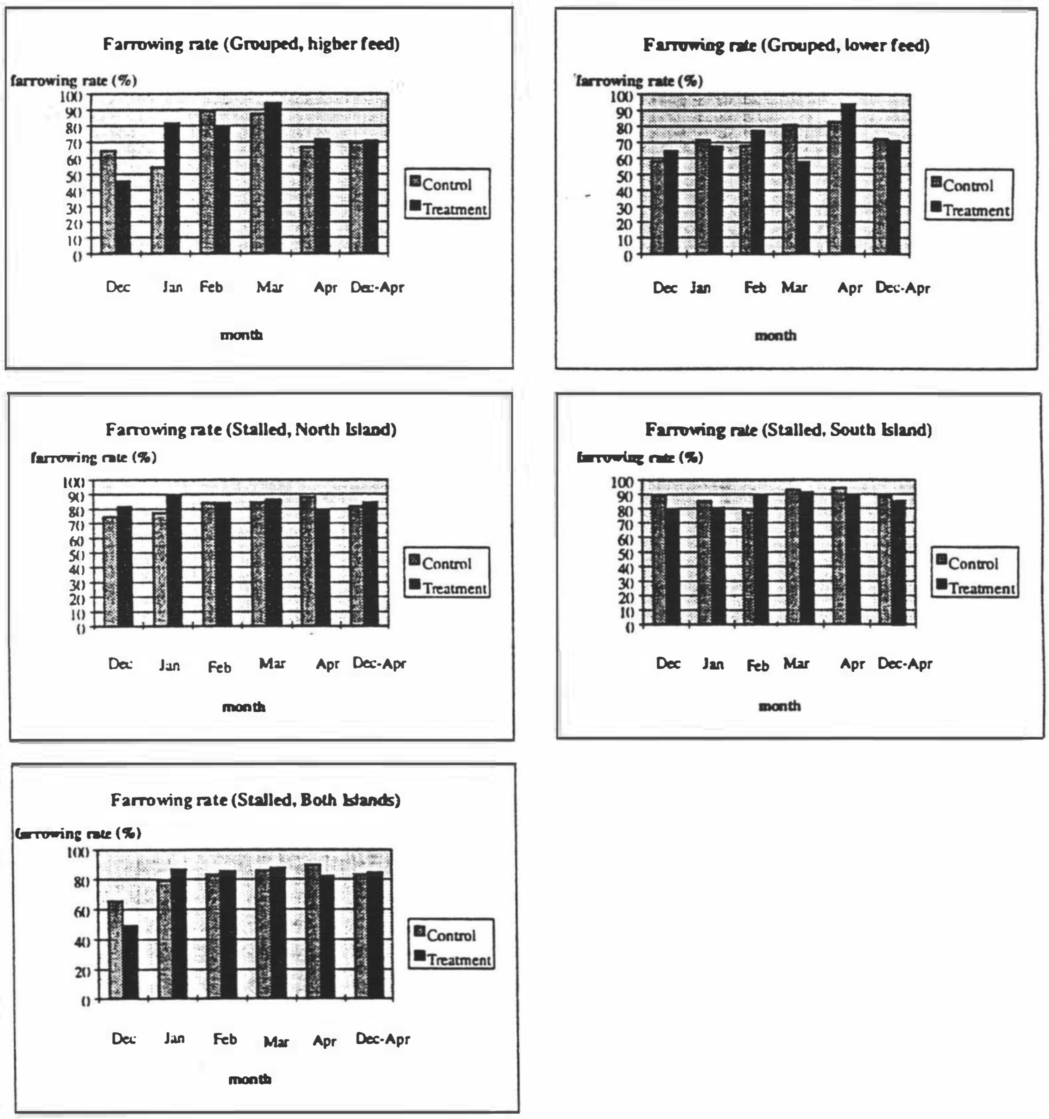
Table 3-29 (continued)

			Dec-Apr	Dec	Jan	Feb	Mar	Apr
St. N	Far	Con	404 (81.29)	71 (74.74)	96[b] (77.42)	79 (84.04)	78[e] (83.87)	80 (87.91)
		Treat	421 (84.2)	84 (81.55)	97 (88.99)	80 (84.21)	88 (86.27)	72 (79.12)
	IP	Cont	45 (9.05)	14 (14.74)	18 (14.52)	3 (3.19)	7 (7.53)	3 (3.3)
		Treat	26 (5.2)	3 (2.91)	3 (2.75)	7 (7.37)	5 (4.9)	8 (8.79)
	NP	Cont	22 (4.43)	7 (7.37)	5 (4.03)	5 (5.32)	1 (1.08)	4 (4.4)
		Treat	31 (6.2)	12 (11.65)	5 (4.59)	2 (2.11)	7 (6.86)	5 (5.49)
	OT	Cont	26 (5.23)	3 (3.16)	5 (4.03)	7 (7.45)	7 (7.53)	4 (4.4)
		Treat	22 (4.4)	4 (3.88)	4 (3.67)	6 (6.32)	2 (1.96)	6 (6.59)
St. S	Far	Cont	152 (88.37)	33 (88.19)	35 (85.37)	23 (79.31)	28 (93.33)	33 (94.29)
		Treat	158 (85.41)	29 (78.38)	33 (80.49)	31 (88.57)	32 (91.43)	33 (88.19)
	IP	Cont	13 (7.56)	2 (5.41)	5 (12.2)	5 (17.24)	1 (3.33)	0 (0)
		Treat	15 (8.11)	7 (18.92)	4 (9.76)	1 (2.86)	2 (5.71)	1 (2.7)
	NP	Cont	5 (2.91)	2 (5.41)	1 (2.44)	1 (3.45)	0 (0)	1 (2.86)
		Treat	9 (4.86)	1 (2.7)	1 (2.44)	3 (8.57)	1 (2.86)	3 (8.11)
	OT	Cont	2 (1.16)	0 (0)	0 (0)	0 (0)	1 (3.33)	1 (2.86)
		Treat	3 (1.62)	0 (0)	3 (7.32)	0 (0)	0 (0)	0 (0)
St. B	Far	Con	556 (83.11)	104[a] (65.41)	131[c] (79.39)	102 (82.93)	106 (86.18)	113 (89.68)
		Treat	579 (84.53)	113 (49.13)	130 (86.67)	111 (85.38)	120 (87.59)	105 (82.03)
	IP	Cont	58 (8.67)	26 (16.35)	23 (13.94)	8 (6.5)	8 (6.5)	3 (2.38)
		Treat	41 (5.99)	40 (17.39)	7 (4.67)	8 (6.15)	7 (5.11)	9 (7.03)
	NP	Cont	27 (4.04)	22 (13.84)	6 (3.64)	6 (4.88)	1 (0.81)	5 (3.97)
		Treat	40 (5.84)	53 (23.04)	6 (4)	5 (3.85)	8 (5.84)	8 (6.25)
	OT	Cont	28 (4.19)	7 (4.4)	5 (3.03)	7 (5.69)	8 (6.5)	5 (3.97)
		Treat	25 (3.65)	24 (10.43)	7 (4.67)	6 (4.62)	2 (1.46)	6 (4.69)

Gr. H = grouped pigs, higher feed; Gr. L = grouped pigs, lower feed; St. N = stalled pigs, North Island farms; St. S = stalled pigs, South Island farms; St. B = stalled pigs, both islands; b = χ^2 9.91, p-value of 0.019; c = χ^2 8.17, p-value of 0.043; e = χ^2 7.81, p-value of 0.0499

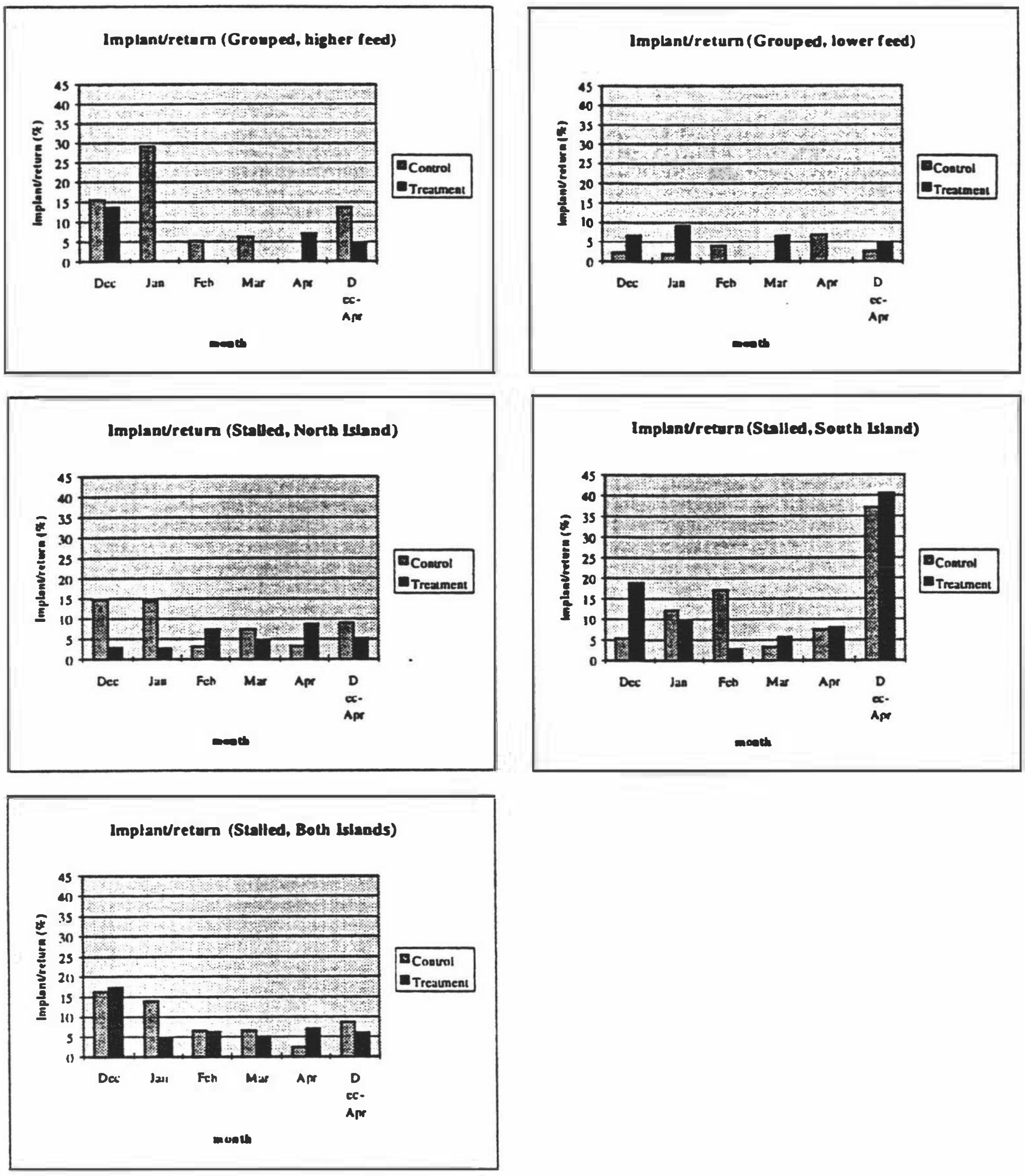
A statistical association between reproductive outcome and treatment status was found for the group-housed lower feed level category during the month of March (percentages for undesirable outcomes greater in treatment groups), for the stall housing category in the North Island during the months of January and March (percentages of undesirable outcomes greater in control groups).

Figure 3-17: Barcharts showing farrowing rates by months and treatment status, stratified by housing/feeding systems



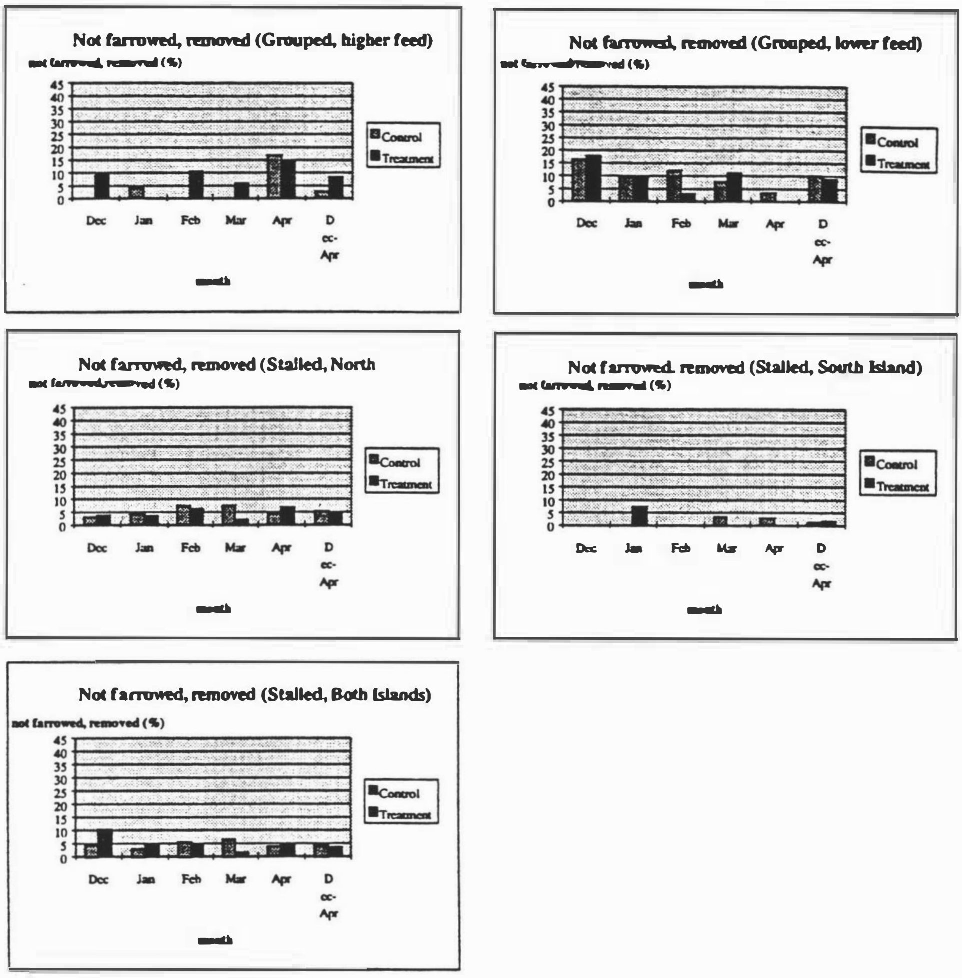
Visual examination of Figure 3-17 suggests that farrowing rates were lower in December than in the other months in grouped pigs and in stalled pigs when including farms from both islands. Pigs managed in stalls had higher farrowing rates than group-housed pigs. In grouped pigs fed the higher level of feed, farrowing rate was the lowest in December.

Figure 3-18: Barcharts showing percentages of "implant/return" pigs by month and treatment status stratified by housing/feeding systems



It can be suggested from Figure 3-18 that there was no clear pattern of occurrence across the study with regard to "implant/return" pigs.

Figure 3-19: Barcharts showing percentages of "not farrowed at due time" pigs by month and treatment status, stratified by housing/feeding systems



"not farrowed" = gilts/sows which did not farrow at due time, removed = gilts/sows removed because of reproductive reason (anoestrus, silent oestrus)

Overall "not farrowed" or removed pigs were found most commonly in the group housing pigs fed lower level of feed (Figure 3-19). However there are no marked differences between groups.

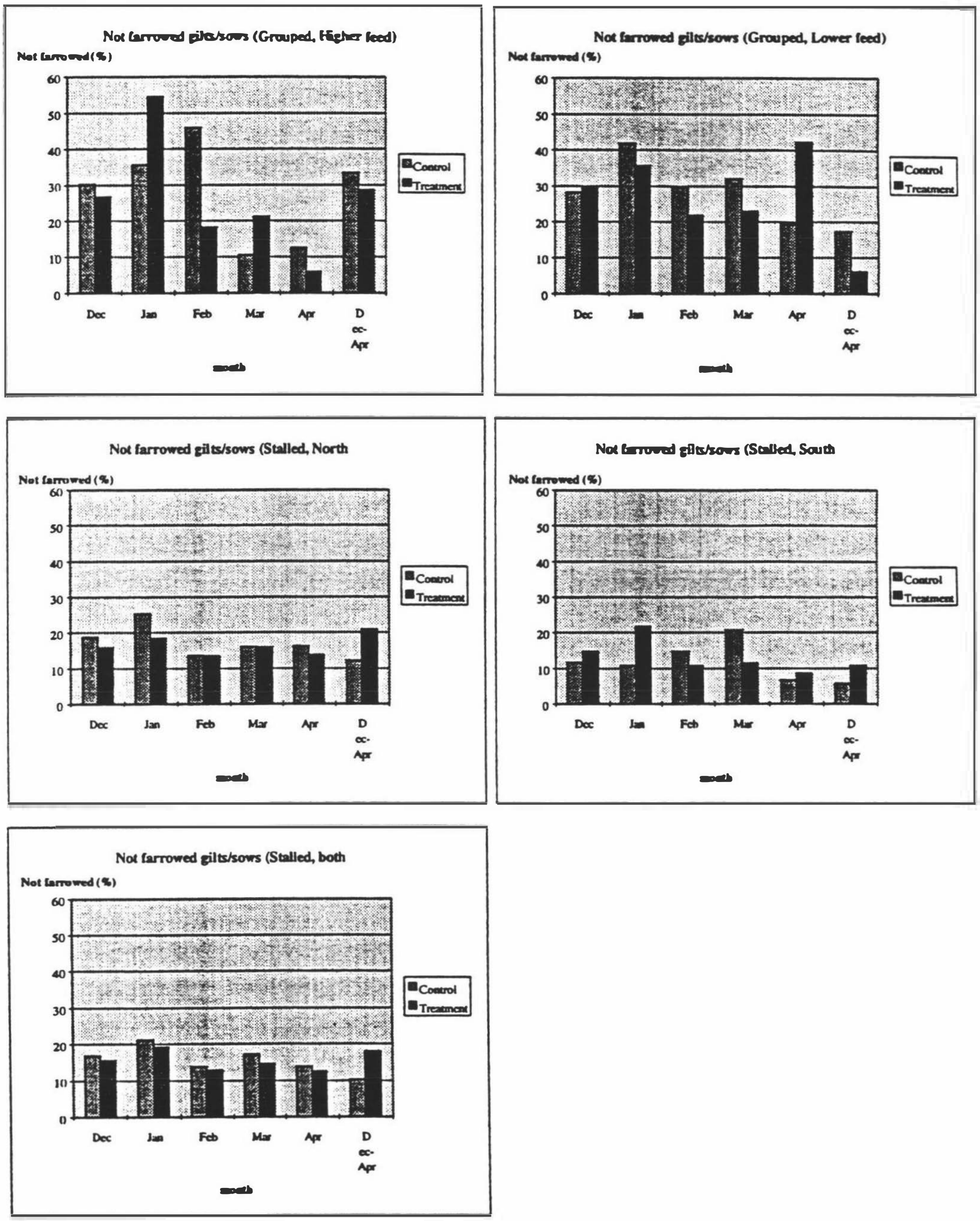
To further increase the power for additional analyses, the animals were aggregated again into "farrowed" and "not farrowed" sows.

Table 3-30: Counts of pigs which farrowed and did not farrow, with Chi-squared value and p-value from Chi-squared analysis, by housing/feeding system, month and control or treatment group

		Farrowed VS Not farrowed											
		Dec-Jan		Dec		Jan		Feb		Mar		Apr	
		Far	NotFar	Far	NotFar	Far	NotFar	Far	NotFar	Far	NotFar	Far	NotFar
Gr. H	Cont	81	35	29	16	13	11	17	2	14	2	8	4
	Treat	69	25	10	12	18	4	15	4	16	1	10	4
	χ^2 (p)	0.33	(0.57)	2.2	(0.13)	24	(.047)	0.29	(0.6)	0.04	(0.8)	0.04	(0.8)
Gr.L	Cont	163	64	25	18	38	16	34	16	42	10	24	5
	Treat	142	59	29	16	29	8	27	8	26	19	31	2
	χ^2 (p)	0.07	(0.8)	0.47	(0.54)	0.73	(0.39)	0.85	(0.4)	6.08	(.014)	1.08	(0.3)
St. N	Cont	404	93	71	24	96	15	79	15	78	15	80	11
	Treat	421	79	84	19	97	15	80	15	88	14	72	19
	χ^2 (p)	1.5	(0.2)	1.85	(0.25)	0	(.979)	0	(.975)	0.22	0.64	2.6	(0.11)
St. S	Cont	152	20	33	4	35	6	23	6	28	2	33	2
	Treat	158	27	29	8	33	4	31	4	32	3	33	4
	χ^2 (p)	0.7	(0.4)	1.59	(0.21)	0.15	(0.7)	0.76	(0.38)	0.11	0.74	0.17	(0.68)
St. B	Cont	556	113	104	28	131	21	102	21	106	17	113	13
	Treat	579	106	113	27	130	19	111	19	120	17	105	23
	χ^2 (p)	0.5	(0.5)	0.16	(0.7)	0.07	(0.8)	0.29	(0.59)	0.11	(0.74)	3.06	(0.08)

Shaded area = housing/feeding system and month for which statistical significant difference was found between control and treatment group using Chi-squared analysis. Gr. H = grouped pigs fed higher level of feed, Gr. L = grouped pigs fed lower level of feed, St. N = stalled pigs in North Island, St. S = stalled pigs in South Island, Cont = control group, Treatment = treatment group, (p) = p-value derived from Chi-square analysis, Far = numbers of pigs which farrowed, Not far = numbers of pigs which did not farrow to service (returned, aborted, removed, did not farrow at due date)

Figure 3-20: Barcharts showing percentages of gilts/sows categorized as "not farrowed" by month and treatment status stratified by housing/feeding system



Significant differences in the percentage of sows not farrowing between treatment groups were detected for March in group-housed pigs on the lower feed level (treatment worse than control), and in January for group-housed higher feed level pigs (treatment better than control) (see Table 3-30 and Figure 3-20).

Farrowing rate

The farrowing rates of treatment group pigs were higher than for the control group during January and February within all feeding/housing categories, but the only statistically significant difference was found in the group-housed higher feed animals in January. In group-housed lower feed animals, the farrowing rate of the treatment group in March was lower than for the control group. (see Table 3-30, Figure 3-20, Table 3-31, and Table 3-32).

Table 3-31: Table summarizing the results of Chi-squared analysis comparing the effect of treatment by month and feeding/housing system

	Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group / higher	☺	☹	☺☺	☺	☺	☺
Group / lower	☹	☺	☺	☺	☹☹	☺
Stall / north	☺	☺	☺	☺	☺	☹
Stall / south	☹	☹	☺	☺	☹	☹
Stall / both	☺	☺	☺	☺	☺	☹

☺ = farrowing rate of treatment pigs is higher than of control pigs., ☹ = farrowing rate of control pigs is higher than of treatment pigs. ☺☺ = farrowing rate of treatment pigs is statistically significant higher than of control group at $p < 0.05$. ☹☹ = farrowing rate of control pigs is statistically significantly higher than of treatment group at $p < 0.05$.

Table 3-32: Counts of gilts/sows mated, farrowing rate (%), farrowing rate differences between control and treatment groups, and p-value of comparison between control and treatment groups using Chi-squared analysis, stratified by housing/feeding system and month

Month	Housing	Control		Treatment		Farrowing rate differences	
		Farrowing rate (%)	No. pigs mated	Farrowing rate (%)	No. pigs mated	absolute difference	P-value
Dec-Apr	Group / higher	69.83	116	73.4	94	3.57	0.568
	Group / lower	71.81	227	70.65	201	-1.16	0.791
	Stall / north	81.29	497	84.2	500	2.91	0.224
	Stall / south	88.37	172	85.41	185	-2.96	0.407
	Stall / both	83.11	669	84.53	685	1.42	0.479
Dec	Group / higher	64.44	45	45.45	22	-18.99	0.139
	Group / lower	58.14	43	64.44	45	6.3	0.544
	Stall / north	74.74	95	81.55	103	6.81	0.245
	Stall / south	89.19	37	78.38	37	-10.81	0.207
	Stall / both	78.19	132	80.71	140	1.92	0.693
Jan	Group / higher	54.17	15	81.81	22	27.64	0.047
	Group / lower	70.37	54	78.38	37	8.01	0.394
	Stall / north	86.49	111	86.61	112	0.12	0.979
	Stall / south	85.37	41	89.19	37	3.82	0.698
	Stall / both	86.18	152	87.25	149	1.07	0.786
Feb	Group / higher	89.47	19	78.95	19	9.48	0.589
	Group / lower	68	50	77.14	35	9.14	0.357
	Stall / north	80.04	94	84.21	95	4.17	0.975
	Stall / south	79.31	29	88.57	35	9.26	0.38
	Stall / both	82.93	123	85.38	130	2.45	0.59
Mar	Group / higher	87.5	16	94.12	17	6.62	0.842
	Group / lower	80.77	52	57.78	45	-22.99	0.014
	Stall / north	83.87	93	86.27	102	2.4	0.638
	Stall / south	93.33	30	91.43	35	-1.9	0.736
	Stall / both	86.18	123	87.59	137	1.41	-
Apr	Group / higher	66.67	12	71.43	14	4.76	0.842
	Group / lower	82.76	29	93.94	33	11.18	0.299
	Stall / north	87.91	91	79.12	91	-8.79	0.11
	Stall / south	94.29	35	89.19	37	-5.1	0.683
	Stall / both	89.68	126	82.03	128	-7.65	0.08

Shaded cells indicate statistically significant difference at $p < 0.05$.

Housing

To examine the association between feeding/housing with farrowing performance, only the control group was compared between the different feeding/housing categories.

Statistically significant differences were found when comparing the adjusted NPD of the control group between stall-housed pigs in the North Island and stall-housed pigs in the South Island for the whole period. Significant differences were also found between average adjusted NPD's of group-housed pigs with higher feed level, group-housed pigs with lower feed level and stall-housed pigs in both islands; and among all four groups when considered over the whole period of the study (December-April). There were also some differences in individual months. (see Table 3-33 and Table 3-34.)

Table 3-33: Means (95% confidence limits) and medians for adjusted non-productive sow days of control gilts/sows in different housing/feeding systems and months

Month	Adjusted NPD of control group	Group / high	Group / low	Stall / north	Stall / south	Stall / both
Dec-Apr	Mean (95% CL)	20.897 (15.44-26.36)	22.93 (18.3-27.58)	19.86 (16.88-22.83)	13.65 (9.99-17.29)	18.28 (15.87-20.68)
	Median	6	6	6	6	6
Dec	Mean (95% CL)	23.16 (14.19-32.12)	31.09 (18.29-43.9)	22.41 (15.5-29.33)	11.62 (5.55-17.69)	19.49 (14.17-24.81)
	Median	6	6	6	6	6
Jan	Mean (95% CL)	28.79 (14.16-43.43)	21.36 (12.09-30.62)	23.6 (16.81-30.4)	18.73 (8.24-29.23)	22.39 (16.71-28.08)
	Median	6	6	6	6	6
Feb	Mean (95% CL)	8.74 (4.7-12.77)	25.78 (15.03-36.53)	16.95 (10.93-22.96)	17 (7.36-26.64)	16.96 (11.89-22.02)
	Median	6	6	6	6	6
Mar	Mean (95% CL)	10.81 (3.02-18.6)	17.96 (9.27-26.65)	20.09 (12.71-24.46)	8.87 (4.26-13.48)	17.35 (11.63-23.07)
	Median	6	6	6	6	6
Apr	Mean (95% CL)	29.33 (.24-58.43)	17.72 (5.8-29.65)	14.85 (8.96-20.73)	11.14 (2.91-19.37)	13.82 (9.04-18.59)
	Median	6	6	6	6	6

Table 3-34: Results of the comparison of non-productive sow days (NPD) for sows between the control group of housing/feeding systems for different months using Kruskal-Wallis ANOVA

Compared categories	p-value for NPD (control group)					
	Dec-Apr	Dec	Jan	Feb	Mar	Apr
Group / high Group / low	0.757	0.549	0.1156	0.0601	0.0514*	0.268
Stall / north Stall / south	0.0002*	0.0643	0.3019	0.6397	0.16	0.3144
Group / high Group / low Stall / north Stall / south	0.0002*	0.0193*	0.1014	0.0926	0.439	0.1029
Group / high Group / low Stall / both	0.0004*	0.0311*	0.0744	0.0446*	0.65	0.068

Shaded cells indicate p-value < 0.05

Relationship between farrowing rates and potential risk factors

Stepwise logistic regression was used to investigate the relationship between farrowing rates and the following potential risk factors, location (North Island, South Island), farm (10 farms), treatment status, and mating period (December 1994 - April 1995). Variables were included in the model if their regression coefficients were significant at a p-value of less than 0.05.

Table 3-35: Final logistic regression model for the effect of parity, farm, housing, and location on farrowing probability

	Const.	*Parity*	*Farm E*	*Farm F*	*Farm J*	*Farm G*	*Housing*	*Location*	*Dec-Jan*
Estimate	3.15	-1.01	-1.23	0.52	1.04	-1.75	-1.09	0.74	-0.38
Std. Err.	0.27	0.181	0.32	0.23	0.35	0.28	0.28	0.24	0.118
p-level	0.00	0.00	0.00013	0.022	0.003	0.00	0.0001	0.002	0.0014

χ^2 = 157.87 (df = 9); p = <0.001; N = 1989
Independent variables : farrowed or not farrowed
Dependent variables (dummy variable) : housing system = group (0) or stall (1), location = North Island (0) or South Island (1), treatment group = control (0) or treatment (1), month of December-January (1) and the other months of the study period (0), and parities of 0 - 6 (0) or 7 - 15 (1)

The final logistic regression model presented in Table 3-35 implies that farrowing probability decreases if sows have more than 6 parities. Farm E, F, J, and G had farrowing rates which were different from the other 6 farms. Farrowing probability was lower in stall housing compared with group housing farms. Farms in the South Island had higher farrowing rates than farms in the North Island. Farrowing rate in December and January was lower than during the other months.

Using the same analytical technique, separate analyses were conducted for each of the three feeding/housing system categories group-housed higher feed level, presented in Table 3-36, Table 3-37, and Table 3-38.

Table 3-36: Final logistic regression model for the effect of parity, farm, housing, and location on farrowing probability, only in group-housed pigs fed at higher feed level

	Constant	*Parity*	*Dec-Feb*
Estimate	2.692	-0.7	-0.842
Std. Err.	0.598	0.335	0.386
p-level	0.00001	0.01	0.03

χ^2 = 10.88 (df = 2); p = 0.004; N of farrowed = 150; N of "not farrowed" = 60

In group-housed pigs fed higher feed levels, older parities and the December to February matings resulted in lower farrowing rates than younger parity sow and the March to April matings (Table 3-36).

Table 3-37: Final logistic regression model for the effect of parity, farm, housing, and location on farrowing probability, only in group-housed pigs fed at lower feed level

	Constant	*Parity*	*Dec-Feb*
Estimate	1.252	-0.018	-0.489
Std. Err.	0.351	0.225	0.23
p-level	0.0004	0.937	0.034

χ^2 = 4.7 (df = 2); p = 0.095; N of farrowed = 305; N of "not farrowed" = 123

In group-housed pigs fed lower feed level, older parity sows and December to February matings resulted in lower farrowing rates than younger parity sows and March to April matings (Table 3-37).

Table 3-38: Final logistic regression model for the effect of parity, farm, housing, and location on farrowing probability, only in stall-housed pigs

	Constant	*Parity*	*Farm B*	*Farm D*	*Dec-Feb*
Estimate	2.842	-1.146	0.364	0.956	-0.333
Std. Err.	0.387	0.332	0.185	0.258	0.16
t (1980)	7.341	-3.452	1.968	3.709	-2.085
p-level	<0.001	0.001	0.049	<0.001	0.037

$\chi^2 = 37.62$ (df = 4); p = <0.001; N of farrowed = 1134; N of "not farrowed" = 219

In stall-housed pigs, older parity sows and mating in December to February resulted in lower farrowing rates than younger parities and March to April matings. Farm B and D had farrowing rates different from the other 8 farms (Table 3-38).

Treatment status was not included in any of the final logistic regression models of farrowing probabilities.

Discussion

Supplying extra feed (2.5 *vs* 3 kg of feed in stalled pigs and 2.5 *vs* 3.5 kg or 3.5 *vs* 4.5 kg of feed in grouped pigs; 12.5 MJ/kg of feed) to pigs had no benefit in improving summer/autumn reproduction in 10 breeding herds in New Zealand. Pigs housed in stalls had lower adjusted non-productive sow days and higher farrowing rates. The adjusted NPD and farrowing rate were lower in December than in the later months of the trial. This is contrary to the findings of others (Hurtgen and Leman, 1980; Love, 1993), that summer/autumn infertility affects pigs mostly in late summer and in autumn.

This trial was conducted in herds where summer/autumn infertility was considered to have been a problem prior to the trial year. In contrast to some other countries, seasonal infertility is considered to be an irregular problem in New Zealand, and to be more marked in the South Island than the North Island. The lowest level of dry sow feeding which could be found in potential cooperating herds in New Zealand which had a reported history of seasonal infertility was already high (2.5 kg/12.5 MJ/kg of feed, 31.25 MJ DE/sow/day for both stalled pigs and grouped pigs) when compared with the basal level of feed in the original experiment by Love *et al* (1995) (1.6 kg of 13.6 MJ/kg feed, 21.76 MJ DE/sow/day). The higher level of feed in the Australian trial was 47-50 MJ DE/sow/day, whereas the higher level of feed in this trial was 3.0 kg/sow/day (37.5 MJ DE/sow/day) for stalled pigs and either 3.5 kg/sow/day (43.35 MJ DE/sow/day) or 4.5 kg/sow/day (56.25 MJ DE/sow/day) for grouped pigs. Herds with group-housed sows which fed a basal ration of 3.5 kg had reported summer-autumn infertility, as well as those feeding the lower level.

In this set of trials the results agreed with those of Love *et al* (1995) that there was no clear difference in reproductive performance between sows fed about 31 MJ DE/day and those fed at higher levels. It was not possible in this trial to use a lower feed quantity than this, since farmers considered this the minimum acceptable amount, and believed that summer-autumn infertility occurred under these conditions. No clear evidence of summer-autumn infertility was detected in sows used in this trial, although there were occasional groups of sows which returned to oestrus after extended intervals. It is concluded that in the summer-autumn period when this study took place, there was no clear evidence of infertility, and no clear evidence of a useful response to feed supplementation. While some results were statistically significant, the large number of analyses conducted could be expected to produce a number of results just based on sampling error, and none of the significant results appeared to be of importance, when viewed in the context of the overall study.

Zearalenone results on feed samples were all negative, showing that at least in this particular season on these farms, there was not a problem of zearalenone intoxication, which could confuse a diagnosis of summer-autumn infertility.

Stall-housed pigs had better reproductive performance than group-housed pigs, which is consistent with the experience of Hurtgen and Leman (1980), Love *et al.* (1993), Klupiec (1994) and Love *et al* (1995). Thus it does appear that group-housing is a risk factor in the South Island of New Zealand for reduced fertility over the summer-autumn period when the trial took place.

Love (1993) explains that crowding has a negative effect on oestrus expression in mature pigs. This effect can be balanced by the presence of males resulting in an appropriate ratio of males to females. Not more than 20 females per group is recommended (Love 1993). In the Australian trial, group sizes were 22-23 sows/group (2 square metres per sow), whereas in this trial, pigs in groups were kept outdoors (except one indoor farm which showed a good performance) and the group sizes were 8-14 for 2 farms (farm F and I), 20-30 for 2 farms (farm H and gilts in J), 100 (farm G) and 150 (sows in J). The area per sow was more than 100 square metres per sow except in farm K, an indoor farm where 4 square metres per sow were provided. The temperature was not recorded.

Most of the returns to oestrus were regular returns. Gilts and sows in the group housing system had lower abortion rates then stall-housed pigs, but this may be because of the difficulty of detecting abortions in group-housed gilts/sows. Gilts and sows in group housing had lower late returns than in the stall housing system. However, interpretation of this result is complicated by the fact that in the group housing system, "catch" boars were put in the mated gilts and sows paddock to catch any return-to-oestrus by gilts and sows, whereas in stall-housed gilts and sows, the return to oestrus detection was dependent on the farmers' skills. Percentages of "not farrowed" at due time pigs (pseudopregnancy, anoestrus) were higher in the group-housing than in the stall-housing system because the anoestrous pigs in the group-housing system were more difficult to detect than in individual stall pigs. Group-housed pigs were kept in large paddocks which made it difficult to detect pregnancy if farmers did not take a close look at the pigs. Removal percentages of stall-housed pigs were on the other hand higher than in group-housed pigs as the anoestrous gilts and sows were detected earlier and culled. The irregular return, late return, and abortion gilts and sows were catgeorised as "embryo implanted yet returned", and anoestrous or pseudopregnant gilts and sows, and removed gilts and sow were catgeorised as others. It was found that stall-housed gilts and sows in the South Island had the highest implanted and return proportion. The "return, abort, anoestrous, removed" gilts and sows were catgeorised as "not farrowed" and it was found that group-housed gilts and sows had higher "not farrowed" than stall-housed gilts and sows.

In December-April, apart from regular returns, return gilts and sows were mostly categorized as late return (47-108 days after mating) in all housing/feeding systems except in group-housing fed lower levels of feed. In this category, returning gilts and sows were mainly in the pseudopregnancy/anoestrous group. The late return gilts and sows might be the 2nd round irregular return gilts and sows, in which the first oestrus was missed. This agrees with the findings of Leman (1986), Reilly and Roberts (!991) and Love (1993) that increasing returns to oestrus occur 25-35 days after mating in summer/autumn, named irregular returns in this report. Wrathall *et al.* (1986) and Love (1993) explain that irregular returns are caused by the disruption of pituitary support in the form of LH, which supports corpora lutea function for the first 14 days after mating, and causes delayed return to oestrus (25-35 days after mating). Either failure of maintenance of the corpora lutea or failure of effective occupancy of receptors to the 2nd signal of oestrogen from embryos leads to delayed return to oestrus.

Melatonin increase in food-restricted sows (60% of *ad libitum* intake) during summer/autumn (Love 1993) possibly was not different between the treatment groups in this trial, as the lowest amount of feed in the control group in this trial was 0.9 kg (9 MJ DE) more than the lowest amount of feed in Love's (1993) trial.

Reducing stress is recommended in summer/autumn infertility problem farms. Pigs need to be fed at a moderate feed level (2.5 kg of feed, 12.5 MJ DE/kg) to prevent extremely low or high feed intake. Group-housed pigs should not be kept at more than 20 pigs per group to reduce the effect of a more complex behavioural hierarchy. Good oestrous detection with good pregnancy diagnosis are needed and individual gestation stalls should be used if possible.

A comparison of different approaches to summer autumn infertility prevention using economic simulation modeling

The merits of particular interventions to control seasonal infertility (additional feed, stalling of sows, etc.) from the viewpoint of a pig farmer will depend not just on whether there is a statistical difference between groups, but also whether the farmer can have confidence that the change will produce a net financial benefit in comparison with simply allowing sows to take longer to farrow (higher non-productive days). In order to carry out such analyses, a standard form of economic analysis was used so that the expected effect of various interventions and the variability in outcome could be evaluated. Since the results of the trial did not show any production benefit overall in favour of supplemented sows, the economic evaluation cannot be expected to show a gain. However the procedure developed for the purpose is illustrated here using the data for each of the farms, in order to demonstrate how the economic benefit of any future control methods could be evaluated using this economic analytical approach.

A stochastic spreadsheet simulation model was developed to simulate the economics of modifying reproductive performance for intensive pig farms. The spreadsheet programme Microsoft Excel for Windows version 5.0 was used as the development environment and the add-in software @Risk version 3 (Palisade Software) provided the stochastic and analytical functionality. The model represents a partial farm budget for change in net income, and is based on the parameters describing reproductive performance. Each simulation run consisted of 300 iterations using latin hypercube sampling for random number generation. The results of individual simulations were presented as histogram distributions.

The importance of various individual simulation parameters was assessed using sensitivity analysis based on a multivariate regression analysis with input distributions of model parameters as independent variables and distributions of output parameters as dependent variables. The regression coefficients for each input variable provide a quantitative estimate of the sensitivity of the output to that particular input distribution. The coefficients displayed at the end of each bar of the tornado graphs are the standardized beta coefficients estimated using regression analysis (@Risk version 3 manual, 1994).

Model structure

The variable ***net income*** is subject to stochastic effects as a result of random variation built into the various parameters represented in the model.

The model structure describes the sequence of events occurring during a sow's parity, beginning with weaning and ending with the subsequent weaning or culling of gilts/sows, and follows the litter produced by this parity from birth until slaughter at the bacon stage. The structure of the model used for gilts/sows is based on the events which can occur during the reproductive cycle of sows and is presented in Figure 3-21. If a sow returns after the first service, then a decision has to be made whether she is to be remated or culled. A remated sow follows the same cycle again. It is assumed that culled sows are replaced by the same number of gilts. The @Risk distribution functions used to describe random variation in parameters defining reproductive performance in the models are presented in Table 3-39.

The model for growing pigs represents the events occurring during the period from birth until they reach market at the bacon stage. The number of pigs born alive is subsequently reduced by pre-weaning mortality, weaner mortality, and grower mortality until the growing pigs reach finisher stage. A schematic outline of the grower model component is provided in Figure 3-22. The main economic output variables from the model are two variables: net income (benefit) from selling bacon pigs per sow for both the control and treatment group, and additional income representing increased income from adopting the extra dry sow feeding programme.

The parameter values for each of the treatment groups with respect to sow numbers, the distributions for days to return and litter sizes were directly derived from the actual information collected during the feeding trial on the different farms. This means that every simulation was performed specifically for the local situation on particular farms.

Table 3-39: Distribution functions used to generate farm-specific random pig populations

Function	*Name of input variables*	*Distribution*	*Input*	*Probability*
Generate sow population distribution	No. of sows returning during days 10-17 (early return)	Binomial	No. of sows mated	Prob. of return days 10-17
	No. of sows returning during days 18-25 (regular return)			Prob. of return days 18-25
	No. of sows returning during days 26-37 (irregular return)			Prob. of return days 26-37
	No. of sows returning during days 38-46 (regular return)			Prob. of return days 38-46
	No. of sows returning during days 47-108 (late return)			Prob. of return days 47-108
	No. of sows returning during days 109-120 (not-in-pig)			Prob. of return days 109-120
Generate distribution of pigs born alive	No. pigs born alive = 0	Binomial	No. of sows farrowed	Prob. of pigs born alive = 0
	No. pigs born alive = 1			Prob. of pigs born alive = 1
	No. pigs born alive = 2			Prob. of pigs born alive = 2
	No. pigs born alive = 3...20			Prob. of pigs born alive = 3...20
	No. pigs born alive = 21			Prob. of pigs born alive = 21
Generate distribution of days open	Total days open, days 10-17	Uniform	No. of sows farrowed	Prob days 10-17
	Total days open, days 18-25			Prob days 18-25
	Total days open, days 26-37			Prob days 26-37
	Total days open, days 38-46			Prob days 38-46
	Total days open, days 47-108			Prob days 47-108
	Total days open, days109-120			Prob days 109-120

RiskUniform is used in the calculation for risk of return to oestrus in a range of days open during days 10-17, 18-25, 26-37, 38-46, 47-108, or 109-120 as gilts and/or sows are considered having the same chance of one of the days in a particular range.
Days open = days between mating and day found not pregnant. Days open range has a maximum returning of 120 as gilts/sows should not be open for more than 120 days.
min = minimum; max = maximum

The values for the distributions other than population parameters used in the model are presented in Table 3-40. The only difference between the control and treatment group was the amount fed in dry sow rations.

Table 3-40: Variables used for calculation of partial budget economics for gilts/sows and other pigs

Function	*Parameter*	*Functions and values*
General parameters for sows/gilts	Weaning to service interval (days)[1]	Normal distribution (mean =5, sd = 1)
	Gestation length (days)	114
	Lactation length (days)	Normal distribution (mean = 26, sd = 1)
Feed parameters for sows/gilts	Dry sow ration per sow per day for stall feeding farms (kg)	• Control group : 2.5 kg for the whole dry sow period • Treatment group : 3 kg for the first 28 days post-service and 2.5 kg after 28 days post-service
	Dry sow ration per sow per day for group housing farms with lower feed level (kg)	• Control group : 2.5 kg for the whole dry sow period • Treatment group : 3.5 kg for the first 28 days post-service and 2.5 kg after 28 days post-service
	Dry sow ration per sow per day for group housing farms with higher feed level (kg)	• Control group : 3.5 kg for the whole dry sow period • Treatment : 4.5 kg for the first 28 days post service and 3.5 kg after 28 days post-service
	Dry sow feed cost per kg ($)[1]	Normal distribution (mean = 0.375, sd = 0.005)
	Dry sow feed cost per sow per day ($)	Dry sow ration per sow per day X dry sow feed cost per kg
	Lactation sow ration per sow per day[1]	Normal distribution (mean = 4.9, sd = 0.25)
	Lactation feed cost per sow per day ($)[1]	Normal distribution (mean = 0.425, sd = 0.005)
	Lactation feed cost per sow per day ($)	Lactation sow ration per sow per day X lactation feed cost per sow per day
Culling rate and return sows	Chopper weight (kg)[1]	150
	Chopper meat return per kg[1]	Uniform distribution (min = 2.6, max = 2.95)
	Risk for culling 1st time return sows (proportion) (best estimated)	Normal distribution (mean = 0.2, sd = 0.05)
	Risk for culling 2nd time return sows (Proportion) (all culled)	1
	Sows return, not culled and mated again	No. sows returns X (1-rate for culling return sows)
Mortality in pigs other than gilts/sows	Pre-weaning mortality[1] (%)	Normal distribution (mean = 12.8, sd = 1.5)
	Piglet survival to weaning (proportion)	(100 - preweaning mortality)/100
	Total pigs weaned	Total pigs born alive X piglet survival to weaning
	Grower & finisher mortality[1] (%)	Normal distribution (mean = 2, sd = 0.5)
	Grower & finisher survival (proportion)	(100 - grower & finisher mortality)/100
	Total numbers of growers & finishers	Total pigs weaned X growers & finishers survival

sd = standard deviation

Table 3-40 (continued)

	Variables	*Functions and value*
General parameters for pigs other than sows/gilts	Average creep feed eating period (days)[a]	21
	Average starter feed eating period (days)[a]	21
	Average weaner feed eating period (days)[a]	30
	Average weaner age (days)	70
	Average growth rate of pork (kg/days)[1,b]	0.75
	Average growth rate of bacon (kg/days)[1,b]	0.85
	Average pork live weight (kg)[b]	57 (from dressed pork weight/dressed percentage = 43/0.79)
	Average bacon live weight (kg)[c]	100
	Average pork age to market (day)	Pork live weight/growth rate of pork
	Average bacon age to market (day)	Bacon live weight/growth rate of bacon
Feed rations and costs for pigs other than sows/gilts	Pork meat returns per kg ($)[1,d]	2.83
	Bacon meat returns per kg ($)[1,d]	2.78
	Creep feed ration per piglet per day (kg)[3,c]	0.002
	Creep feed cost per kg ($)[1,c,e]	0.6975
	Creep feed cost per piglet per day ($)	Creep feed ration per piglet per day X creep feed cost per kg
	Total creep feed cost ($)[1]	Creep feed cost per piglet per day X No. pigs born alive X creep feed eating period
	Starter feed ration per piglet per day (kg)[3,b]	0.4
	Starter feed cost per kg($)[1,c,e]	0.52365
	Starter feed cost per piglet per day ($)	Starter feed ration per piglet per day X starter feed cost per kg
	Total starter feed cost ($)[1]	Starter feed cost per piglet per day X No. pigs born alive X starter feed eating period
	Weaner feed ration per pig per day (kg)[1,c]	1.2
	Weaner feed cost per kg ($)[1,c,e]	0.4448
	Weaner feed cost per pig per day ($)	Weaner feed ration per pig per day X weaner feed cost per kg
	Total weaner feed cost ($)	Weaner feed cost per pig per day X No. pigs wean X weaner feed eating period
	Grower feed ration per pig per day (kg)[1,b]	2.5
	Grower feed cost per kg ($)[1,c,e]	0.3406
	Grower feed cost per pig per day ($)	Grower feed cost per pig per day X grower feed cost per kg
	Total grower feed cost ($)	Grower feed cost per piglet per day X No. pigs after weaned X grower feed eating period
	Finisher feed ration per pig per day (kg)[1,b]	2.5
	Finisher feed cost per day ($)[1,c,e]	0.3406
	Finisher feed cost per pig per day ($)	Finisher feed cost per pig per day X finisher feed cost per kg
	Total finisher feed cost ($)	Finisher feed cost per piglet per day X No. pigs after weaning X grower feed eating period
Labour, shed cost	Labour cost per sow per day ($)[1,f]	Normal distribution (mean = 1.1, sd = 0.05)
	Shed cost per sow per day ($)[2,f]	Normal distribution (mean = 0.4, sd = 0.001)
Income from finishers & choppers	Value of finishers ($)	Bacon weight X bacon meat return per kg
	Value of choppers ($)	Chopper weight X chopper meat return per kg

1 = values from New Zealand data (in NZ$); 2 = values from Australian data (in NZ$); 3 = values from Canadian data (in NZ$); a = Patience *et al.* (1995); b = Cargill (1995); c = McIntosh (1996); d = Outlook (1995); e = Lysart (1996); f = PigStat (1995)

Table 3-41 describes the functions used to summarize the economic analysis processes leading towards the net income per sow and the additional income from adopting a treatment programme.

Table 3-41: Functions used for partial budget calculation

Name of variables	*Functions*
Total finishers	Total pigs born alive - (preweaning mortality + growers and finishers mortality)
Total days open (for all sows)	Total days open 10-17 + total days open 18-25 +...+ total days open 108-120
Total days open <= 28 days (for all sows in treatment group)*	Total days open 10-17 + total days open 18-25
Total days open > 28 days (for all sows in treatment group)**	Total days open 26-37 + total days open 38-46 + total days open 47-108 + total days open 109-120
Total feed cost wasted ($)	Total days open X dry sow feed cost per sow per day
Total labour cost wasted ($)	Total days open X labour cost per sow per day
Total shed cost wasted ($)	Total days open X shed cost per sow per day
Total feed cost for finishers ($)	Creep feed cost + starter feed cost + weaner feed cost + grower feed cost + finisher feed cost
Total net income	Value of finishers + value of choppers - (total feed cost wasted + total labour cost wasted + total shed cost wasted + Total feed cost for finishers + total feed cost for sows from weaning to subsequent weaning + total labour cost for sows + total shed cost for sows)
Net income per sow	Total net income/No. of sows mated
Additional income per sow	Net income per sow of treatment group - net income per sow of control group

*Total days open <= 28 can be added up to days open 26-37 if there are sows return after 25 days post-service.

**Total days open > 28 is added from days open 38-46 of there are sows return after 25 days post-service

Results

The probability distributions for additional income per sow are presented in Figure 3-23 (see also Table 3-42). A negative average additional income from adopting the dry sow extra feeding programme was estimated for 2 of the stall housing farms (farms D and E), one of the group housing farms with higher feed level (farm H), and one of the group housing farms with higher feed level (farm I). The benefit/cost ratios for individual farms did not change significantly after adopting a treatment programme, as shown in Table 3-43.

Table 3-42: Results of partial budget economic analysis for net income per sow by treatment group and additional income per sow from 300 iterations in @Risk

Housing/level of feed	*Farm*	*Group*	*Minimum*	*Maximum*	*Mean*	*Std. Dev.*	*Variance*	*Expected Value*
Stall-housing	A	Control	1729.22	3216.09	2507.38	256.07	65570.04	2503.2
		Treatment	1549.71	3230.29	2523.5	270.23	73023.05	2520.65
		Additional income	-801.0	732.95	16.13	280.13	78472.31	17.45
	B	Control	1958.42	3881.38	2909.42	298.64	89196.74	2913.51
		Treatment	2182.05	4282.43	3124.43	281.76	73989.9	3128.29
		Additional income	-1090.11	1309.88	210.88	384.06	147505.4	214.79
	C	Control	199.34	2969.39	1273.08	545.62	297705.6	1271.14
		Treatment	-10.81	6933.64	2208.51	1075.87	1157502	2118.76
		Additional income	-2198.1	5851.24	925.18	1236.03	1527768	847.62
	D	Control	1877.73	4016.36	2858.67	3851	148305	2864.29
		Treatment	1456.33	5300.67	2587.34	644.59	415500.3	10673.2
		Additional income	-1743.56	2140.19	-271.33	693.1	480383.4	-365.41
	E	Control	1124.26	4680.43	2621.28	500.18	250175.1	2607.21
		Treatment	1371.7	4359.38	2503.6	494.03	244060.9	2471.04
		Additional income	-1818.99	1787.22	-117.66	650.52	423172.6	-136.17
Group-housing / lower feed level	F	Control	2003.99	4404.23	2936.28	403.18	162556.6	2828.84
		Treatment	2113.62	4307.08	3071.63	430.25	185113.9	3061.81
		Additional income	-1325.05	1771.13	135.35	533.02	284106.6	132.97
	G	Control	110.67	2609.29	820.36	357.77	127999.3	776.89
		Treatment	149.44	3061.12	1185.91	469.31	220249.7	1137.63
		Additional income	-1215.3	1775.15	365.55	568.81	323540.4	360.75
	H	Control	1026.79	4673.48	2837.75	631.91	399315.1	2818.39
		Treatment	1252.55	4850.98	2756.6	661.52	437610.8	2739.36
		Additional income	-2396.64	2112.21	-82.18	870.27	757378.1	-79.03
Group-housing / higher feed level	I	Control	729.01	3742.65	2017.86	601.63	361959.8	1983.99
		Treatment	-345.28	4301.76	1481.49	710.8	505241	1392.06
		Additional income	-3136.66	2350.73	-536.37	914.92	837077.8	-591.93
	J	Control	11290.57	3872.58	2111.15	445.89	198820.7	2092.8
		Treatment	1022.41	3526.11	2179.9	438.67	192432	2168.75
		Additional income	-2204.56	2211.63	68.75	637.04	40582.1	75.95

shaded area = farm's losses from adopting the method of feeding
Expected value = the best estimate value or average value

Table 3-43: Averages for total expense, total income, net income (benefit) and benefit/cost ratio for control and treatment groups for each of the farms

Farm	*Total expense (cost)*		*Total income*		*Net income (benefit)*		*Benefit/cost ratio*	
	Control	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*
A	334028.5	317361.2	821286.9	781273.2	487258.5	463912	1.46	1.46
B	166628.4	187140.5	430554.7	488399.5	263926.3	301258.9	1.58	1.61
C	7308.2	9298.1	17477.3	21429.4	10169.1	12131.4	1.39	1.3
D	105567.2	116503.1	270834.1	292443.2	165266.9	175940.1	1.57	1.51
E	43442.4	56486.5	109134.1	143842.4	65691.7	87355.9	1.51	1.55
F	139358.1	123909.3	386245.9	343670.6	246887.8	219761.3	1.77	1.77
G	56190.2	34111.6	95638.6	66666.9	39448.3	32555.3	0.7	0.95
H	37555.9	38291.4	101391.4	102100.6	63835.5	63809.2	1.7	1.67
I	33329.1	20026.9	77951.01	41976.1	44621.9	21949.1	1.34	1.1
J	74736.7	67728.9	180165.8	158069.7	105429.1	90340.6	1.41	1.33

Total expense (cost) = total feed cost wasted + total labour cost wasted + total shed cost wasted + total feed cost for finishers + total feed cost for sows from weaning to subsequent weaning + total labour cost for sows + total shed cost for sows

The benefit/cost ratio for the treatment group of farm G was higher than for the control group, and the average additional income per sow from adopting this feeding method was $360.75. In contrast, the benefit cost ratio of control group of farm I was higher than for the treatment group (1.34 > 1.1), this farm lost on average $591.93 per sow from adopting this method. The probability distributions for additional income per sow are presented in Figure 3-23, Figure 3-24, and Figure 3-25.

Figure 3-23: Probability distributions of additional income per sow from adopting the treatment programme for gilts/sows for each farm with a stall-housing system

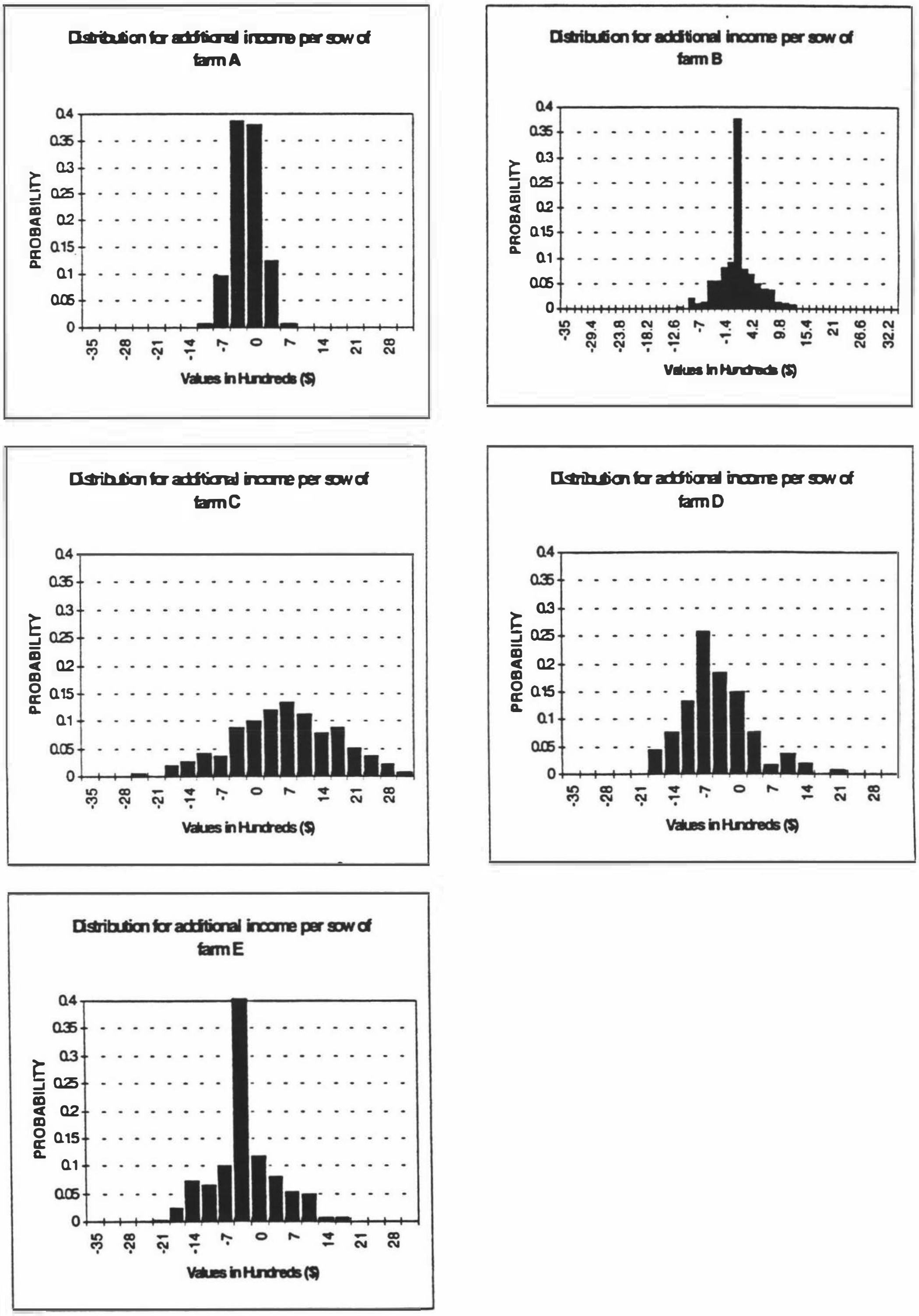
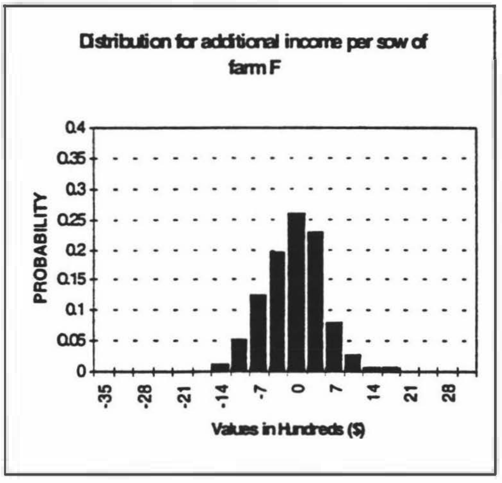
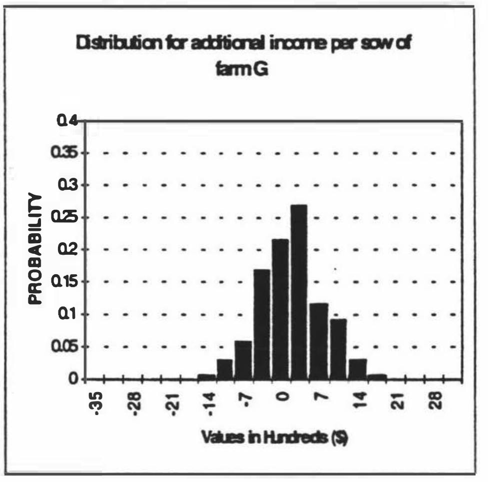


Figure 3-24: Probability distributions of additional income per sow from adopting a treatment programme for gilts/sows for each farm with group-housing system feeding lower feed level





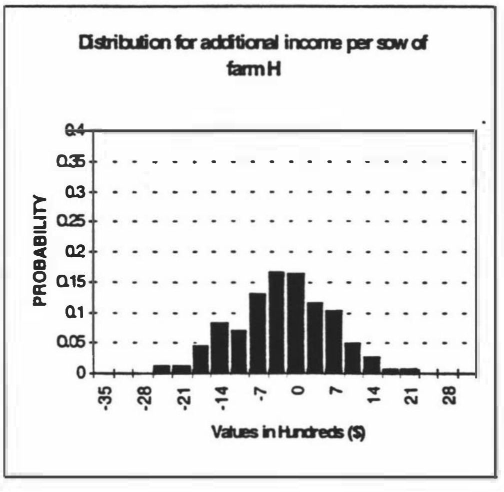
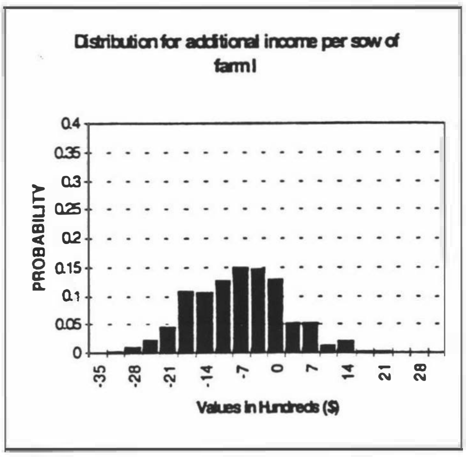
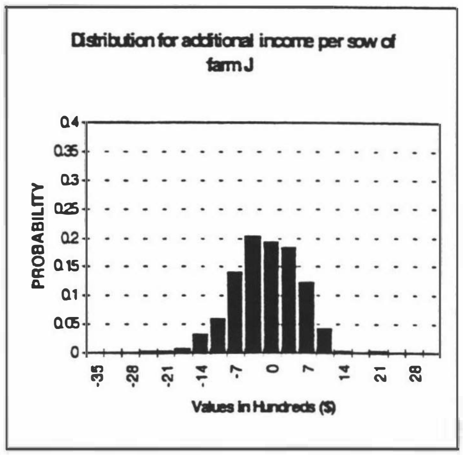


Figure 3-25: Probability distributions of additional income per sow from adopting a treatment programme for gilts/sows for each farm with group-housing system feeding higher feed level





Sensitivity analysis

The sensitivity analysis of the simulation model was conducted for selected farms for each housing systems with the highest and lowest average additional income from adopting the treatment. The codes used to represent the input variable distributions in the tornado graphs summarizing the results from the following regression sensitivity analysis are presented in Table 3-44.

Table 3-44 : Variables used in the partial budget economic analysis models and their definitions

Variables used	*Definitions*
BaconMeatReturnsPerKg	Bacon meat price per kilogram
ChopperPricePerKg	Culled sows meat price return per kilogram
DrySowFeedCost/kg	Dry sow ration cost per kilogram
FeedCostWaste	Total feed cost spent for sows found open
GrowerFinisherMT	Growers and finishers mortality
LabourCostPerSowDay	Labour cost per sow per day
LactationLength	Lactation length
LactFeedCostPerKg	Lactation ration cost per kilogram
No.SowsFarrowed	Total numbers of sows farrowed
No.SowsPigsBorn1	No. sows farrowed with pigs born alive = 1
No.SowsPigsBorn2	No. sows farrowed with pigs born alive = 2...
No.SowsPigsBorn21	No. sows farrowed with pigs born alive = 21
PreWeaningMT	Pre-weaning mortality
ReplacementCostPerGilt	Price of a replacement gilt
ShedCostPerSowDay	Shed cost per sow per day
SowsReturn10-17	No. sows return to service within 10-17 days post-service (early return)
SowsReturn18-25	No. sows return to service within 18-25 days post-service (regular return)
SowsReturn26-37	No. sows return to service within 26-37 days post-service (irregular return)
SowsReturn47-108	No. sows return to service within 47-108 days post-service (late return)
SowsReturn109-120	No. sows return to service within 109-120 days post-service
TotalDaysOpen	Total days open
WeanServInt	Weaning to first service interval

The variables beginning with treat- are the variables used in treatment group with the same definitions as the variables for the control group shown in this table.

The results of the sensitivity analysis by farm are presented in Figure 3-26 to Figure 3-40.

Figure 3-26: Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the control group of farm B (highest average additional income for stall-housing system)

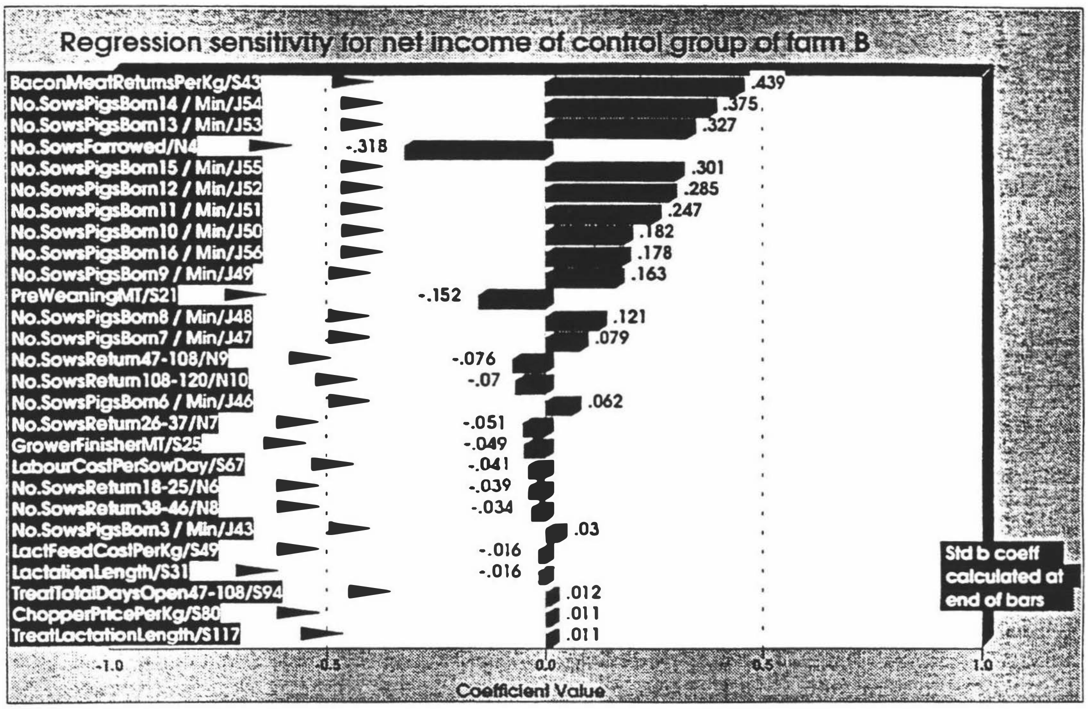


Figure 3-27 : Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the treatment group of farm B (highest average additional income for stall-housing system)

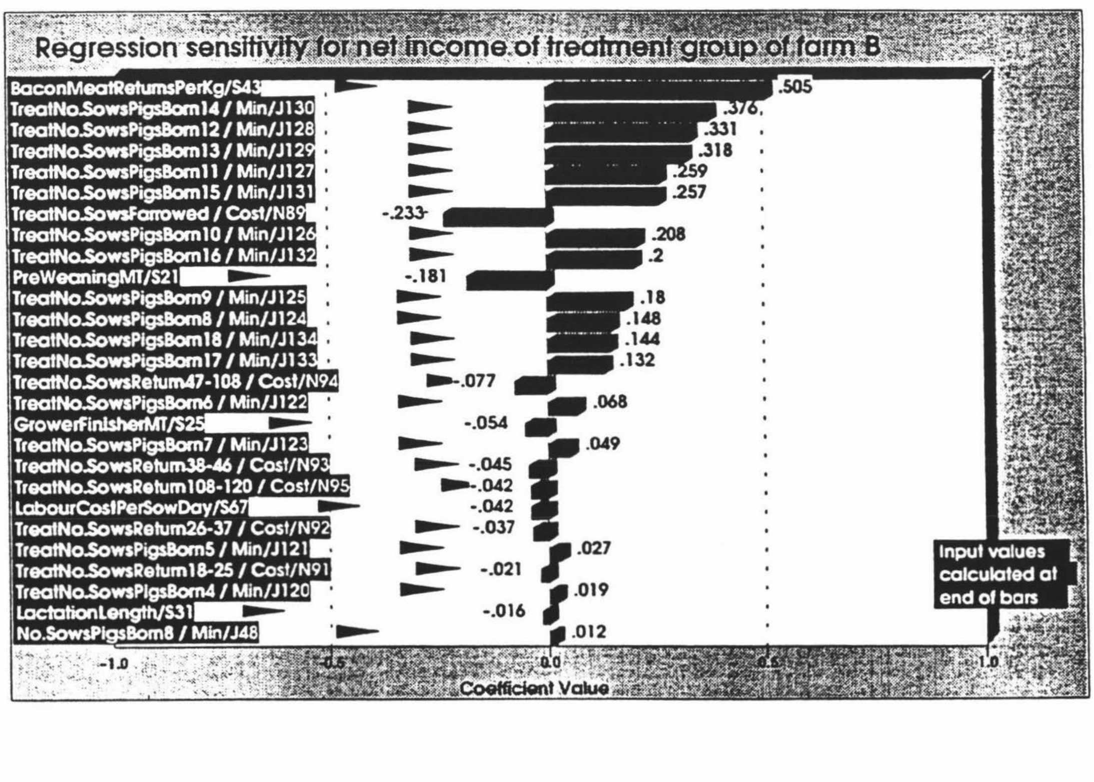


Figure 3-28 : Tornado graph presenting the results of the regression sensitivity analysis for additional income per sow of farm B (highest average additional income for stall-housing system)

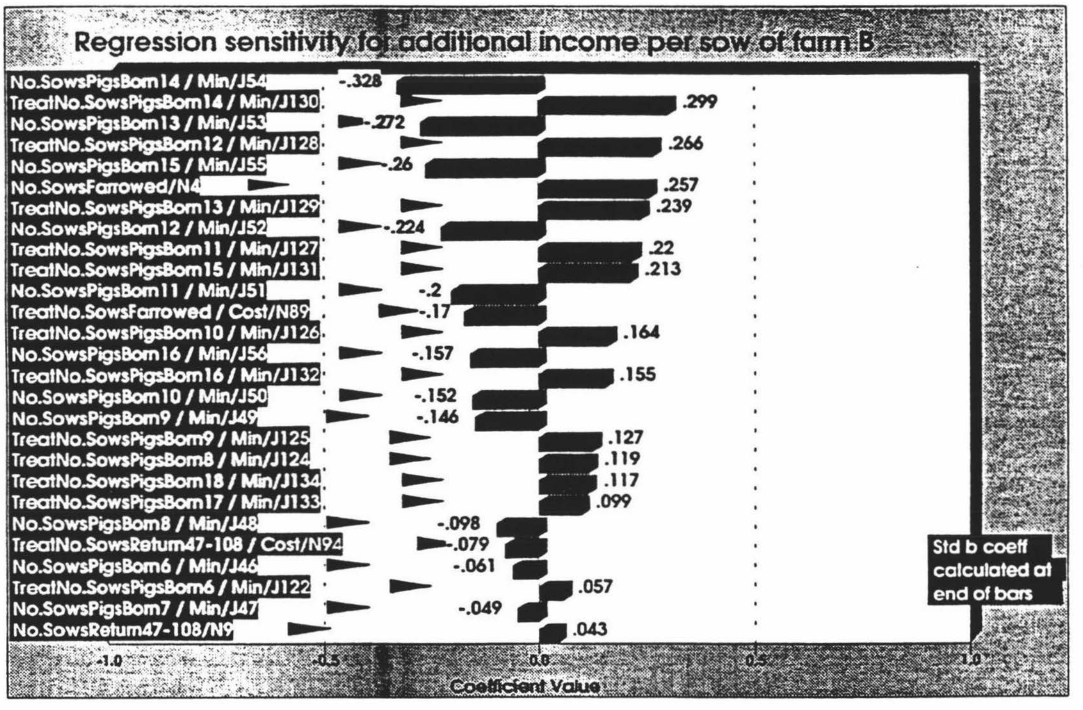


Figure 3-29 : Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the control group of farm D (lowest average additional income for stall-housing system)

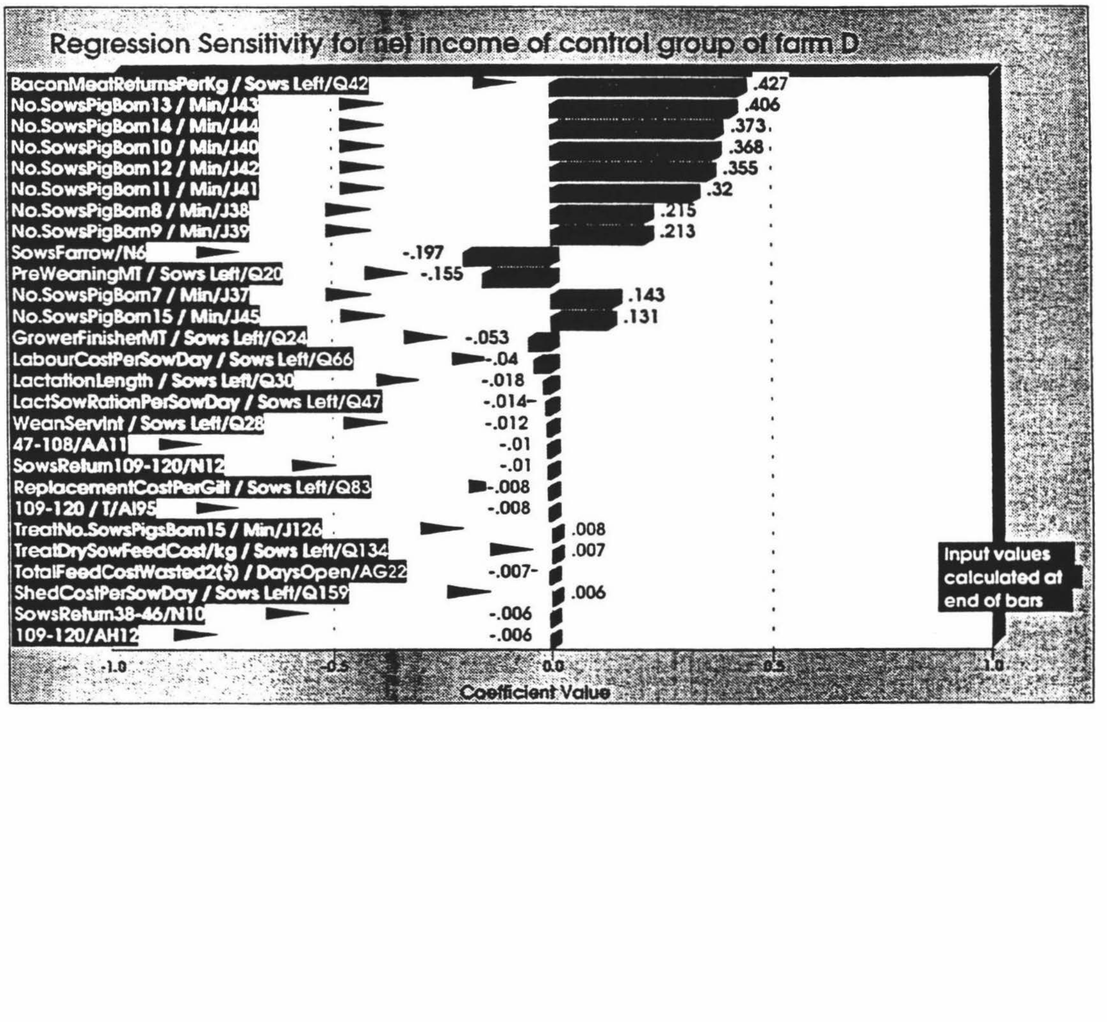


Figure 3-30: Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the treatment group of farm D (lowest average additional income for stall-housing system)

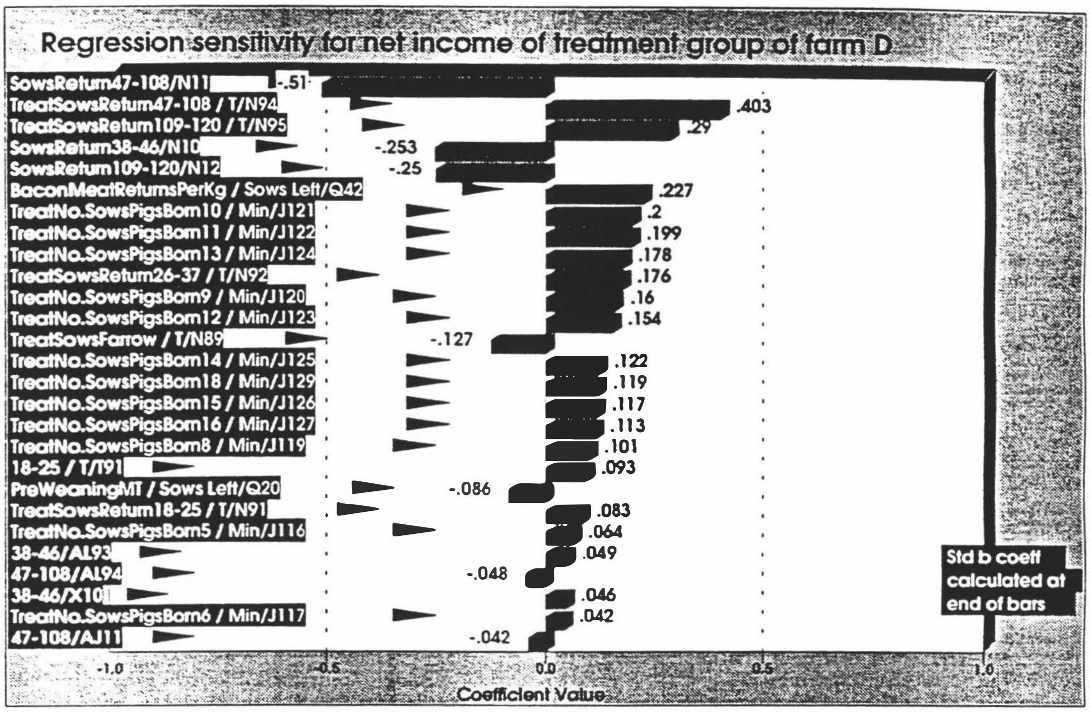


Figure 3-31: Tornado graph presenting the results of the regression sensitivity analysis for additional income per sow of farm D (lowest average additional income for stall-housing system)

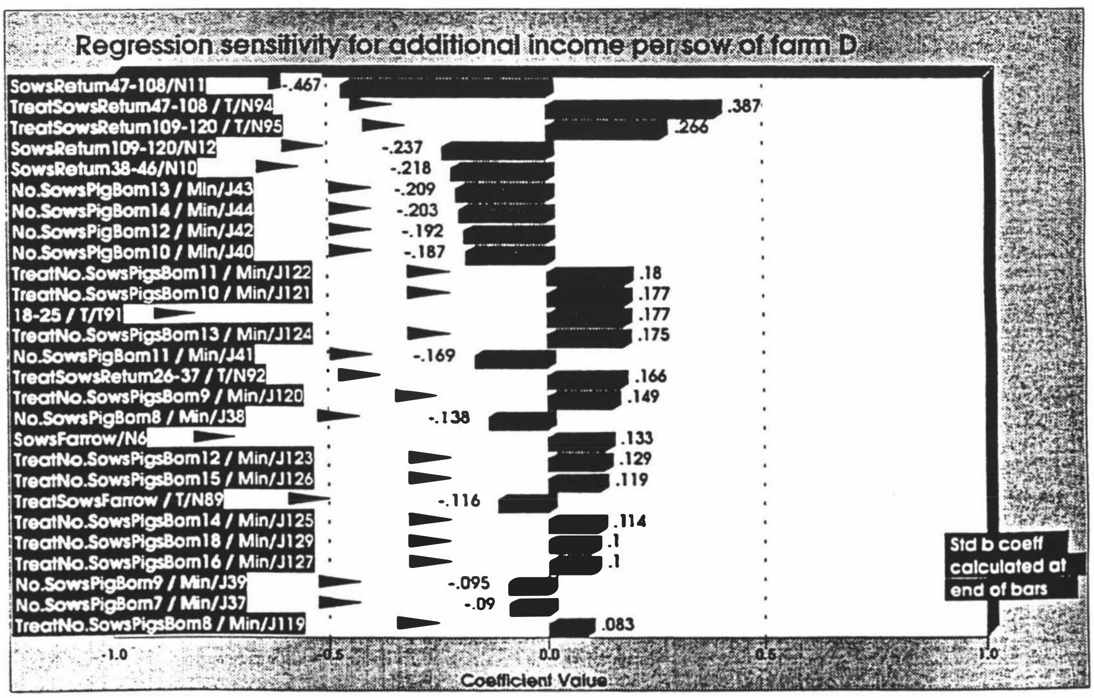


Figure 3-32 : Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the control group of farm G (highest average additional income for group-housing farms feeding lower feed level)

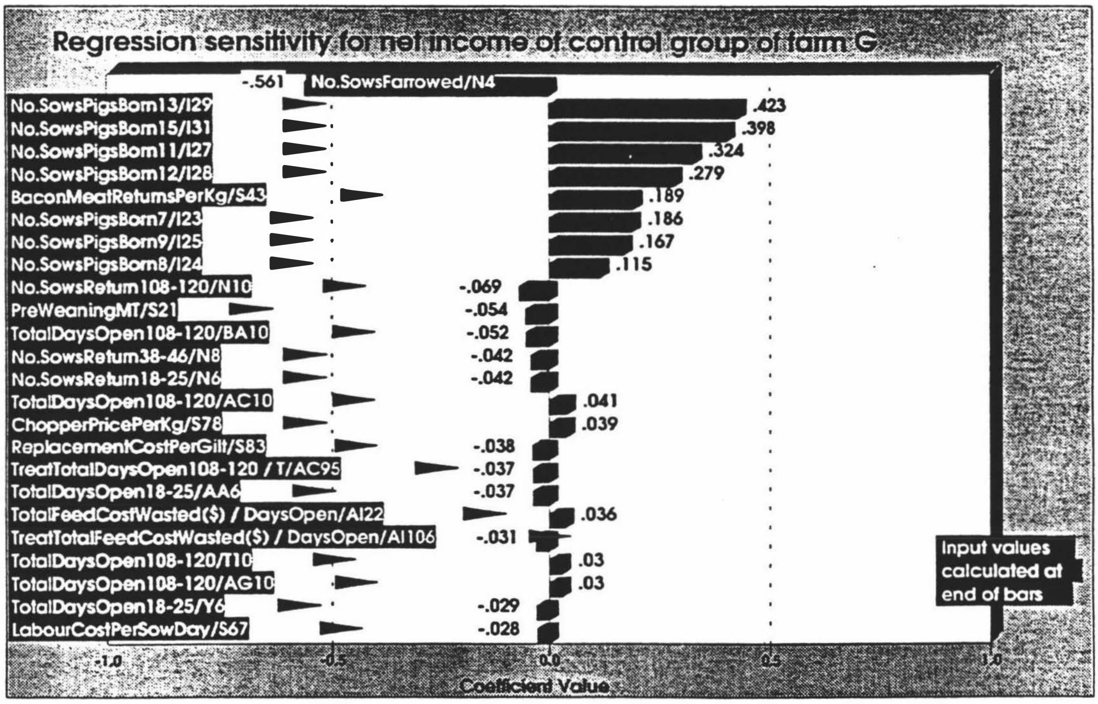


Figure 3-33 : Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the treatment group of farm G (highest average additional income for group-housing farms feeding lower feed level)

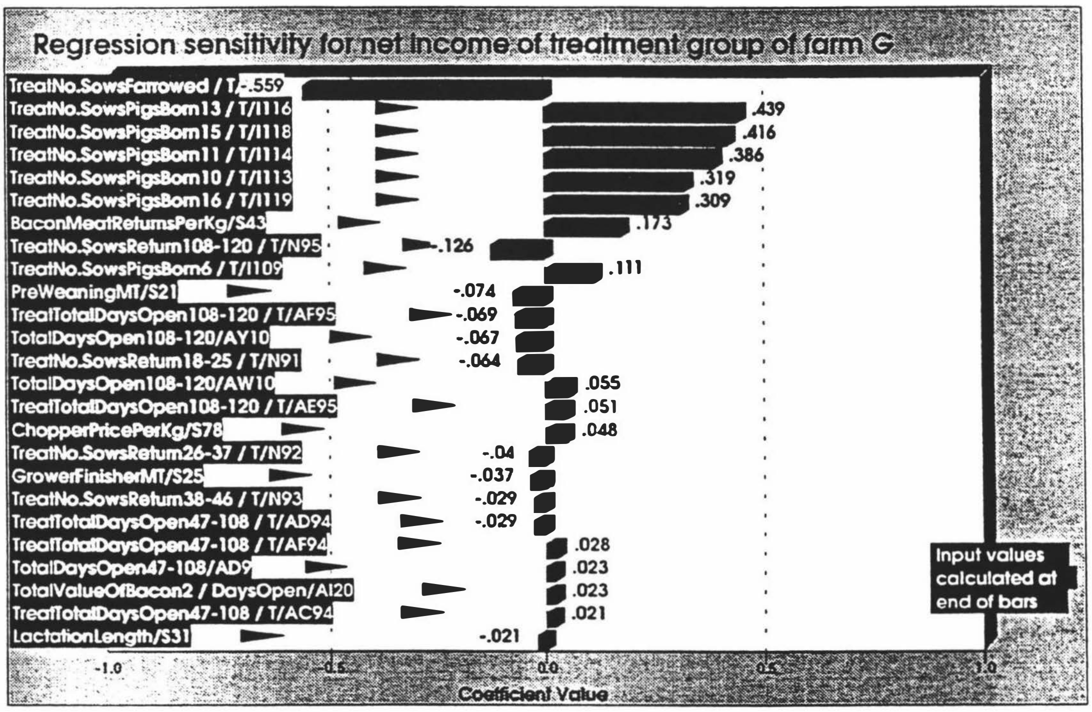


Figure 3-34 : Tornado graph presenting the results of the regression sensitivity analysis for additional income per sow of farm G (highest average additional income for group-housing farms feeding lower feed level)

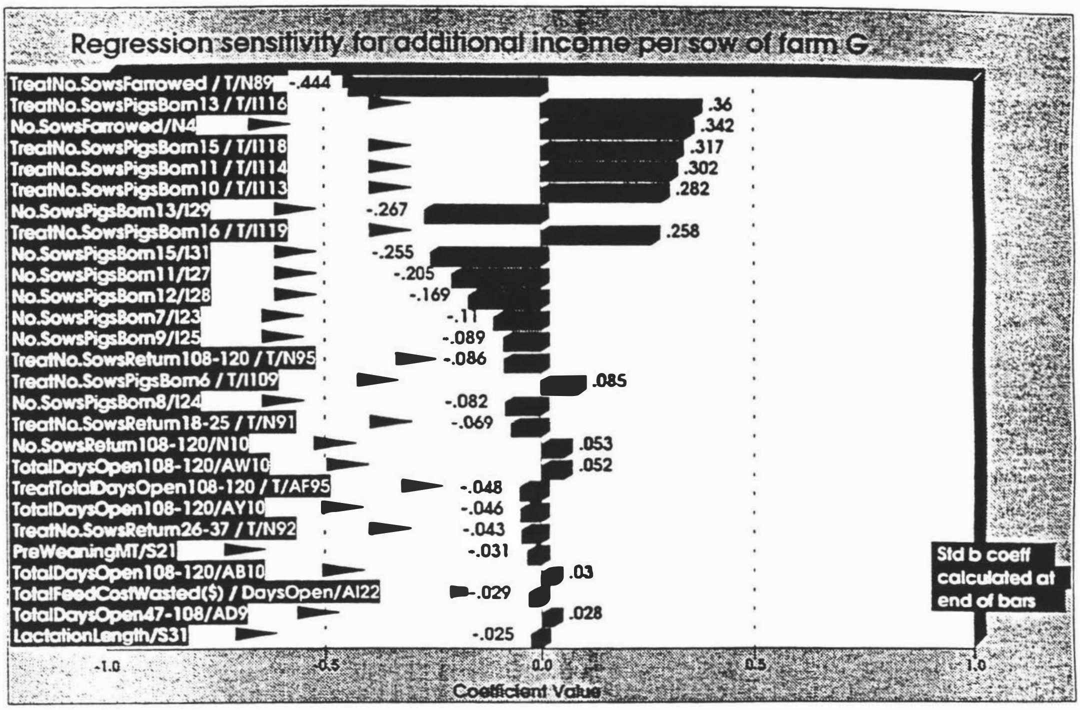


Figure 3-35: Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the control group of farm H (lowest average additional income for group-housing farms feeding lower feed level)

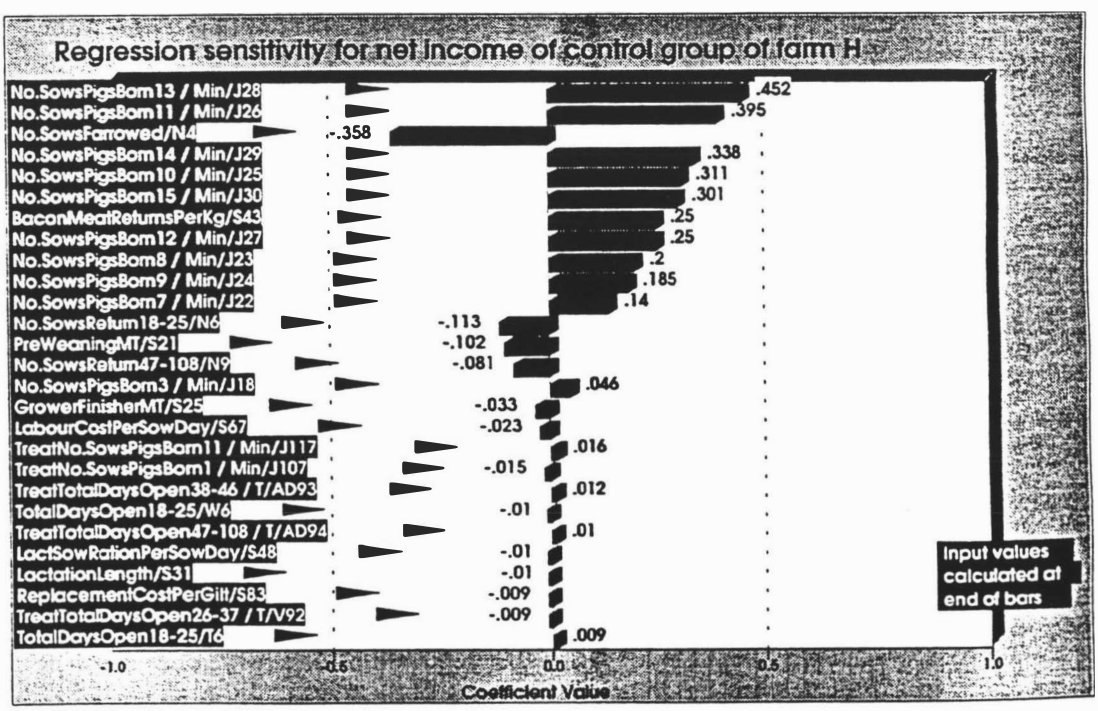


Figure 3-36 : Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the treatment group of farm H (highest average additional income for group-housing farms feeding lower feed level)

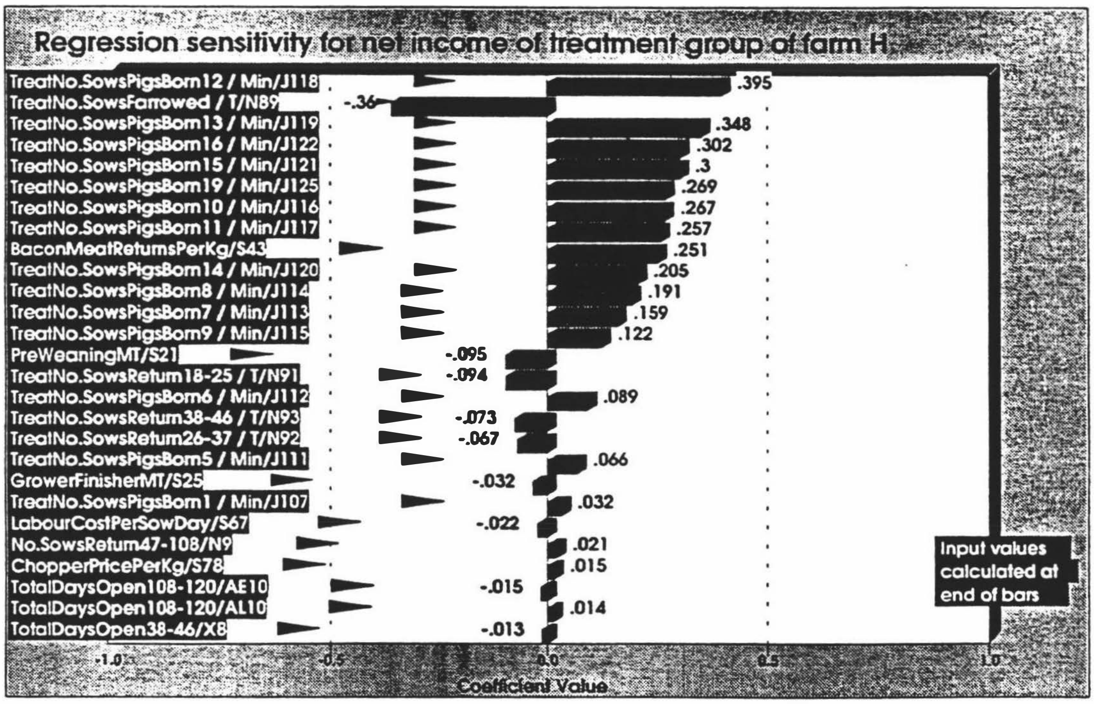


Figure 3-37 : Tornado graph presenting the results of the regression sensitivity analysis for additional income per sow of farm G (highest average additional income for group-housing farms feeding lower feed level)

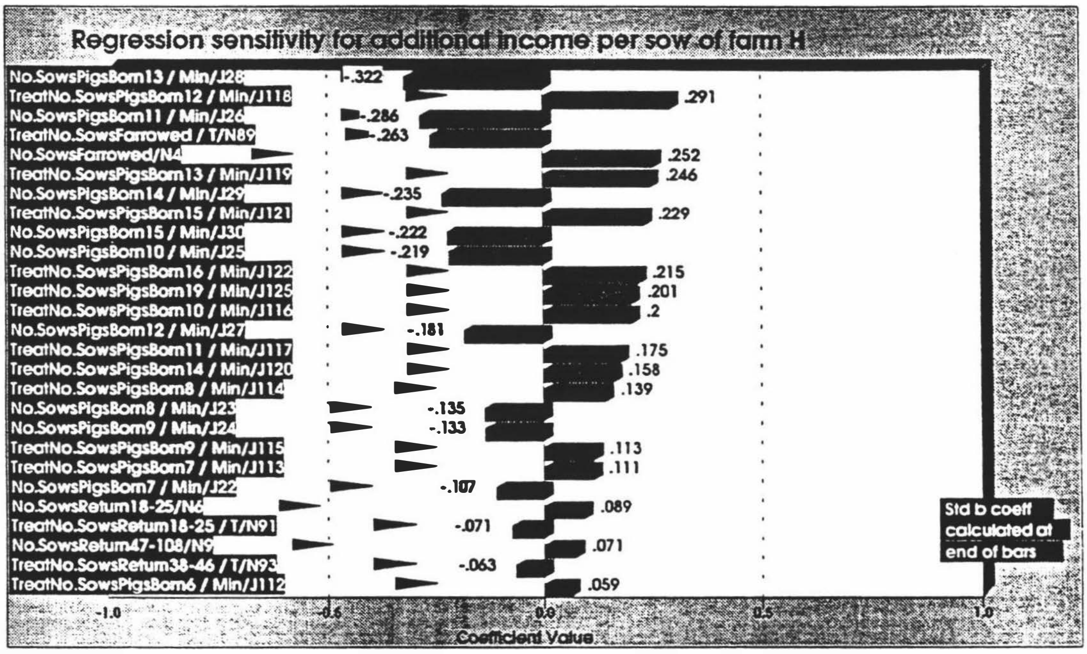


Figure 3-38 : Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the control group of farm J (group-housing farms feeding higher feed level)

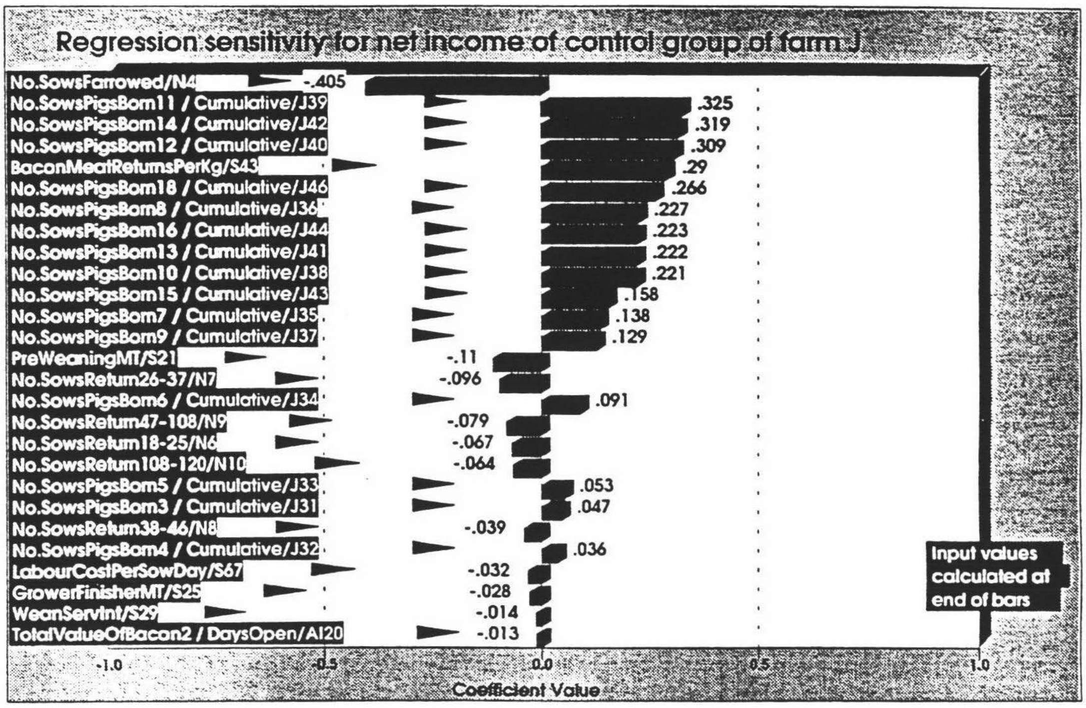


Figure 3-39: Tornado graph presenting the results of the regression sensitivity analysis for net income per sow for the treatment group of farm J (group-housing farms feeding higher feed level)

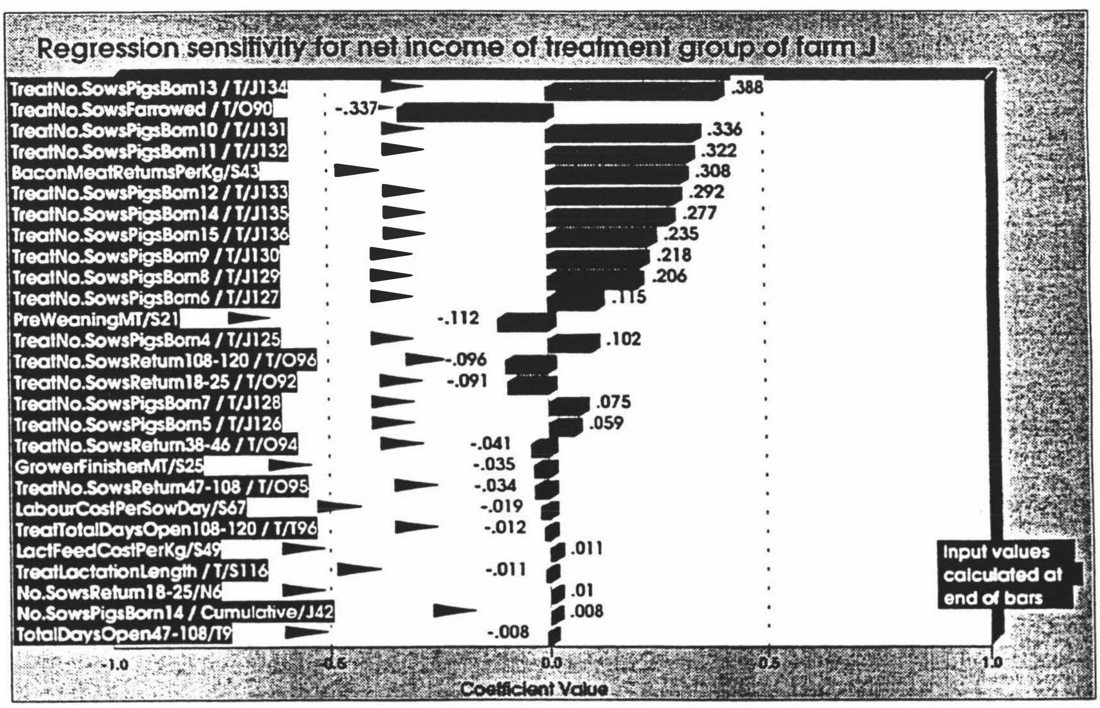
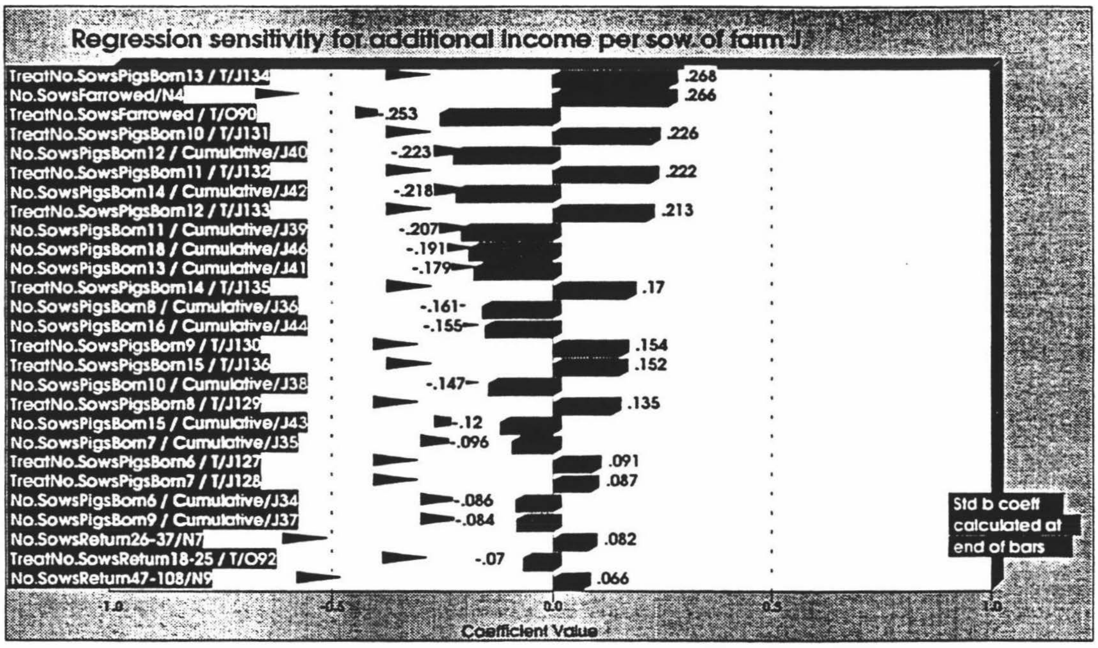


Figure 3-40 : Tornado graph presenting the results of the regression sensitivity analysis for additional income per sow of farm J (group-housing farms feeding higher feed level)



The net income (income - expense) per sow was most sensitive to the variation in bacon meat return per kg in any of the farming systems. The number of sows farrowed showed a negative correlation, because the net income was calculated on a per sow basis. The additional income varied with the number of sows farrowed in each group, and the correlation with numbers of sows returning was low.

Farm economics are strongly influenced by bacon meat market prices and by the number of sows farrowed. The regression sensitivity analysis did not indicate that dry sow feed, which was the only change on each farm, had a significant effect on additional income per sow on any of these 5 farms. Only in the control group of farm D it was found that the dry sow feed cost per kg had a weak correlation ($r^2 = 0.007$) with net income per sow.

Discussion

This analysis was conducted in order to evaluate the economic benefits of feed supplementation of newly mated sows on reproductive performance during summer-autumn. Since the trial did not produce any clearcut evidence of a benefit in fertility, and feed costs were incurred, it could not be expected that there would be a benefit overall. However the development of the economic analysis procedure was continued, because of its wider benefits in conducting simple analyses of the effects of various changes on herd income. In principle, consideration should also be given to whether there may be a benefit for individual producers even though there is no gain overall. Thus it may be worthwhile conducting analyses for individual farms, and example analyses have been conducted at this level. However it is unlikely that there is a true measurable benefit for individual farmers from the feed supplementation program used in this study.

Any economic model depends on the settings for parameters which are included in the model structure. This model attempts to represent all the factors relevant to the reproductive cycle of a sow. This includes any biological, management as well as dietary events. For an economic analysis the production capacity of a sow is largely determined by the absolute numbers as well as the survival of her offspring. Factors representing this chain of events were also included in the model. As many of the parameters are either not exactly known or subject to natural variation, a stochastic modeling approach was used to evaluate the economic effect of any measures targeted at improving production. The model was developed in a spreadsheet which has the advantage that the investigator does not have be an experienced computer programmer, but still can perform very complex calculations very effectively.

The results of the analysis indicate that most of the farms except for the ones with group-housing and a higher feed level would probably benefit financially from adopting a dry sow extra feeding programme. The expected outcome can be very effectively presented as a probability distribution which illustrates visually the range of values which can be expected.

The sensitivity analysis is very useful to indicate the parameters which are most influential at determining the values of the outcome variable. Clearly the market values of the pigs produced were most important for net income, which was directly followed by litter size. A sensitivity analysis of additional income was mainly influenced by litter size. The more piglets were born to treated sows the higher was the additional income. The more piglets born to untreated sows the lower was the additional income. Hence, an effect on litter size was crucial for farmers to have an economic advantage from the treatment. The effect of treatment on days open did not seem to be as significant for the farms included in this study.

CHAPTER 4

DISORDERS OF THE REPRODUCTIVE TRACT IN CULLED SOWS

Chapter 4: Disorders of the reproductive tract in culled sows

Introduction

The detrimental effect that low reproductive performance, and in particular the culling of sows because of low productivity, can have on profitability is well recognised - especially in large commercial piggeries (Badman, 1987). In many such piggeries, infertility problems are largely investigated by examination of annual production records in conjunction with examination of reproductive tracts at slaughter. The abattoir has thus become an integral part of the process for monitoring efficiency of swine production systems. Reproductive slaughter checks allow investigators to examine entire urogenital tracts with subsequent submission of samples for histopathology and culture (Dee, 1992). Reproductive tract evaluation is particularly useful for investigation of delayed puberty, failure to return to oestrus after weaning, regular and irregular returns to oestrus after breeding, and pseudopregnancies (Almond and Richards, 1992). Shortcomings in breeding management and physiological abnormalities in sows may be confirmed (Almond and Richards, 1992). Pointon *et al.* (1990) also drew attention to the considerable value that slaughter monitoring has in formulating extension messages for producers.

Post-slaughter examination of the reproductive system involves an assessment of ovarian function from a detailed examination of ovaries, uterus and endometrium, while a count of foetuses is useful for assessing ovulation rate and determining the accuracy of oestrus detection (Straw *et al.*, 1986).

Culling is an integral part of pig production and management, and inappropriate culling of sows reduces profitability. Valuable gilts need correct management if they are to have a long, productive life, and part of this management is the systematic and planned replacement of sows culled for poor productivity. Non-productive time is introduced when sows returning to mating are culled and have to be replaced by maiden gilts (Richardson, 1994).

The slaughter check assessment of culling policies may lead to misleading conclusions if confounding from parity, season of the year and culling for reasons other than reproductive failure are not taken into account. Another relatively common problem is that sample sizes are often inadequate for precise inference (Almond and Richards, 1992). These authors point out that while practitioners are faced with problems of trying to identify subclinically affected animals, and also in determining which animals are representative of the clinical problems, they also need to be aware of the statistical and epidemiologic limitations of reproductive slaughterchecks.

Literature review

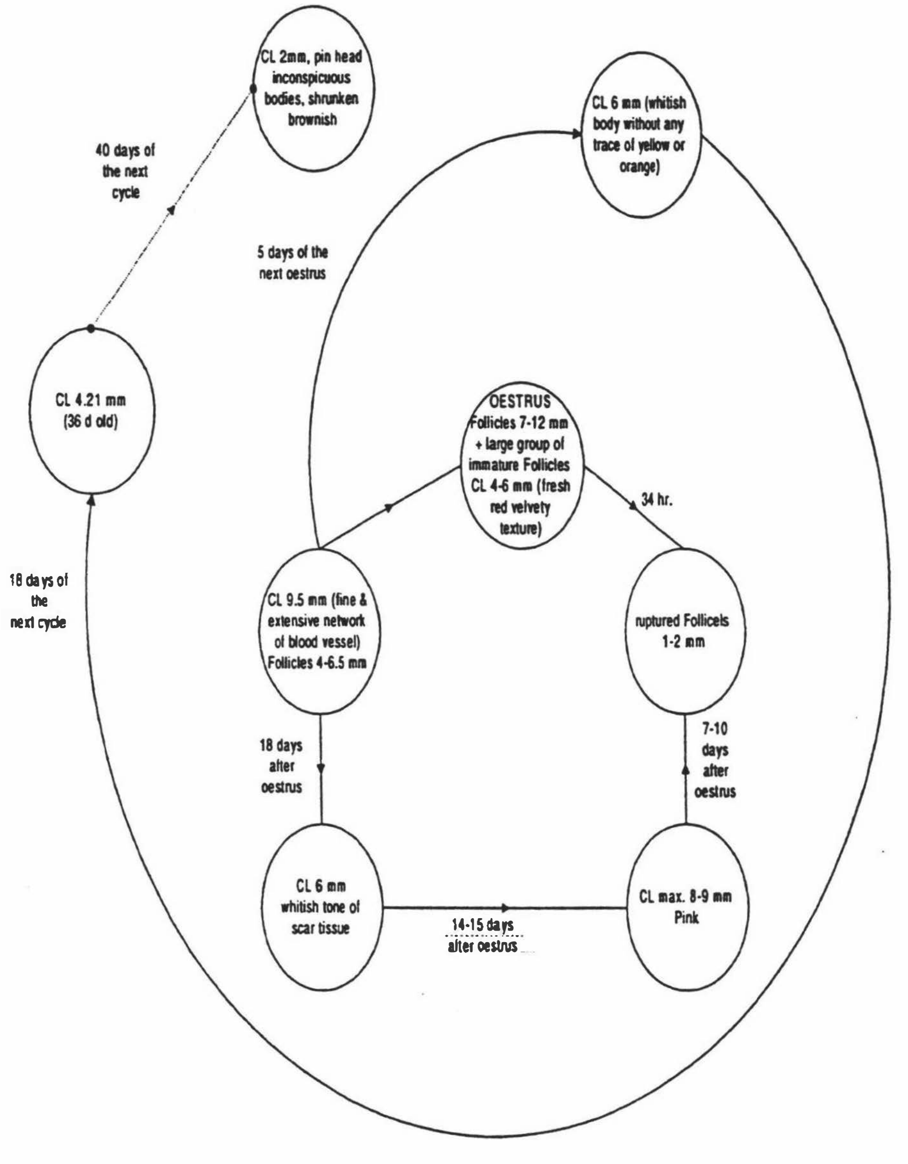
Gross anatomy

A sound knowledge of anatomy and in particular the changes which accompany normal cyclicity is needed if abnormalities are to reliably identified.

Ovaries

Ovaries are classified as cyclic if they contain structures larger than 15 mm in diameter and these structures are either follicular or luteal and apparently functional (Straw *et al.*, 1986).

The morphological changes of the ovary during the oestrous cycle have been reported by several authors and are represented diagrammatically below (Cutler *et al.*, 1981; Badman, 1987; Burger, 1952; Straw *et al.*, 1986).



Oviduct

The oviduct of the sow is 15 to 30 cm long and its mucosa projects into the uterine lumen, as folds well-supplied with blood (Roberts, 1971).

Uterus

The endometrium of the uterus of domestic animals is the structure which forms a placental attachment to allow normal development of the embryo and foetus. The muscular coat of the uterus is composed of smooth muscle in circular and longitudinal layers. The uterus receives its blood supply from the middle uterine artery, the utero-ovarian artery and a branch of the internal pudendal artery. The uterine body is about 5 cm long with torturous horns that are freely movable because of the long broad ligaments. In pregnant animals the horns may be 1.2 to 1.8 m long (Roberts, 1971).

Cervix

The cervix is poorly defined and is characterized by a thickened wall with transverse folds. It is about 10 to 20 cm long and is directly continuous with the vagina (Roberts, 1971).

Vagina

The vagina is 7.5 to 11.5 cm long, is small in diameter, and is lined with thick mucosa in three longitudinal folds. It opens out through the vulva which is fairly small and surrounded with thick lips which rejoin below in an acute angle where the erectile organ, the clitoris, is found (Roberts, 1971; Serres, 1992). Mesonephric ducts are occasionally present as vestigial structures (Roberts, 1971).

Vulva

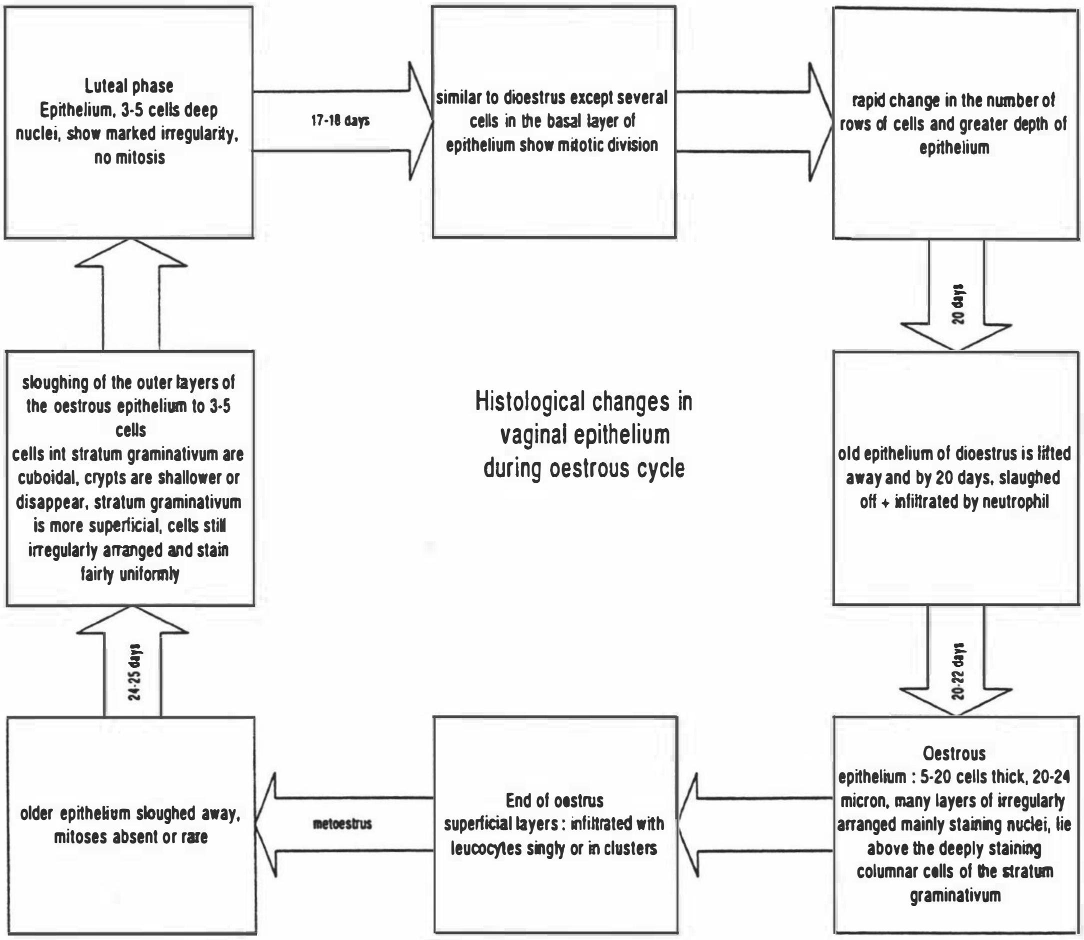
The vulva, comprised of the two thick labia, the dorsal and ventral commissures and the clitoris, and the vestibule located between the vulva and the vagina form the caudal termination of the genital tract. The vestibule in the sow is fairly long, about 8.9 cm. The vestibular glands are small and variable in number. The clitoris is located about 2 cm cranial to the ventral commissure. There is a cul-de-sac on either side of the cranial portion of the floor of the vestibule (Roberts, 1971).

Histology

Morton and Rankin (1969) listed the main histological features of the anterior vaginal epithelium as:

- presence or absence of mitosis in cells of the basal layers.

The histological changes in the vaginal epithelium reported by Morton and Rankin (1969), Cole and Foxcroft (1969), Mather *et al.* (1970), Walker (1967), O'Reilly (1967) are presented diagrammatically below:



Histology of the vagina

The initial pattern of changes in the vagina of the pregnant sow is similar to those seen in the non-pregnant sow until dioestrus or resting period. However, as pregnancy progresses there is a further sloughing of surface epithelial cells so that by day 22 (Morton and Rankin, 1969; Williamson and Hennessy, 1975; Cole and Foxcroft, 1982; Mather *et al.*, 1970) there is a layer, 2 to 3 cells deep, characteristically arranged parallel to the basement membrane (Walker, 1972). In contrast to the non-pregnant sow, there are no cells in mitosis (Morton and Rankin, 1969; Williamson and Hennessy, 1975). This arrangement usually persists throughout gestation, although occasionally in the last 3 weeks, there may be an increase in cells due to oestrogen generated by the placenta (Walker and Wickham, 1967). Changes similar to those of pregnancy often occur in immature non-cycling gilts, non-cycling sows, sows following ovariectomy, sows and gilts given anterior pituitary-inhibiting drugs, and lactating sows (Mather *et al.*, 1970). Typically, the epithelium of pregnancy is 2 to 3 cells thick, (12μ to 15μ) (Walker and Wickham, 1967) and contains nuclei, often with condensed chromatin, disposed in rows parallel with a level basement membrane (Walker, 1972). The cells are at first cuboidal, but by the third month of gestation most are flattened and have densely staining nuclei (Mather *et al.*, 1970). Cell types, ranging from polyhedral, columnar, flattened or almost squamous forms, may be present in a single biopsy. Large vacuole formation was commonly observed, but only in the epithelium of early pregnancy (up to 35 days) (Walker and Wickham, 1967). Walker and Wickham (1967) also reported that a high proportion of nuclei in pregnancy showed degenerative changes, e.g. irregular shrunken shape, chromatin condensation or frank pyknosis. In late pregnancy (from about 3 months) various types of epithelial cells were encountered, viz. typical nuclear row formation and epithelium of normal pregnancy height but composed of cells processing a high cytoplasm/nucleus ratio and in some cases a complete reversion to vacuolar degeneration or dioestrous mucosa (Walker and Wickham, 1967).

O' Reilly (1967) compared the number of rows of cells in the epithelial layer and the thickness of the epithelium in the anterior vagina between pregnant and non pregnant states, between pregnancy and follicular and luteal phases and cystic ovary states and between cystic ovary states and luteal and follicular phases. His summary data are shown in Table 4-1.

Table 4-1: Comparison of the mean number of rows of cells and average thickness of epithelium in the anterior vagina between pregnant and non-pregnant states, between pregnancy, follicular and luteal phases and cystic ovary states and between cystic ovary states, luteal and follicular phases

State of vagine	No. of animals	Mean no. of rows of cells (1)	Mean epithelial thickness (2)	p-values (1)	p-values (2)
Pregnant Non pregnant	31 175	2.7 5.9	15.7 33.8	0.001	0.001
Pregnant Follicular phase	31 53	2.7 7.9	15.7 49.5	0.001	0.001
Pregnant Luteal phase	31 98	2.7 4.8	15.7 26.7	0.001	0.001
Pregnant Cystic ovaries	31 24	2.7 4.9	15.7 28.1	0.001	0.001
Cystic ovaries Luteal phase	24 98	4.9 4.8	28.1 26.7	not significant	not significant
Cystic ovaries Follicular phase	24 59	4.9 7.9	28.1 49.5	0.001	0.001

From O'Reilly (1967)

The notable differences in the characteristics of vaginal biopsies taken from pregnant and non-pregnant sows are presented in Table 4-2.

Table 4-2: Notable differences in the characteristics of vaginal biopsies between pregnant and non-pregnant sows

Epithelium	Pregnant	Non-pregnant
Cell arrangement	regular, 2-3 rows	irregular, >=3 rows
Cell type	uniform, cuboidal/flattened	variable, usually mixed
Crypts	none to few, usually simple	few to many, may be branched
Leucocyte infiltration	absent	variable
Depth	2-3 cells	4-20 cells

From Mather *et al.* (1970)

The criteria used for diagnosis of pregnancy from histological examination of vaginal biopsies taken 18-25 days after mating are presented in Table 4-3.

Table 4-3: Diagnostic criteria used to determine pregnancy status from histological examination of vaginal biopsies taken 18-25 days after mating

Epithelium features	Pregnant	Non-pregnant
Mitosis	absent	present
Cell depth	2 to 5	5 to 20
Epithelial ridges	absent	present
Regular arrangement of nuclei	variable	absent
Sloughing	absent	present

From Morton and Rankin (1969)

Histology of the endometrium

The histological evaluation of endometrial biopsies of sows is complicated because the number of cells vary between stages of the oestrous cycle (de Winter *et al.*, 1992). During oestrus, the endometrial stroma is oedematous and hyperaemic, and there are increased numbers of neutrophilic granulocytes and lymphocytes in the subepithelial layer. During dioestrous, there is less oedema and the endometrial stroma is more homogeneous. Lymphocytes and eosinophilic granulocytes can still be found in low numbers, but plasma cells and neutrophilic granulocytes are almost absent. Any focal accumulation of lymphocytes, or a high number of lymphocytes or neutrophilic granulocytes in the endometrial stroma, or migration of lymphocytes into the uterine glands with destruction of the glandular epithelium, should be considered as pathological changes. In endometritis, inflammatory cells, particularly lymphocytes and macrophages, become numerous in the submucosa (Dial and MacLachlan, 1988).

De Winter (1992) used the following rules to categorize endometrial inflammation:

- If the number of neutrophilic granulocytes was significantly higher than normally seen in oestrous conditions and if no alterations on the epithelium of endometrium or endometrial glands was noticed, the case was considered to be moderate acute endometritis.
- If the number of neutrophilic granulocytes had considerably increased and the epithelial cells of the endometrium and/or endometrial gland had been damaged, this was considered indicative of a severe acute endometritis.
- If the number of lymphocytes, plasma cells and histiocytes was significantly higher than is

normally seen in oestrus, the condition was considered as chronic endometritis.

- If the number of both neutrophilic granulocytes and lymphocytes had significantly increased, this was considered to indicate subacute endometritis.

Vaginal biopsies of sows with large cystic ovaries showed the superficial cells of the vagina to be vacuolated to the extent that their basely situated nuclei were pressed into a cupped shape (Walker and Wickham, 1967).

Pregnancy - (embryonic and foetal development)

Four-cell embryos enter the uterus at about 48 hours (Cutler *et al.*, 1981). The development of the embryo from a relatively undifferentiated group of cells is rapid and is essentially complete by day 25 (Cutler *et al.*, 1981). Attachment, or implantation of the trophoblast to the endometrium, has commenced by day 13 (Almond and Richards, 1992; Cutler *et al.*, 1981) or by day 12 after conception (Van der Leek and Becker, 1993). Four viable embryos are necessary at this stage for maintenance of pregnancy (Cutler *et al.*, 1981, Van der Leek and Becker, 1993). The embryonic period begins at about 14 days after conception (Cutler *et al.*, 1981) and the embryonic sacs range from 18 to 35 cm in length (in situ) in the period from day 13 to day 18 (Almond and Richards, 1992). The foetal period begins at about day 35 of pregnancy when skeletal calcification begins (Cutler *et al.*, 1981).

If all or nearly all the embryos die before day 12 of pregnancy, the dam will probably fail to recognize her pregnancy status and return to normal cycling (Cutler *et al.*, 1981; Van der Leek and Becker, 1993). If embryonic failure occurs around day 12, a delayed return may occur (Cutler *et al.*, 1981; Van der Leek and Becker, 1993). In this case the sow usually returns to oestrus after day 27 post-mating, or alternatively she may develop a pseudopregnancy and not return until toward the end of her anticipated gestation (Cutler *et al.*, 1981). Death of part or all of the litter during the foetal period usually has no noticeable effect on the maintenance of pregnancy. Foetal death may, however, delay the time of initiation of normal parturition (Cutler *et al.*, 1981). Foetal death after day 30-35 results in mummification (Cutler *et al.*, 1981) and/or maceration (Van der Leek and Becker, 1993).

Crown-rump length of the foetuses can be applied to determine the day of gestation, which can then be used to evaluate the culling system, the accuracy of pregnancy diagnosis, and to determine the stage of pregnancy failure. The relationship between approximate crown-rump length and days of gestation (foetal age) from Almond and Richards (1992) is shown in Table 4-4.

Table 4-4: The relationship between approximate crown-rump length and days of gestation (foetal age)

Day of Gestation	Approximate crown-rump length (mm)
25	20
35	35
45	65
55	110
65	150
75	170

from Almond and Richards (1992)

With regard to ageing foetuses from crown-rump measurements, Spercher *et al.* (1975) stated: "The age of swine foetuses can be determined easily to within ±10 days by the mean crown-rump length of the litter. The approximate age of a foetus 1 inch in crown-rump length is 25 days. Each additional inch of crown-rump length represents approximately 10 days."

Cutler *et al.* (1981) developed a similar formula for calculating foetal age which reliably estimates foetal age from 30 days on. The formula is

foetal age (y) = 21.07 + 0.311x

x = crown-rump length (mm)

Crown-rump measurements of 1.8-2.5 cm, 8-11 cm, 17-23 cm, 23-29 cm thus correspond respectively to the foetal ages of 30 days, 60 days, 90 days, and time of farrowing, respectively (Cutler *et al.*, 1981). Van der Leek and Becker (1993) use a general rule and consider any foetus with a crown-rump length of more than 17 cm to be older than 70 days.

Ovarian pathology

Acyclic Ovaries

Ovaries from anoestrous sows are similar to those of lactating sows. Affected ovaries are tan in colour, have an overall size of about 2.5 x 2 cm (Straw *et al.*, 1986), contain follicles about 5mm in diameter (Almond and Richards, 1992), or 1-6 mm (Straw *et al.*, 1986), and have well regressed corpora albicantia and no corpora lutea. Ovaries from prepubertal gilts or gilts with delayed puberty tend to contain numerous small follicles (<4 - 5mm diameter) and have no corpora lutea or corpora albicantia (Almond and Richards, 1992).

Cystic Ovaries

A small proportion (about 1.5%) of pregnant sows have at least one follicular or luteal ovarian cyst which may be differentiated as follows:

- *follicular cysts* - thicker cyst wall, larger than normal, proliferation of thecal lining cells, partial luteinization of the cysts
- *luteinized cysts* - no evidence of ovulation (no papilla) and a thicker layer of luteinization around the central spherical cavity
- *cystic corpora lutea* - normal ovulation, persistence of a central cavity in the luteinized tissue.

Ovarian cysts in swine can be single, multiple, unilateral, or bilateral. Miller (1984) categorized them into three categories:-

- multiple large
- multiple small
- single large or small.

While single cysts have no apparent association with infertility, multiple cysts are usually associated with permanent or temporary sterility. Swine with single ovarian cysts (small or large) usually exhibit normal reproductive behaviour but may have small litters because they produce fewer ova and are thus less fecund than normal (Miller, 1984).

Ovarian cysts have been reported in both pregnant and non-pregnant sows. The highest incidence of ovarian cysts occurs in post-parturient sows following weaning, and in spring (Miller, 1984).

Multiple large ovarian cysts

Multiple large cysts are common (Miller, 1984; Roberts, 1986). An average of 5.6 cysts, 2-6 cm in diameter (Miller, 1984), 2-20 cm (Roberts, 1986) were recorded on each ovary (Roberts, 1986). The walls of multiple large cysts are totally or partially luteinized (Miller, 1984; Roberts, 1986) and they contain lower levels of oestrogen and higher amounts of progesterone than normal follicles (Miller, 1984). Roberts (1986) considered that progesterone, or progesterone converted into androgens was responsible for the following phenomena:

- progestational changes in the uterine endometrium
- extreme irregularity of the oestral cycle, with between oestrus intervals of 2 to 90 days

- heats of greater intensity but of the same duration as those in normal non-cystic females
- a larger and longer clitoris in 60% of affected sows

Multiple small ovarian cysts

Multiple small (0.5-1 cm) ovarian cysts occur occasionally (Miller, 1984; Roberts, 1986). In these cases the ovaries resemble a cluster of grapes and the number of cysts (mean = 22.5 small cysts per ovary) always exceeded the number of follicles normally found (Roberts, 1986). The walls of these cysts show no luteinization (Miller, 1984), and are lined by normal granular cells (Roberts, 1986). The cysts contain higher levels of oestradiol and lower progesterone than normal follicles (Miller, 1984). Animals affected by these cysts show marked irregularities in the length of the oestrous cycle and the same intense and marked manifestations of oestrus seen in animals affected by larger cysts (Roberts, 1986).

Single ovarian cysts

Single ovarian cysts, either small or large, are common and have no effect on ovulation. These cysts may coexist with normal corpora lutea and follicles (Miller, 1984).

Levels of luteinizing hormone may vary seasonally, causing sows to be more susceptible to stress when the surges are least, thus explaining the higher incidence of ovarian cysts in spring (Miller, 1984). In canines, reducing the duration of lactation increases the risk of cystic follicles, or cystic endometrial hyperplasia and subsequent pyometra, and by analogy, the role of hormonal influences should be at least considered as potential initiating factors for similar problems in swine (Dee, 1992).

Uterine pathology

Congenital and inherited abnormalities

Roberts (1986) examined 19 "repeat breeding" gilts. He found a unilateral missing segment of the uterine horn (*uterus unicornis*) in 11.4% , bilateral tubal abnormalities in 43.2% and bilateral missing segments such as a missing vagina, cervix, or body of the uterus in 4.5%. Hydrosalpinx, pyosalpinx and bursitis were included under bilateral tubal abnormalities. Structures that appeared to be rudimentary ducts or remnants of the mesonephric or Wolffian duct system were present in the broad ligament of some of the gilts.

He also examined 79 female swine that had been bred at an average of 2.8 services without conception and reported a unilateral missing segment in 2% of the gilts and 3.6% of the sows. In a study in Belgium, 2.2% of 1000 female swine examined had missing segments of the uterine horn, 3% of the gilts had hydrometra, four gilts had *uterus didelphys* (double cervix) and one had a missing uterine body. Hydrosalpinx was the major cause of sterility within this abnormal group. Cutler *et al.* (1981) examined 5143 sow tracts and found absence of one uterine horn in 0.3% and 0.6% respectively of non-pregnant and pregnant sows. Litter size is reduced with this abnormality, but pregnancy rates are apparently not affected (Cutler *et al.*, 1981). Hermaphrodism is seen in swine occasionally but affected animals are usually male pseudohermaphrodites.

Tubal abnormalities

Thirty-five percent of sterile female swine, most commonly gilts, had an obstruction accompanied by an accumulation of fluid in the lumen of the fallopian tube at about two-thirds of the distance from the ovary to the uterine horn. Two percent of 1000 female swine had bursal adhesions and this condition and bursitis occurred in association with hydrosalpinx. Ninety-seven percent of the cases were bilateral (Roberts, 1986).

Cystic endometrium

Cystic endometrium was diagnosed when multiple endometrial cysts from 0.1-3.0 cm in diameter were visible grossly. Although cysts sometimes occurred sparsely, large numbers were often found in the body and occasionally throughout both cornua. The endometrial or cervical cysts ranged in diameter from 0.1 - 0.3 cm in two-thirds of affected organs and in the rest were 0.4-1.0 cm, except for a few where they were 1.0-3.0 cm in diameter (Thain, 1965).

Metritis

In metritis, oedema and pus are found throughout several layers of the myometrium. In chronic cases there is a diffuse infiltration of lymphocytes and the endometrial epithelial lining may be missing (Dee, 1992).

Endometritis

It is generally thought that endometritis starts from of an imbalance of microflora contaminating the patent cervix. In established infections, the effects on conception rate and litter size are devastating (Dee, 1992). Outbreaks of vaginitis and endometritis have occasionally been reported in gilts. Older sows (parity $\geq$ 5) may be prediposed to chronic endometritis and urinary tract infections, and the problem affects seed stock herds in particular, where there is understandable reluctance by producers to cull expensive pure-bred animals (Dee, 1992).

The stage of the oestrous cycle has an important influence on the onset of endometritis but the oestrous cycle has been suggested to be also importantly involved in uterine defence mechanisms (de Winter *et al.*, 1994). These authors concluded from a trial in which *E. coli* was inoculated into the uterus of 10 pubertal unmated gilts, that the resistance to *E. coli* infections was higher when the gilts were inoculated during oestrus. During pro-oestrus and the first part of oestrus blood oestrogen levels are high and progesterone concentrations are low (Dial and Britt, 1986). Oestrogen causes an increased migration of neutrophils into the endometrium and the lumen of the uterus, with an associated increased phagocytosis and bactericidal activity. An increased uterine perfusion and an enhanced permeability of the tissues allows neutrophils to reach the uterus faster and easier; enabling bacterial infections (that commonly occur at service) to be easily overcome. These processes have not been observed during the luteal stage of the oestrous cycle when blood progesterone levels are high and oestrogen levels are low. Consequently, uterine defence capacities are low at that time. For this reason it is very important that service or insemination occurs during oestrus. At service or insemination a sound uterine defence mechanism is required because on these occasions many bacteria are introduced into the uterus (Meredith, 1986). During the second part of oestrus blood oestrogen levels are already low while blood progesterone levels increase very soon after ovulation, so that even levels up to 10 ng/ml can be observed at the end of oestrus (Dial and Britt, 1986).

Grossly visible lesions of endometritis vary from pus-filled uterine horns to slightly hyperaemic uterine mucosal surfaces, and in some cases, no gross lesions are found (Dee, 1992). Dee considered that long standing cases of endometritis commonly manifest as chronic recycling sows because infiltration of fibrous connective tissue into the endometrial lining causes interference with implantation.

Uteri of affected sows may be free from mucopurulent debris, particularly after oestrus, so it is necessary for diagnostic purposes to collect tissue samples for histopathology (Almond and Richards, 1992). Cases of endometritis accompanied by slight infiltration of leucocytes cannot be distinguished from normal because those changes are similar to the normal cellular profile of oestrus (Dee, 1992).

Endometritis is characterized by the accumulation of neutrophils and necrotic cellular debris within the uterine lumen and glands, and infiltration of lymphocytes and plasma cells into the lamina propria. Mononuclear inflammatory cells are most numerous in the stratum compactum, surrounding uterine glands and around vessels throughout the lamina propria. Necrosis of lumenal and glandular epithelium is never extensive, but individual cell necrosis is usually present and some tracts show discrete aggregates of necrotic epithelium. In some dioestrous gilts, endometritis consists predominantly of mixed mononuclear inflammatory cell infiltrates with fewer neutrophils. Lymphocytes and plasma cells are most prominent adjacent to the lumenal and glandular epithelium, and around vessels (MacLachlan and Dial, 1987).

Endometritis in gilts usually resolves after one or more oestrous cycles, suggesting that oestrogenic stimulation of the endometrium produces an environment less conducive to bacterial growth. Cyclic oestrogenic stimulation of the uterus, and development of a mucosal immune response, may facilitate resolution of uterine infections in gilts (MacLachlan and Dial, 1987).

Uterine infections cause some embryonic losses. The work of Scotfield *et al.* (1974) showed that the embryonic losses in pigs with infected uteri were significantly higher than in those with sterile uteri. The difference in the number of ova missing between the sterile and infected groups was greatest for pigs killed 3 days after coitus, at which stage uterine infections were apparently associated with about 40% of ova loss. Although it has been suggested that uterine infections increase embryonic mortality, definitive evidence indicating that endometritis is consistently linked with reduced litter size is lacking. It may be that uterine disease in the sow is primarily a problem of fertility with no effect on fecundity (Dial and MacLachlan, 1988) although some studies have demonstrated that bacterial infections cause some embryonic deaths, particularly at about 13 days post-breeding (Dee, 1992). Scotfield *et al.* (1974) found uterine infection to be a common cause of returns of service, with an incidence of about 20% per sow service, in commercial herds.

Endometritis is associated with both temporary and permanent infertility. While gilts which develop uterine infections before mating have dramatically reduced fertility relative to non-infected females, those which become infected after mating rarely conceive. Occasionally, sows and gilts which develop uterine infections after conception have failed pregnancies through abortion or foetal resorption and subsequently return to oestrus after an interval longer than 18-24 days post-coitus (Dial and MacLachlan, 1988).

Pseudorabies (Prv) endometritis

Moderate, diffuse, and focally intense lymphohistiocytic endometritis with lymphocytic perivascular and periglandular cuffing, congestion, and oedema was seen in all of 15 gilts infected with Prv via the uterus (Bolin *et al.*, 1985). Multiple endometrial ulcers, surrounded by lymphocytes, plasma cells, macrophages, and neutrophils were also seen.

Staphylococcal endometritis

Microscopic examinations of a case of Staphylococcal endometritis showed uterine contents consisting of exfoliated epithelial and inflammatory cells. The uterine mucosa was ulcerated in many areas and was affected by foci of chronic inflammatory cells extending deep into the laminal propria. The inflammatory infiltrate consisted of macrophages, lymphocytes, and plasma cells with a few neutrophils. Polygonal epithelioid cells surrounded larger foci of inflammation and necrosis disseminated through the lamina propria. Clusters of gram-positive cocci were present in these foci and there was occasion ulceration with epithelial exfoliation. There was extensive proliferation of granulation tissue underlying the areas of inflammation and necrosis (Everitt *et al.*, 1981).

Vulvovaginitis from zearalenone toxicity

Zearalenone (F-2) is an anabolic oestrogen-like mycotoxin produced naturally by *Fusarium* growing in grains stored under high moisture conditions. Feeding this mycotoxin causes infertility accompanied by small ovaries and atretic follicles containing no CL and squamous metaplasia of the epithelium of the genital organs. Moderate doses fed to pregnant gilts cause decreased weights of uteri, placental membranes and foetuses, while high levels of mouldy feed fed between 3 to 34 days of gestation cause inhibition of foetal development and decreased numbers of foetuses (Roberts, 1986).

Oestrogenic mycotoxin (zearalenone) contaminated feeds are responsible for outbreaks of vaginitis, in many cases accompanied by signs of oestrus and vaginal discharges in both prepubertal gilts and mature females (Dee, 1992).

Zearalenone toxicity causes excessive uterine oedema which may be sufficiently severe to give false-positive diagnoses of pregnancy with amplitude-depth pregnancy detection instruments. Continuous exposure to zearalenone induces endometrial gland hyperplasia and release of uteroferin into the lumen of the uterus (Almond and Richards, 1992).

Vulva/vaginal discharge

Farms which record vaginal discharges in more than 2% of the breeding herd are considered to be problem herds (Dee, 1992). Producers should expect vulval discharges to occur in less than 2% of bred sows and less than 2% of farrowing sows by day 5 postpartum (Dial and MacLachlan, 1988). Vaginitis is considered to be the result of excessive contamination of the vaginal tract while the animal in the progesteronal stage (Dee, 1992). Excessive levels of laxative in rations, particularly laxatives of a chemical nature, can produce very loose stools and enhance contamination of the perineal region. Water that is high in sulphates also produces excessive looseness (Dee, 1992). These particular factors should be always be considered when outbreaks of vulval discharge occurs.

If vulvitis/vaginitis is to be accurately diagnosed, it is necessary to select sows for examination that are in an acute phase of a visible vaginal discharge, and preferably those that have been discharging for no longer than 24-48 hours, according to Dee (1992), or no longer than 24 hours, according to Muirhead (1984). Dial and MacLachlan (1988) recommend that affected animals should be slaughtered within two days of the onset of the first observed discharge because of potential changes in the microflora. It is not uncommon to find completely normal reproductive tracts in sows that were discharging for 2-3 days prior to the examination (Dee, 1992) because metritis can resolve in a short time (Muirhead, 1984). At least four sows should be sampled for diagnostic purposes and the degree of accuracy of diagnoses improve with increasing sample size (Dee, 1992).

Uterine infections in gilts and sows result in copious amounts of purulent exudate discharges (Dial and MacLachlan, 1988). A discharge in an unmated gilt usually indicates a commensal infection with implications for an underlying hormonal cause (Tubbs, 1995b). Discharges in virgin gilts may occur within a few days of their introduction to the breeding herd and usually after initial boar exposure to initiate oestrous cycling (Dial and MacLachlan, 1988).

The underlying theory for uterine infections and vulval discharges is that the cervix, which is open during oestrus, allows entry of commensal organisms from the vagina into the uterus. After oestrus, the cervix closes under the influence of progesterone. During the following luteal phase of the oestrous cycle, the uterine environment is conducive to and allows bacterial growth to proceed. About 16-18 days after oestrus, the cervix opens again under the influence of oestrogen, and a discharge may be seen. The probability of a fertile mating at the subsequent oestrus is low.

The discharges occasionally seen in gilts that have been mated and in sows after either weaning or mating are similar. A discharge after weaning is probably due to a residual infection from farrowing which did not resolve during lactation. Such infections are usually low-grade and chronic but may interfere with conception. A discharge 16-18 days after mating usually indicates a disruption of pregnancy and Tubbs (1995b) recommends culling of affected sows when that occurs. It may be, for sows bred after weaning, that the occurrence of post-coital endometritis is caused by perioestrous ascension of vaginal microbes through a relaxed cervix rather than to the coital transfer of pathogens in the boar's semen or via a contaminated penis.

In the dry (non-lactating) sow, the discharge may be sporadic but is most often observed during pro-oestrus or around oestrus, when the cervix is patent and the endometrium is dominated by oestrogen. Most vulval discharges occur in the 6 days before oestrus. Consequently, vulval discharges associated with post-coital infection of the uterus usually are not observed until about 3 weeks after mating. Records indicating continued discharge beyond 3 days postpartum are suggestive of endometritis. Post-coital endometritis typically does not produce a discharge after mating. Moreover, the discharges occur regardless of the stage of the oestrous cycle, do not influence fertility and are most likely to be accompanied by urinary tract or vaginal infections (Dial and MacLachlan, 1988).

Dial and MacLachlan (1988) have postulated that perhaps the role of a boar in initiating genital infections in gilts is associated with the boar stimulating the onset of oestrous cyclicity rather than through transmission of pathogens during coitus.

Urinary tract infections

The urinary tract may also be a source of discharges from the vagina. While urinary tract discharges cannot be definitively distinguished clinically from those originating from the reproductive tract, The character of the discharge can give a good indication of the source. Discharges from the urinary tract often contain pus or copious amounts of blood. Mild urinary tract infections may result in residual salts of calcium or other minerals clinging to the vulva. In severe cases of urinary tract infection, especially those of the upper urinary tract, sows show signs of systemic illness, in contrast to the purely local signs accompanying most genital tract infections. A good diagnostic indicator of urinary tract infection is urine pH, which is normally 5.5-7.5, but can rise to 8-9 in cases of pyelonephritis or cystitis (Tubbs, 1995b). Discharges which occur regardless of the stage of the oestrous cycle, and do not influence fertility are most likely indicative of urinary tract or vaginal infections. Discharge from urinary tract infections can occur at any time after mating, including during pregnancy or lactation. Urinary tract infections are associated with the development of puerperal endometritis and with infertility. Reduced fertility accompanied by increased rates of regular returns to oestrus and repeat-breeder sows is observed in herds with a high prevalence of urinary tract disease (Dial and MacLachlan, 1988). Rations fortified with excessive levels of calcium, phosphorus and vitamin D promote abnormally high calcium excretion via the urinary tract, resulting in renal inflammation and potential nephrotoxicity (Dial and MacLachlan, 1988).

The organism most commonly found in association with urinary tract infections is *Eubacterium suis* which requires an alkaline environment for growth and multiplication. Dee (1991) points out that the vaginal tract is normally slightly acidic, but during oestrus, oestrogen causes the uterine pH to rise and then remain slightly alkaline for up to 3 weeks post-weaning, thus enhancing growth of the organism. The migration of *E. suis* from the vaginal tract into the bladder may be aided by the piliated surface of *E. suis*.

There is some anecdotal evidence that the use of artificial insemination (AI) decreases the prevalence of vaginal discharges in problem herds (Tubbs, 1995a).

Eubacterium suis

Eubacterium suis (*E. suis*) was called *Corynebacterium suis* (*C. suis*) until Wegienek and Reddy (1982) claimed, on the basis of detailed examination of one isolate, that *C. suis* should be assigned to the genus Eubacterium. In this context, *Eubacterium suis* (*E. suis*) is used throughout instead of *Corynebacterium suis* (*C. suis*).

E. suis was reported for the first time in England (Soltys and Spratling, 1957), but has since been found in Canada (Percy *et al.*, 1966), Denmark (Biering-Sorensen, 1967), the Netherland (Dijkstra, 1969, Frijlink *et al.*, 1969), Hong Kong (Munro and Wong, 1972) and Australia (Glazebrook *et al.*, 1973) Finland (Kauko *et al.*, 1977), Denmark (Larsen, 1970), Mexico (Lastra *et al.*, 1982) and Brazil (de Oliveira *et al.*, 1988). *E. suis* has also been isolated from bladder of culled sows in New Zealand but the report is unpublished. No seasonal distribution of the disease has been observed (Høgh *et al.*, 1984). *E. suis* is a primary pathogen in 90% of cases of pyelonephritis in pigs in Europe (Carr *et al.*, 1995).

Characteristic of the organism

The initial event in most bacterial infections is the attachment of the responsible organisms to epithelial cells of mucous membranes in the host organism (Beachey, 1981). Micro-organisms which do not adhere are removed by the secretions bathing the mucosal surfaces. *E. suis* strains have been indicated the existence of fimbriae or other surface proteins with specific adhesive antigens of pathogenetic importance. Its strains have an agglutinating effect on a erythrocytes from variety of species and trypsinization did not influence the haemagglutinating ability of *E. suis* (Larsen *et al.*, 1988).

E. suis did not react with porcine mucin, the same kind as mucin found in the urinary tract. Owing to the organisms' ability to haemagglutinate porcine red blood cells, the phagocytic capabilities of the immune system are reduced (Beachey, 1981; Larsen *et al.*, 1988).

E. suis was capable of surviving in water temperatures up to 76.5° C. The bacteria remained viable for as long as 4 days when held at 20° C and 17 days at 4° C. The organism was sensitive to extreme cold, it was capable of surviving only up to 24 hours when held at -20° C (Dee *et al.*, 1993). Positive isolates were obtained at up to 18 hours from solutions with a pH of 5 to 7 and for 2 and 5 hours at a pH of 3 and 4, respectively (Dee *et al.*, 1993). The viability of *E. suis* was poor when directly exposed to oxygen. Viable cultures from the concrete surface were obtained for as long as 1 hour when mixed with semen, 12 hours when mixed with urine, and 24 hours when covered with hog manure; isolates were mixed with urine or semen and held at 20° C also lasted for 24 hours. The samples placed within the porcine kidney survived for 3 days (Dee *et al.*, 1993).

Carr *et al.* (1995) give an explanation for the pathogenesis of urinary tract infection in the sow. They note that normally healthy bladder will be able to withstand almost any bacterium which finds itself within the lower urinary tract. However, if the defences are compromised then a bacterium may be able to colonise and damage the uroepithelium. The major defence mechanism of the bladder is flushing with sterile urine; if the renal urine is not sterile, bacteriuria and possible cystitis will be present. A sow must urinate every 6 hours to maintain her bacterial concentration below 100 cfu/ml of urine. The bacteriuria is more likely to develop if there is a decrease in urine output, and increase in the time interval between each micturition, and increase in the bladder residual volume or an increase in the initial bacterial load.

The boar

E. suis has been found in the prepuce of healthy boars (Jones, 1986; Lastra *et al.*, 1982), in semen samples (Jone and Dagnal, 1984). Jones and Dagnall (1984) investigated male pigs from testing stations and artificial insemination centres throughout the U.K. and found that most male pigs over 4 months of age harbour *E. suis* in the preputial diverticulum. Jones (1986) conducted a preliminary investigation into the carriage of *E. suis* in pig and found that 75% of 65 adult males harboured this organism in the prepuce. Høgh *et al.* (1984) could isolate *E. suis* from 59 or approximate 24% of boar semen samples. They found that isolation of *E. suis* from the urinary system met the assumption that cystitis and pyelonephritis in sows and gilts are epidemiologically related to the presence of *E. suis* in boars. Jones (1982) notes that most male pigs aged over 10 weeks, harbour *E. suis* in the preputial diverticulum and in semen samples (Jones and Dagnall, 1984). Lastra *et al.* (1982) and Dee (1991) considered it as the main habitat of *E. suis* because the presence of *E. suis* did not seem to alter semen quality and fertility (Høgh *et al.*, 1984). The organism readily transmitted among male pigs at 2 to 3 months old (Jones and Dagnall, 1984). The carriage of *E. suis* by young pigs seems to be governed by the degree of contact they have with older, infected pigs (Jones and Dagnall, 1984). More recently it was isolated from the preputial sacs of 21-day-old piglets from sows with chronic renal disease (Carr *et al.*, 1990). Walton (1990) could isolate *E. suis* from 3-week-old male piglets suckling sows with chronic urinary tract infections.

Because of the organism's predilection for the prepuce, it is logical to assume that boars carry the organism and transmit it to sows at breeding (Jones, 1982; Dee, 1991). Urine cross-contamination may also occur (Dee, 1991). The contents of the preputial diverticulum of older pigs, a rich source of *E. suis*, voided onto the floor of the pens, are sources of infection; spread of infection would be facilitated by sharing the same floor area, the absence of solid partitions between the pens and by movement of personnel between pens (Jones and Dagnall, 1984). *E. suis* has been isolated from the floor of pens occupied by male pigs over the age of 10 weeks (Jones, 1982). It is likely that contaminated feet of animal attendants and cleaning equipment which had been in contact with floors of pens are the organism transmitter. The transmission experiments show that male pigs, free from *E. suis*, become infected if they are in close contact with carrier males (Jones and Dagnall, 1984). Dee *et al.* (1993) hypothesize that piglets can be infected with *E. suis* during parturition, particularly if they are born to an infected sow because they are positive for *E. suis* immediately after passing through the vaginal tract; and it has been shown that piglets born to dams which are sporadic shedders of *E. suis*, were infected in their first week of life.

Gilts and sows

E. suis is pathogenic in female pigs, but on some occasions, it can be isolated from the vaginal vestibule of healthy females (Jones, 1982; Lastra *et al.*, 1982). There is no evidence that sows of a particular parity are more prone to the disease (Jones 1982). Dee *et al.* (1993) reported that gilt carriers were present throughout the farm, as 27% (23 of 85) of the gilts (ranging in age from 14 days to 6 months) tested via vaginal swabs were positive for *E. suis*. Urinary tract infected pigs are not easily detected, as Dee *et al.* (1993) found that except for one gestating sow, no evidence of urinary tract infection was detected visually or by urinalysis in any of the other females examined. In agreement, Akkermans (1980) reported that asymptomatic bacteriuria was found in breeding sows. These bacteriurias have been discussed as important in the development of fertility problems (Akkermans, 1980) and the MMA syndrome (Pattison, 1980). By contrast, Jones (1984) noted that the organism is rarely isolated from the urinary tract of healthy females, but is a major cause of pyelonephritis/cystitis in sows (Jones, 1978).

Bacterial cystitis of breeding sows can cause heavy losses in some herds, mostly from *E. suis* (Bollwahn *et al.*, 1984). The disease occurs in sows principally within 1-3 weeks of mating but it may occur at any time during the reproductive cycle, e.g. in mid-pregnancy and after parturition. There are a few reports of the disease occurring in females which have been artificially inseminated (Jones, 1982).

It is considered that pyelonephritis/cystitis results from an ascending bacterial infection of the urinary tract, that it occurs mainly in adults and is one of the main causes of death in breeding sows (Walton, 1984; Jones, 1968). The housing environment of the sows is also important in development of cystitis and pyelonephritis in general. Sows in outdoor herds seldom have problems with cystitis and pyelonephritis, compared with sows raised under modern, intensive confinement conditions (Dee, 1991) because in gestation stalls, there is higher incidence of faecal contamination of the perineum (Dee, 1991; Muirhead, 1986; Bollwahn *et al.*, 1984), and a reduction in activity (Dee, 1991; Dial and MacLachlan, 1988), water consumption, and daily urination (Dee, 1991). Urine stagnation raises urine pH and leads to rapid multiplication of *E. suis* (Dee, 1991; Dee, 1992).

E. suis requires an alkaline environment for growth and multiplication. The vaginal tract is normally slightly acidic (a pH of 6) (Muirhead *et al.*, 1990), making it an unsuitable environment for *E. suis*. During oestrus, however, oestrogen causes the urine pH to rise and remain slightly alkaline for 0 to 3 weeks postweaning, thus enhancing growth of the organism (Muirhead, 1986; Dee, 1992).

The migration of *E. suis* from the vaginal tract into the bladder may be aided by pili on *E. suis* (Larson *et al.*, 1988). The short, wide shape of the sow's urethra may also promote migration (Dee, 1991; Dee, 1992). In the bladder, *E. suis* produces urease, which splits urea into ammonium. The ammonium ions, in turn, damage bladder epithelial cells and initiate the precipitating of urinary salts and crystals, particular struvite causing urinary calculi (Walker and MacLachlan, 1989; Dee, 1992). Calculi formed as a result of the rise in pH are usually composed of magnesium ammonium phosphate (struvite), calcium oxalate, apatite, calcium phosphate, or urate (Dee, 1991). These calculi irritate the mucosal surface and provide a nidus for bacterial growth and protection form antibiotics and body defence mechanisms (Dee, 1992). Recent studies suggest that an *Escherichia coli* toxin may also play a role in *E. suis* infection (Carr *et al.*, 1990). This toxin may damage the ureteric valve, allowing the retrograde flow of urine to the kidneys. Damage to this one-way valve may result in hydronephrosis and the reflux of *E. suis* into the kidneys, resulting in acute renal failure or sudden death (Dee, 1991).

Transmission

E. suis is passed to the sow via venereal transmission and possesses a pilus, enhancing its attachment to the vaginal mucosa (Larsen *et al.*, 1988). Cystitis and pyelonephritis may result after mating with infected boars (Jones, 1981). Slight trauma at breeding, especially in small gilts, may be the predominant factor. An excessive pool of boars or poor management of them can lead boars to be aggressive at mating, hence producing, traumatized sows (Jones, 1982). Two or 3 weeks later, the sow may pass urine stained with blood and pus, and this sign will continue for a long period, although sometimes it is difficult to detect (Jones, 1981). Metritis often can be found in cases of ascending cystitis-pyelonephristis, but *E. suis* usually has not been isolated from the uterus (Jones, 1981).

Walton (1990) could isolate *E. suis* from pen floors of 10-week-old barrows, and from the boots of stockmen working in the breeding area, so staff are also a disease carrier.

Clinical signs

In mild cases, signs may be limited to changes in the urine which may become turbid and contain flakes of fibrin or pus and a few small clots of blood. In severe cases there is polyuria, haematuria and pyuria, and general signs of illness, including inappetence, thirst and loss of weight. In some sows, blood-stained urine drips from the vulva. In some systems, regularly checking individual pigs is difficult, and the only sign attracting attention may be loss of weight (Jones, 1982).

Jones (1986) divided signs to 3 categories, including acute and chronic renal failure and sudden death. Dee (1991) described how in acute renal failure, pigs are unwilling to rise and appear to be lame in the rear limbs. Haematuria and pyuria are common. Mortality is high unless the infection is treated aggressively. The interval between initial presenting signs and death may be only a matter of days (Carr *et al.*, 1995). If the sow survives the acute stage of infection, weight loss ('thin sow syndrome') (Jones, 1984; Carr *et al.*, 1995) and polyuria/polydipsia follow, with little chance of recovery. The sow may have a vaginal discharge, may become a repeat breeder and may have to be culled because of poor reproductive performance (Jones, 1984). Dee (1991) hypothesized that *E. suis* infection may ascend into the uterus and damage the endometrium. The damaged endometrium may then interfere with the implantation of fertilized ova, resulting in reduced conception rates (Dee, 1991). Urinary tract infections are associated with the development of puerperal endometritis, so reduced fertility is potentially observed accompanied by increased rates of regular returns to oestrus and repeat-breeder sows (Dial and MacLachlan, 1988). Farrowing rate is reduced partly due to sow mortality (Carr *et al.*, 1995). The discharges that accompany infections of the urinary tract are not associated with any particular stage of the oestrous cycle or with reproductive status. Discharge can occur at any time after mating, such as during pregnancy or lactation (Dial and MacLachlan, 1986).

Risk factors

The risk factors of concern have a cumulative effect, so the more numerous they are in a herd, the higher is the probability for the disorders to occur. According to Madec *et al.* (1984), the risk factors are:

- bad hygiene (poor protection of the bladder),
- lack of exercise and movement (motor activity),
- limb injuries,
- constipation,
- water intake (less than 15 litres/day per pregnant sow),
- water characteristics (acidity, pH <5.7, nitrates),
- individual factors (the risk rises with parity).

Gestating sows housed on solid floors with inadequate drainage or on slatted floors with insufficient waste removal have a high prevalence of urogenital infections (Dial and

MacLachlan, 1988). Failure to completely empty the bladder at micturition, high urinary pH, changes in the composition of urine (e.g. increased urea concentration) and hormonal influences on the epithelium of the lower urogenital tract are factors which may play a part in establishment of *E. suis* in the bladder (Jones, 1982). Muirhead (1990) reported that urinary tract infection is common when pigs are housed in gestation stalls, particularly if the slatted flooring does not lead to easy manure removal and if water availability is reduced. Such factors lead to an increase in microorganisms around the perineal and preputial regions. Limited water results in the reduction of the frequency of urination, then producing stagnant urine in the bladder, potentiating microbial growth (Dee, 1992). Dee (1992) noted that incidence of urinary tract infection is higher if the perineal area is contaminated.

Diagnosis

Urine

The urine of acutely infected sows is brown (Jones, 1984; Walker and MacLachlan, 1989), viscous and has a foetid odour (Walker and MacLachlan, 1989). On the farm, pH is easy to measure using pH paper which permits making a presumptive diagnosis of urinary tract involvement, since pH of urine is high (>=8) (Madec *et al.,* 1984; Walker and MacLachlan, 1989; Lastra, 1982). The alkalinity of the urine did not appear to be inhibitory to *E. suis* (Walker and MacLachlan, 1989). The mucus in the bladder may provide protection from the pH effects, although *E. suis* was readily isolated free in urine obtained by cystocentesis (Walker and MacLachlan, 1989). Urine dipsticks allow for the measurement of a wide range of urinary parameters such as specific gravity, occult blood, protein, nitrate levels, etc. (Dee, 1992). Nitrite is a good indicator of significant bacteriuria in first urine in the morning, but bacteria may be present at high level without nitrituria (Madec *et al.,* 1984). Walker and MacLachlan (1989) tested urine of two infected sows and found that urine has a large amount of protein and moderate amount of blood. Urine specific gravities were 1.025 and 1.016 and urine osmolalities were 777 and 562 mosm/kg. Microscopic examinations of urine sediment revealed 1 to 4 and 5 to 10 WBC/hpf, many triple phosphate crystals, and a moderate amount of mucus. Many gram positive rods and cocci were seen from material taken from affected bladders. Few inflammatory cells were observed.

Clinical diagnosis may be confirmed by the demonstration of gram-positive slender coryneform rods (usually in large numbers) in films of urine sediment or vulval discharge (Jones, 1982).

Swab samples, particularly from preputial diverticulum should be collected and cultured under anaerobic conditions (Dial and MacLachlan, 1988). With the help of an experienced microbiologist, the infected boars then can be identified.

Culturing E. suis

E. suis can be isolated from urine samples. Samples should be collected in sterile containers from sows housed in stalls. The best collection time is usually early in the morning at feeding time. While still at the farm, dip a swab into the urine sample and immediately place the swab in Kary Blair medium for transport to the laboratory (Dee, 1991).

E. suis is an obligate anaerobe. Swabs from Kary Blair medium should be placed onto Colistin-naladixic acid (CNA) agar which contains antibiotics effective in controlling growth of Gram-negative bacteria and Proteus. Dial and MacLachlan (1988) suggest to add Metronidazole to the columbia colistin nalidixic blood agar. The culture jars have to be put under an anaerobic environment and incubated at 37 °C for 5 to 7 days (Dee, 1992) or 2 days (Jones, 1982).

Pathology

The effects of infection with *E. suis* are confined to the urinary tract; pathological changes attributable to *E. suis* have not been found elsewhere in the body (Jones, 1982).

Gross lesions

Pyelonephritis : Infection can be unilateral and/or bilateral (Jones, 1982). In acute pyelonephritis there may be no gross changes of scarring in the renal cortex or medulla whereas chronic active pyelonephritis presents with active infection and scarring of the cortex and medulla (Carr *et al.*, 1995). The ureter is thick, dilated (Jones, 1982; Carr *et al.*, 1995), tortuous, haemorrhagic, ulcerated, necrotic (Carr *et al.*, 1995) and enlarged. The ureteric orifice is open, with ragged edges in cases of acute pyelonephritis (Carr *et al.*, 1990). By contrast, the orifice is shrunken and swollen in animals affected with chronic pyelonephritis. Acute and chronic pyelonephritis induce a dramatic shortening of the intravesicular portion of the ureter. The shortening is believed to be caused by bacterial product (Carr *et al.*, 1990). The mucosa of the pelvis and the contiguous part of the ureter is sometimes ulcerated. The tips of the renal pyramids may be grey-green and obviously necrotic. When pyelonephritis is at an advanced stage, yellow bands of degenerating and necrotic tissue extend from the renal medulla into the cortex. Yellow areas of various sizes occur in the kidney, commonly at the poles of the kidneys (Jones, 1982).

Cystitis : *E. suis* induces hyperaemia and oedema of the mucosal surface of the bladder, in some cases with a moderate amount of white, mucinous material and several discrete ulcers covered by a fibrinous exudate (Walker and MacLachlan, 1989). The bladder may contain purulent exudate or calculi (Dee, 1991). Thickening of the bladder wall and polypoid projections of the mucosa are apparent in chronic cystitis (Dee, 1991; Almond, 1992). Cystitis if mild, may be associated with a microscopic haematuria or bacteriuria which may not detected by the stockperson.

Histopathology

The histopathological lesions of *E. suis* infection are localized to the urinary tract and the infection is ascending in nature. The bladder's mucosal surface is haemorrhagic. Histopathologic examination of the ureteric valves from pigs with acute disease or chronic renal failure reveal intense inflammation, necrosis, and subsequent fibrosis. Toxins produced by *Escherichia coli* may have the ability to damage these valves, allowing *E. suis* access to the kidneys (Carr and Walton, 1990).

Treatment

Carr *et al.* (1995) recommend antibiotic sensitivity assay by the Kirby-Bauer method which produces results within 12 to 24 hours and generates little expense. But still, the organism has to be cultured first.

Treatment of individual sows is carried out when renal function is impaired but the blood urea is still less than 15 mmol/litre, in order to save the life of the sow (Carr *et al.*, 1995). Carr *et al.* (1995) recommend euthanasia if the blood urea concentration is greater than 15 mmol/litre, as less than 25% of renal tissue will be functional and few cases have survived without very intensive care.

Walton (1984) conducted an effective treatment programme in a 650 sow breeding unit which had an unacceptably high death rate from *E. suis* pyelonephritis/cystitis. He found it more appropriate to medicate boars at frequent intervals than treat sows once when they become infected. Every 12 weeks all stock boars were treated by inserting into the preputial diverticulum the contents of terramycin intramammary solution (426 mg oxytetracycline hydrochloride (14.2 g tube, 30 mg per g) as the magnesium complex in a propylene glycol base). The boars were treated for over 12 months. He treated the females (which may carry *E. suis* for a varying period of time after service) with oxytetracycline at the time of service. He suggested treatment of boars on a quarterly basis to control the incidence of pyelonephritis/cystitis and to decrease percentage returns to service.

Jones (1982) noted that *E. suis* was sensitive *in vitro* to ampicillin, penicillin, cephalosporins, erythromycin and tetracyclines; it was resistant to sulphonamides, trimethoprim, metronidazole and streptomycin. He recommended penicillin for treatment of promptly detected disease which was often successful. In sows which were more severe in affected or where the disease was several days' duration, treatments were usually unsuccessful. He suggest instillation of antibiotics into the preputial sac as a control measure.

Penicillin and Ampicillin have been recommended by a number of authors including Høgh *et al.* (1984), Jones (1982), Dee (1991) and Carr *et al.* (1995). One advantage of using penicillins when treating renal disease is their enhanced activity at alkaline pH, absence of nephrotoxic side effects, and that antibiotic is excreted in high concentrations via the urine (Fraser, 1986; Gustafsson, 1984). Ampicillin and related compounds have a greater spectrum of activity, which may assist therapy (Fraser, 1986). They are safe to use in pregnant gilts/sows (Dee, 1991).

Dee (1991) notes that *E. suis* induced-renal failure can be successfully treated with 11 mg/kg of ampicillin b.i.d. or 11 mg/kg of penicillin s.i.d. for 3 to 5 days. Dee *et al.* (1995) suggest treatment with penicillin for 3 consecutive days, the third treatment usually consisting of long-acting benzathine penicillin (2.2 mg/kg). In extremely toxic sows with acute renal failure, sodium penicillin should be administered intravenously via the ear vein at 2.2 mg/kg (Dee *et al.* 1995); however, blood levels are relatively short (4-8 hours) (Fraser, 1986; Gustafsson, 1984). Ampicillin should be administered at 2.2 mg/kg twice daily for 3 to 5 days, depending on clinical response (Dee *et al.*, 1993).

The withdrawal time of time of injectable ampicillin is 21 days, while that of penicillin is 7 days (Dee, 1992). In chronic *E. suis* infections, chances of full recovery is poor. Calculi may surround the *E. suis* organism, thus reducing an antibiotic's contact (Lastra, 1982).

Oral administration

Oral administration is used when dealing with a herd problem. If annual adult sow deaths are below 3%, it is unlikely that cystitis and pyelonephritis is a major disease on the farm. However, if annual deaths are in excess of 5% then cystitis and pyelonephritis must be considered and rectified (Carr *et al.*, 1995).

When such outbreaks do occur, water-soluble ampicillin may be used for mass medication (Dee, 1991; Carr *et al.*, 1995). The withdrawal period for the water-soluble form of ampicillin is 24 hours (Dee, 1991; Carr *et al.*, 1995). For this mass treatment to be effective, the entire herd must have free-choice access to the medicated water (Dee, 1991). Water-soluble ampicillin is approved for use in swine, and affected animals are usually thirsty (Carr *et al.*, 1995).

Feed-grade antibiotics are rarely cost-effective because they are rapidly degraded by gastric enzymes, low pH, and colonic bacteria (Gustafsson, 1984) in the gastrointestinal tract, which reduces their bioavailability (Dee, 1991). Feed-grade penicillin is at best 60% available

(Gustafsson, 1984). Levels of 400 g/ton do not come close to the required dosage of 2.2 mg/kg (Carr *et al.*, 1995). Another problem with medicating the feed is that affected animals are usually anorectic. Despite that, some practitioners have had some success feeding sick hogs high levels (>400 g/ton of feed) of tetracyclines (Dee, 1992).

Preputial infusion

Infusing boar sheaths with antibiotic preparations has been effective in some instances (Walker and MacLachlan, 1989; Muirhead, 1986), but only as a short-term solution. It is unlikely that boars would ever be cleared of E. suis, but such preparations may reduce the prevalence of the organism in the preputial sac and reduce its transmission to sows (Dee, 1991). Antibiotic infusions vary in composition from penicillin to tetracycline to ampicillin/gentamicin combinations (Dee, 1991) to nitrofurazone (Muirhead, 1986). During a severe outbreak, the preputial sacs of all herd boars should be flushed with 20 ml of an antibiotic preparation 2 to 3 times (Dee, 1991) or 3 to 5 times (Carr *et al.*, 1995) a week for 3 weeks. After the outbreak has subsided, the infusions can be performed 2 to 3 times monthly as a maintenance program (Dee, 1991; Carr *et al.*, 1995). Carr *et al.* (1995) mentioned that the response to such programmes has been beneficial when used as treatment programme, but it is questionable whether the returns justify the cost and the labour involved when used as a preventive. Such treatment is not a guarantee that a long-term substantial reduction in microflora would occur.

Therapeutic protocols

Carr *et al.* (1995) recommend that affected sows must be loose-housed and exercised to encourage urination. They may need assistance to rise. They must have continuous access to clean water. The sows may even need drenching initially. The addition of electrolytes and lactose to the water will help to restore plasma sodium and bicarbonate concentrations. The addition of water sweeteners may also be useful to encourage water intake.

Carr *et al.* (1995) suggest treating affected sows or boars aggressively. Their chances of recovery can be good if signs are recognized early enough. Antimicrobial therapy is required. Lincomycin (10 mg/kg) as a single intramuscular injection for 3 days has proved clinically useful against *E. suis* (Carr *et al.*, 1995). Treatment with lincomycin and another broad spectrum antimicrobial, such as tetracycline for 5 days is recommended as there are normally mixed infections and the microflora in affected animals is usually complex (Carr *et al.*, 1995).

Response to treatment can be monitored by a reduction in urine pH; the urine will appear to have a more normal yellow colour, its specific gravity will rise and the characteristic ammoniacal smell associated with *E. suis* will disappear. These changes are generally seen within 48 hours of the start of treatment (Carr *et al.*, 1995).

Culling chronically infected animals is usually the most cost-effective measure, particularly if they have become repeat breeders (Dee, 1992) and if farmers are unable to give the sows intensive care (Carr *et al.*, 1995). If the affected animals are pregnant or otherwise valuable, they should be isolated from others to reduce the transmission of infection through urine cross-contamination (Dee, 1992; Carr *et al.*, 1995). Valuable sows should be rested for an entire oestrous cycle before being rebred (Dee, 1992; Carr *et al.*, 1995) to enhance the cleansing of the uterus and regeneration of the endometrial lining (Carr *et al.*, 1995). Proper therapy, such as injectable penicillin or ampicillin at the previously recommended dosage and time, should also be instituted. *E. suis*-infected boars should be allowed to serve only these sows, thereby preventing the spread of infection throughout the herd (Dee, 1992).

Carr *et al.* (1995) recommend oxytetracycline injection at weaning followed by in-feed medication, at 400 g oxytetracycline per ton for 21 days, which can offer a temporary solution to cystitis and pyelonephritis in the herd. During the post service period, the average sow consumes 2.5 kg of feed per day and so will only receive 1 g of oxytetracycline per day(equivalent to a dose of 5 mg/kg for a 200 kg sow; Carr *et al.*, 1995).

Nutritional therapy

Acidifying the urine to reduce the multiplication of urinary pathogens that require alkaline conditions. Nutritional modifications such as adding vitamin C, D-L methionine, or ammonium chloride to the feed as well as increasing crude protein by 2% will lower urine pH (Dee, 1992). Diets for sows should contain 0.35 to 0.5% salt to increase sows' water consumption (Dee, 1991) but this requires that water supply must be adequate. Practitioners should work closely with a swine nutritionist to ensure that changes in the ration do not reduce its nutritional value or the hogs' feed consumption (Dee, 1991).

Acidifying alkaline water supplies has helped on some farms, possibly through making the water quality more acceptable to the sow and thereby assisting intake. Acid also helps to remove deposits in the pipeline, hence increasing the water flow (Carr *et al.*, 1995).

Prevention

With the high prevalence of E. suis infection on today's hog farms (ranging from 33 to 61%) (Pijoan *et al.*, 1983), it is better to prevent the problem than to rely on frustrating long-term, expensive antibiotic therapy (Dee, 1991).

Limiting exposure to the organism can be achieved. The sows' places must be clean. Proper gestation housing design is essential to avoid a wet, dirty environment. Dee (1991, 1992) notes that ideally, the length of the slatted portion should range from 3 to 4 feet and slats should be 4 inches wide, with 1 inch gaps. Although as yet unproved, new types of slatted flooring look promising, particularly those with slats that run perpendicular to the direction the sow is standing. In these designs, the gaps between slats become wider toward the back of the stall, reaching up to 1½ inches wide. The edges of the slats must be smooth. The solid portion of the floor should slope gently toward the slats. The layout should be properly constructed to facilitate manure removal (Dee, 1992). If the animals are to be housed in pens, proper square footage should be provided. Pregnant sows should be provided 20 square feet per sow; pregnant gilts require 15 feet. If the animals are cycling, an additional 5 square feet of pen space is required. Sow numbers should not exceed 6 to 10 per pen (Dee, 1992).

Carr *et al.* (1995) recommend twice a day feeding to promote activity, resulting in increased frequency of urination. They also recommend that water quality should be of a standard suitable for human consumption. Dissolved solids and a high mineral content can affect the palatability of water and can form deposits, reducing flow; acid may be added to the water line to remove deposits. The farm should have a tank holding 24 hours' water supply. Drinking devices should be suitable and provide enough flow for sows. In a pen, nipple and bite drinkers should be at a minimum of 2 drinkers per pen, with at least 1 drinker between 8 to 10 sows and 2 metres apart. Drinking devices must provide water at a suitable flow rate at a low pressure. Suitable flow rates from bite and nipple drinkers are 1.5 to 2.5 litres per minute. Observations on sows drinking from a trough have revealed that they may drink 3 litres of water in about 45 seconds. Position of nipple or bite drinkers should be just above animal shoulder height, i.e., at 76 to 90 cm for adults. Bowl drinkers should be large enough for the sow's lips and nose to enter the bowl, Trough drinkers should be of mid-chest height. The depth of water in a trough should be 4 cm. Food left over from anorectic or removed sows must be cleaned up, as it can block the water drainage system.

Artificial insemination has been successful in reducing deaths from cystitis and pyelonephritis. This may be in part due to the general absence of *E. suis* and other potential bacterial pathogens in diluted semen to which antimicrobial agents have been added, and to the increased awareness of service hygiene by the stockmen that artificial insemination demands (Carr *et al.*, 1995).

Increasing the lactation length from 21 to 28 days has reduced cystitis and pyelonephritis on several farms, presumably because there is more time for any damage to the urogenital tract to heal (Carr *et al.*, 1995).

When hand-mating swine, producers should wear plastic disposable gloves to minimize transmission of contaminants on their hands. Faecal material around the vulva or prepuce should be removed with a paper towel before mating. Each sow should be given an intramuscular injection of 2.2 mg/kg benzathine penicillin after an assisted farrowing.

Older sows are more prone to urogenital disease and culling is often the most cost-effective measure in preventing urogenital disease.

Animal's mating area should be cleaned with disinfectants. Phenol (Dee, 1991; Dee *et al.*, 1993), 3% iodine, 5% hypochlorite, formaldehyde (Dee *et al.*, 1993) and quaternary ammonium compounds (Dee, 1991) were capable of inhibiting growth of *E. suis* at the manufacturer's recommended rates of dilution (Dee *et al.*, 1993). Iodine at 3% was the disinfectant that demonstrated ability to inhibit growth of *E. suis* and would be nonirritating if applied directly to the animal, so it can be used effectively in conjunction with a lubricant for coating plastic sleeves before farrowing assistance is given (Dee *et al.*, 1993). Quaternary ammonium compounds can be inactivated by urine or faeces so pens must be thoroughly cleaned before application of a disinfectant (Dee, 1991). *E. suis* was isolated from the plastic sleeve used by a farrowing house manager after assisting the piglets through the vaginal canal, although the sleeve had initially been coated with chlorhexidine surgical scrub (Dee *et al.*, 1993) so sleeves should be changed as often as possible.

Although *E. suis* has not been reported officially in New Zealand, the organism has been isolated from the bladder of culled sows. It is important to handle those infected sows and boars with a proper hygienic technique so as not to spread the disease. Sows may not show signs, or farmers may not recognize this disease; the disease continues to spread among farms and can be a major source of loss in the future. Slaughter check of culled sows is of value in assessing the prevalence of the condition.

Slaughtercheck findings

Dial and MacLachlan (1988) commonly observed acyclic ovaries and either chronic endometritis or pyometra in lactating culled sows at slaughter.

Ovary

Einarsson and Linde (1974) examined 54 "anoestrus" gilts with a mean age of 10.8 months at slaughter:

35.2% of the gilts slaughtered because of failure to exhibit oestrus had no luteal tissue in their ovaries and had never ovulated. In 14 of 19 gilts, the ovaries contained follicles of up to 5-8 mm size, and the ovaries in the remaining 5 contained only small follicles. Twenty-five gilts had solid Cl in combination with small follicles in their ovaries and 3 were pregnant. Cystic corpora lutea, normal corpora lutea and follicles which had not ruptured were commonly observed on the same ovary. The walls of luteinized cysts were as a rule thin, but contained patches of luteal tissue 2-3 mm thick, although the thin walled parts of the cysts contained no luteal tissue. Of these gilts examined at 7-8 months of age, 85.7% had no luteal tissue in their ovaries, compared with 11.1% age ≥ 10 months. The mean age was also higher for gilts with cystic Cl and/or cysts in their ovaries.

Roberts (1986) also found that a high proportion (42%) of "anoestrus" gilts had active corpora lutea and explained the finding as due to poor observation of signs of heat and/or lack of signs of oestrus. The prevalence of anoestrus is higher in gilts kept in cages than in gilts moving free in boxes, and gilts having their first oestrus later than normal are more likely to exhibit either weak signs or no signs of oestrus at all (Einarsson and Linde, 1974).

Cutler *et al.* (1981) examined the tracts of 5143 sows and found that 27.1% overall had inactive ovaries, whereas the prevalence of inactive ovaries in lactating sows was 82%. In the non-pregnant group of sows, 53.6% of ovaries contained corpora lutea. Corpora lutea were frequently found in conjunction with follicles which had failed to ovulate, some of which had grossly visible luteal tissue. One or more cystic corpus luteum was present in every 24.5 pairs of ovaries (on average) examined.

Oviduct

Blockage of the oviducts was reported as the most common finding in females culled for infertility Cutler *et al.* (1981). Oviduct cysts were recorded in 0.3% of sows, none of which were pregnant. Local diverticulization of the oviduct wall was observed in 0.2% of non-pregnant sows and in one pregnant sow. Hydrosalpinx was observed in 0.55% of non-pregnant sows and 0.2% of gilts but never in pregnant pigs.

Uterus

A condition grossly resembling cystic endometrial hyperplasia was observed in 1.7% of non-pregnant sows in the study by Cutler *et al.* (1981).

Season of year

The prevalence of anoestrus varies from 20 to 40% in both gilts and sows in the summer months, which is the time of year when it is most common (Roberts, 1986). Cutler *et al.* (1981) found a higher percentage of immature reproductive tracts during late summer in gilts slaughtered routinely throughout the year. The proportion of gilts showing normal oestrous cycles at nine months of age was lower for gilts reared during summer, than for gilts reared during the winter. The influence of factors other than light factors in regulating fertility in the summer months confounds the role of light in swine production. The strong confounding influence of lactation was demonstrated by Cutler *et al.* (1981) who found that 82% of lactating sows had inactive ovaries at slaughter.

Culling pattern

The rate at which sows are culled strongly influences the profitability of pig enterprises. An optimal culling rate balances parities of sows to make the best use of the highest productive parities (3-5). Increasing the culling rate to a high level in sow herds will result in a high percentage of gilts among the female breeding stock and is reflected by a low average number of litters per sow, if production is to be held constant (Svendsen *et al.,* 1975).

Richardson (1994) shows the effect of two culling rates on sow productivity in Table 4-5:

Table 4-5: The effect of two removal rates (36.9% and 41.06%) on sow productivity in two different years

	1983	1992
Sows sales and deaths (%)	36.9	41.0
Sow lifetime (years)	2.71	2.44
Pigs reared/sow/year	20.5	21.5
Pigs reared/sow lifetime	55.6	52.6

From Richardson (1994)

Jones (1967) reported a loss of 37.2% of sow from death and culling in a herd of 124 sows over one year. This rate of loss, expressed in terms of population turnover, implies a complete change every 2.7 years. Death accounted for 10.1% of the losses and two-thirds of the deaths occurred during winter months. The single most important cause of death was urinary tract disease and it was responsible for at least 20% of all deaths.

The finding from 8 separate studies which detailed the reasons for culling are presented in summary form in Table 4-6.

Table 4-6: Summary of separate studies detailing the percentage of pigs which were culled for the various reasons set out in the left-most column

	Source						
Removal Reason	***1***	***2***	***3***	***4***	***5***	***6***	***7***
Reproductive Failure		32.3		39.2		29.6	
Not-In-Pig							18
Anoestrus				5.4			11
Aborted				2.8			2
Failure to Breed				31			
Peripartum Difficulties	21.4		41.8	4	37.5	5	
Inadequate Performance	32.5		9	4.6	13.8	9.4	
Small Litter Size							10
Lactation Problems						8.8	
Udder Problems	6.1		2.5	2.3	0.6		
Mammary Dysfunction		5.6					
Rearing Ability							3
Age	15	8.1	29.1	27.2	24.4		19
Health Problems							3
Degenerative Problems						17.9	
Specific Systemic disease						0.8	
Disease	7.5		1.4	1.3	3.3		
Posterior Paralysis		12.1					
Rectal Prolapse		8.9					
locomotor Disturbance			9.4		11.8	11	
Lameness		22.6		88			9
Death				6.5		10.7	12
Transfer						0.3	
Miscellaneous	17.5	10.4	6.8	2.2	8.6	6.6	13

1=Pomeroy (1960), 2=Jones (1967), 3=Dagorn and Aumaitre (1969), 4= Pattison (1980), 5=Stein (1988), 6=Richardson (1994)

Dagorn and Aumaitre (1979) separated the culling pattern into:

- Voluntary culling : for old age, lowered productivity
- Enforced culling : for pathological reasons and other conditions, e.g. farrowing difficulties, milk let down failure and udder disease, lameness, respiratory disease and infectious disorders.

Enforced culling imposes a severe restriction on the purposeful culling component and influences the amount of pressure for desirable genetic qualities and characteristics which can be applied (Jones, 1967).

In a more recent study by Richardson (1994) only 32% of sows were culled because of a positive management decision, notably for age, rearing ability and small litter size, all of which may be classed as reproductive failure. Sow lameness and deaths accounted for a further 20% which simply failed to cope with the production system, and this group reduced the culling pressure that could be applied to sows with low productivity. Twenty-two percent of young sows were culled due to failure to show oestrus post-weaning and a further 30% failed to conceive, giving an overall total of 52% of young sows, which were culled for reproductive failure after only one or two litters (Richardson, 1994).

Jones (1967) reported that enforced culling account for 27.1% of the sows loss. When the ages of the culled sows were examined, it was of concern to find that over 405 of discarded sows did not reach 3 years of age. Thus, not only does the expected potential of such animals remain unfulfilled, but the capital invested in rearing them is poorly rewarded.

In a study of the 1975-1976 records of 106,242 sows (1049) herds in Frances, Dagorn and Aumaitre (1979) found that voluntary culling accounted for 29.2% of the reasons determined for culling. The average number of litters weaned in these sows during their reproductive life was 7.4 litters. Poor litter size at birth and at weaning were reasons for culling 8.4% of the sows from which only an average of 6.6 piglets were weaned per litter during their reproductive life. Enforced culling accounted for 24.9% of the reasons for culling. Failure to breed after one or several matings was a major reasons for culling and applied to 31% of the culled sows. On-farm deaths were responsible for a further 6.5% of all culls.

The intensity of culling for breeding failure was higher in sows weaned during the summer time (about 35% during June, July and August) and lower in sows weaned in January (27.2%). The intervals between weaning and a fertile mating decreased as the litter number at culling was raised; and the intervals between the last weaning and culling had a marked effect on the number of piglets weaned per sow per year. However for all sows in the herd, litter productivity was low, except for sows with more than six litters (Dagorn and Aumaitre, 1979). Early culling is influenced by many factors, including nutritional status of the young gilts during their early life, mating at an early age, and environmental and housing conditions. An increase in the percentage of sows discarded during the summer may be directly associated with seasonal disturbances in reproductive performance, and in particular, with the increased weaning-fertile mating interval encountered during hot periods. No effect on culling could be associated with early weaning practices (Dagorn and Aumaitre, 1979).

Svendsen *et al.* (1975) reported that within the Danish Observation and Control Herds, 40 to

50% of the year-sows [1] are replaced annually. A high culling rate in sow herds results in a high percentage of gilts among the female breeding stock if overall production is to be maintained at the same level, and results in a low average number of litters per sow. The number of culled sows per year averaged 239.0, which equates to a culling rate of 0.548 per sow year and the number of culled sows as a percentage of farrowings was 25.8%. The culling rate in sow herds appears high, at 0.548 per sow year, or 0.4 for individual sows. In order to maintain the same level of production in terms of litters, an average of 26% of the farrowing animals in a herd would need to be primiparous. The average number of litters produced per sow before culling was 3.6 but 26.4% (252 sows) of the culled sows only produced 1 litter. Arthritis, osteomyelitis or endocarditis accounted for 25.5% of the deaths or euthanasias, and most of these cases occurred in sows with three or more farrowings. Pyelonephritis and/or cystitis was encountered in 9.6% of the cases. Death was attributed to central circulatory failure in 15% of cases. Fractures or apophysiolysis occurred in 7.0% of the cases with apophysiolysis occurring almost exclusively in primiparous animals. A total of 9.6% of the culled sows were dispatched because they had been suffering from mastitis, metritis and/or agalactia.

Culling policies

Culling policies affect the length of the farrowing interval and consequently the average number of piglets weaned per productive sow per year. Good oestrus detection, control of mating and a policy of culling infertile sows are the most important factors for ensuring high productivity. When advising pig breeders, good health management practices and the need to produce a sufficient number of replacement gilts to allow infertile animals to be discarded as soon as possible after weaning, should be emphasized (Dagorn and Aumaitre, 1979).

The culling rate influences herd performance in a variety of ways. Enforced culling reduces the scope for objective culling and selection of animals with desirable characteristics. Culling a high proportion of animals before they reach their peak in terms of litter size will influence average herd litter size. Problems associated with the supply of replacement female animals may lead to a sub-optimal sow population and reduced throughput. High culling rates require increased numbers of replacement animals and leads to a high proportion of young animals in the herd, with concomitant increased health risks. Over-vigorous culling has been shown to increase the whole herd farrowing interval and to reduce output. Efficient oestrus detection,

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[1] "Year-sow" was defined as 365 sow feeding days per year. Thus, the number of year-sows in a particular herd was calculated by adding the number of feeding days during a year for each animal, beginning at the date of the first farrowing, and dividing the resulting total by 365 (Svendsen *et al.*, 1975).

control of mating, a policy of culling infertile sows at an early stage and the precision of supply of sufficient numbers of replacement gilts are all important factors in the drive to maximize herd output. While these may be looked upon to some extent as palliative measures, in that they minimize the effect of high levels of culling, it is equally important to understand the factors predisposing to the high level of wastage of young sows, which are caused in the main by impaired reproductive performance and lameness (Pattison, 1980).

In pig production, substantial economic loss is involved in early culling of sows due to low fertility, leg problems, etc.. Kroes and van Male (1979) analysed data from 15,000 services on 85 commercial pig farms (Netherlands) to quantify the importance of these losses. They found that the cost price per weaner was highest for the first litter and decreased over the next two litters, with the "remainder life value"[2] reflecting the expectations per individual sow for its further productivity. If a sow, for whatever reason, has to be culled directly after weaning, the damage is equal to the remainder life value. If she is culled at a later stage in the reproductive cycle, there is an additional loss equal to the costs of housing and maintenance during the non-productive days. The culling rate has a great impact on the composition of the sow herd. High culling rates and difficulties in supply for immediate replacement of culled animals will lead to a sub-optimal sow population, with an additional negative economic effect. High culling rates necessitate many replacement animals which, if purchased, will carry with them an additional health risk (Kroes and Van Male, 1979). A high culling rate will result in a high percentage of first and second litters produced in a herd. Baltussen (1985) considered an average culling rate of 40-50% per year to be generally acceptable and this level would be still acceptable at present.

Kroes and Van Male (1979) studied the effects of low average and high culling rates on farm productivity. Summary data from that study are presented in Table 4-7:

[2] "remainder life value" was an indication of the expected profit per sow in the remainder of her productive life, assuming a weaner price of Dfl. 115 at 22 kg. The remainder life value reflects the expectations per individual sow for its further productivity. If a sow has to be culled at a later stage in the reproductive cycle, there is an additional damage equal to the costs of housing and maintenance during the non-productive days (dfl. 4 per day) (Kroes and van Male, 1979).

Table 4-7: The effect of low average and high culling rates on productivity and costs of production

	Low culling rate	Average culling rate	High culling rate
Litter/sow/year	2.06	1.97	1.89
Weaners/sow/year	17.9	17.1	16.4
Cost price/weaner (Dfl.)	108.05	111.91	116.12
Labour income/sow (Dfl.)*	556	485	413

*Labour income - all income minus all costs excluding labour.

Baltussen (1985) studied the effects of annual replacement rates varying from < 30% to 55% on productivity. His summary results are presented in Table 4-8.

Table 4-8: The effects of varying levels of replacement rate on sow productivity

	Results at a replacement rate of			
	<30%	30-35%	35-45%	45-55%
Number of farms	51	59	159	121
Average replacement rate (%)	25	33	40	50
Litter per sow per year	2.06	2.12	2.09	2.07
Piglets born alive per litter	10.4	10.3	10.2	10.2
Piglet mortality rate (%)	14.4	14.6	14.7	15.7
Piglets raised per litter	8.9	8.8	8.7	8.6
Piglets raised per sow per year	18.4	18.7	18.2	17.0
Age at weaning (days)	34	32	32	32

Farrowing index

The number of piglets weaned per sow per year in a herd is the product of the number of litters produced per sow per year and the number of piglets weaned per litter. The number of litters produced per sow per year (farrowing index) is calculated as the total number of litters farrowed in a year divided by the average number of sows in the herd. Most of the increase in the number of piglets weaned per sow per year during the 1970"s and early eighties was achieved by reducing lactation length which pushes the farrowing index higher (Baltussen, 1985).

Dagorn and Aumaitre (1979) studied the association between the number of litter per sow up to culling on productivity, measured in terms of piglets weaned per productive sow per year and per sow present per year. Table 4-9 shows their summary data and illustrates a positive association between the number of litter per culled sow and productivity.

Table 4-9: Sow productivity data in relation to the number of litters per culled sow

	Litter per culled sow				
	<3	3-3.99	4-4.99	5-5.99	>=6
Number of farms	154	247	281	211	156
Lactation length (days)	31.1	32.6	32.2	32.6	32.0
Piglets born (total) per litter	10.17	10.58	10.58	10.69	10.79
Piglets weaned per litter	8.25	8.53	8.51	8.61	8.71
Piglets weaned					
per productive sow per year	18.1	18.7	18.8	19.0	19.4
per sow present per year*	15.5	16.5	16.7	17.1	17.6

*The sow was considered as present from 210 days of age until discarding. From Dagorn and Aumaitre (1979).

The highest number of piglets raised (to about 23 kg) per sow per year was found on farms with a replacement rate of 30-35 percent. With 2.12 litters per sow per year this means a replacement rate of approximately 15.5% per reproductive cycle. Piglet mortality was high on farms with a replacement rate of 45-55%.

Kozma (1985) could not demonstrate any effect of mating age (<210 to >340 days) on the number of piglets born or weaned per litter in first and later parities. However, gilts mated before 210 days of age and also those mated after 320 days of age were culled at a higher rate.

Reducing lactation length to about 3 weeks is known to improve herd productivity (te Break, 1978). Although it might be thought that a higher reproductive rhythm because of a reduced lactation length would result in a higher annual culling rate, in practice, the differences in replacement rate among farms have not been associated with age at weaning.

The sow productivity index is meant only for use as an aid in culling sows on the basis of their expected productivity and should not be confused with a breeding value estimate. The productivity index predicts the future value of a sow and is estimated from already realized production. If the expected productivity of a sow in the next litter(s) is lower than the expected value of an average replacement gilt, then culling is indicated. The expected value of an average replacement gilt is the value of an average sow up to the time of culling. Van der Steen (1985) considered that litter size at birth (total born), the proportion of piglets weaned and the interval from weaning to mating were the most important traits to be included as components of the productivity index. However, low correlations (about + 0.2) were found between predicted and true values for these traits (te Brake, 1986).

Achieving high productivity

Herd productivity is adversely affected by a high culling rate and culling policies should be aimed at achieving high herd productivity. An effective policy starts with introducing gilts which are able to produce many litters into the herd . A high rearing intensity, i.e. a high level of feed or energy intake during rearing, is detrimental to lifetime performance but the need to mate gilts at about 6 months of age in order to farrow at about 300 days of age has to be taken into consideration and balanced with high lifetime performance. Culling of sows is not influenced by age at weaning, and reducing lactation length to about 3 weeks will increase herd productivity. Remating animals which have returned twice is not recommended. Pregnancy diagnosis is particularly useful for eliminating non-pregnant animals which are returning late to oestrus or are not showing any heat signs after mating.

The average annual culling rate in commercial sow herds varies between 35 and 50% (Dagorn and Aumaitre, 1979; Kroes and van Male, 1979; Dijkhuizen *et al.*, 1989; D'Allaire *et al.*, 1989; Stein *et al.*, 1990; Ridgeon, 1991). Reasons of below par productivity and inadequate reproductive performances account for more than half of the annual replacements. The decision to cull a sow for either of these 2 reasons is usually based on economic considerations. A sow is replaced, not because she is no longer able to produce in a biological sense, but because a replacement gilt is expected to yield more (Dijkhuizen *et al.*, 1986). The benefits of improved herd life are especially dependent on the replacement cost, which is the difference in price between replacement gilts and culled sows (Dijkhuizen *et al.*, 1986; Huirne *et al.*, 1991). A thorough consideration of this type of decision has to be made under varying circumstances of production and price.

The number of litters per sow per year is influenced by the farrowing interval and the number of non-productive days (i.e. the interval from weaning to culling) of culled sows. An increase in farrowing rate allows a decrease in culling rate, an increase in the number of pigs sold per sow per year and an improved gross margin. An increase in slaughter value or an increase in price of a replacement gilt results in a higher culling rate, since more sows are culled voluntarily. Huirne *et al.* (1991) showed that optimal replacement decisions for individual sows are most sensitive to changes in the replacement cost, which is the difference between the price of replacement gilt and the slaughter value of culled sows. A reduction of this difference results in a lower rate of voluntary replacement. Huirne *et al.* (1991) concluded that the optimal replacement decisions are not very sensitive to changes in feeder pig price and litter size.

The number of pigs sold per sow per year is often used as a starting point in evaluating the performance of sow herds. Differences in economic results are mainly related to differences in culling rate. High culling rates affect productivity by shifting the herd age distribution towards younger sows with lower production sow days. For example, when studying the effect of changes in farrowing rate, the number of pigs weaned per sow per year was affected by the changes in number of non-productive days of sows. The conclusion can be drawn that the number of pigs sold per sow per year has limited potential as an economic indicator when comparing reproduction and replacement strategies (Jalvingh *et al.*, 1992).

Decisions concerning reproduction and replacement should be taken at defined points in time such as immediately after weaning when sows have not conceived and replacements are gilts. Disposal due to other reasons, e.g. leg problems, diseases and accidents, and mortality of the takes place at weaning, reflecting the disposal of animals that should have been culled in an earlier stage, but were depth to finish their current cycle and raise a litter (Dijkhuizen *et al.*, 1989).

When farrowing rates are reduced, the annual culling rate in a herd increases, since more sows are culled for reproductive reasons. The culling rate becomes very high when the oestrus detection rate before first insemination is reduced. The economic relevance of oestrus detection rate after first insemination is rather low, since it affects only a fraction of the sows, viz. those that do not conceive after first insemination and will come in oestrus again (Jalvingh *et al.*, 1992).

Conclusion from literature review

Herd productivity and profitability is optimised at a replacement rate of 30-40% of sows per year. Increased enforced culling restricts purposeful culling and selection of animals, leads to higher proportion of young pigs in the herd, slows genetic improvement and causes substantial economic losses from early culling of sows. Oestrus detection and pregnancy diagnosis are important management practices which assist culling decisions and better control of non-productive days.

Slaughter checks of reproductive tracts are indicated in herds with high replacement rates and poor reproductive performance and are also useful for regular monitoring of herd performance. Record of culling reason is important in epidemiological point of view and the accuracy of culling decision can be improved by slaughter check.

The procedure needs to be carried out carefully by experienced operators if precise epidemiological estimates of disease and altered states are to be obtained and used to advantage in decision making processes which affect herd productivity and profitability.

Physiological and pathological study of cull sows/gilts at slaughter

The objective of this study was to determine the physiological and disease states of cull sows/gilts sent for slaughter and to assess the validity of farmer decisions for culling those particular animals.

Materials and methods

All cull sows/gilts from two commercial pig farms (a 370 sow unit in the Wairarapa and a 250 sow unit in the Manawatu region of the North Island of New Zealand) which were sent for slaughter during a 3 month period between 9/8/1994 and 15/11/1994 were examined at slaughter.

The animals were sent for slaughter on Tuesdays and Wednesdays of each week and the observer was informed of the numbers of animals and their identifying ear tags on the day before slaughter.

Reproductive tracts, ovaries, urinary bladder and kidneys were collected at the veterinary inspection point of the slaughter process and stored separately with identifying ear tag in plastic bags prior to transport to Massey University for further examination.

Gross examination

The organs were first examined for gross abnormalities. At this stage, based on ovarian examination, the animals were also categorized into follicular, luteal or anoestrus phases of the oestrous cycle.

Follicles, 5-10 mm in diameter, were considered indicative of pro-oestrus to oestrus, corpora lutea of 2-10 mm as early luteal phase , and regressing corpora lutea and small follicles <5 mm as late luteal phase (Bara and Cameron, 1994). Gilts with follicles <5 mm in diameter and no corpus albicans were classified as anoestrus.

The volume and size of ovaries (measured along the longest, widest and thickest axes) and the diameter and thickness of the uterus (measured at the mid points of the uterine horns) were recorded, along with any uterine abnormality or evidence of cystitis.

Bacteriology

Swabs from bladders of sows with signs of cystitis were collected and several were submitted for culture to detect the possible presence of *Eubacterium suis*.

Histopathology

After fixation in 10% neutral buffered formalin for at least 1 week, specimens of vaginal and uterine walls were embedded in paraffin, sectioned at 3 μm, stained with haematoxylin-eosin (HE) and examined microscopically. The types and density of inflammatory cells were recorded and the thickness of the epithelial layer of the endometrium measured.

Endometritis was classified according to criteria established by de Winter *et al.* (1992) and with due consideration to the phase of the oestrous cycle. If the number of neutrophils was considerably higher than normally seen in oestrus conditions and if no alterations on the epithelium of the endometrium or endometrial glands was noticed, the case was considered as moderate acute endometritis. If the number of neutrophils was greatly increased and if the epithelial cells of the endometrium and/or endometrial glands had been damaged, the case was considered as severe acute endometritis. If the number of lymphocytes, plasma cells and histiocytes was considerably higher than normally seen in oestrus, the case was considered as chronic endometritis. If the numbers of both neutrophils and lymphocytes were increased, the diagnosis was subacute endometritis.

Classifications used for analytical and descriptive purposes

On the basis of gross lesion distributions in other than the reproductive system, animals were classified as (a) normal, (b) as having disorders of the urinary system, or (c) as having disorders of the gastrointestinal system, or (d) as having other miscellaneous conditions.

On the basis of gross examinations of the reproductive tract, animals were classified as (i) normal (*ie.* cycling), (ii) pregnant, (iii) inactive ovaries, (iv) cystic ovarian disease, (v) uterine pathology (pyometra, macerated foetus, cervicitis, endometrial hyperplasia) or (vi) with scarring of the ovaries.

Reasons for culling were taken from farmer records and were classified as reproductive failure (fail to farrow, abortion, negative pregnancy test), inadequate farrowing or weaning performance (including poor farrowing productivity and small litter size), lactation problems, leg weakness or lameness, degenerative problems or old age, miscellaneous condition including rectal prolapse, and also transfers and management decisions.

Data analysis

The software program, Statistica ® version 5 (StatSoft, Tulsa, was used to produce descriptive statistics and for all statistical analyses.

Results

Culling patterns, reasons for culling and gross and histopathological findings

Thirty nine gilts/sows (81.25%) were culled after weaning, 7 sows (14.58%) were culled after mating, 1 sow (2.08%) was culled after farrowing and 1 sow (2.08%) was culled after abortion (Table 4-10).

Table 4-10: Descriptive statistics of culled gilts/sows showing the relationship to time of culling to weaning, mating, farrow and abortion

Time of culling	Valid N	Mean (95% CL)	Median	Min-Max	Lower-Upper Quartile	Quartile Range	SD
After weaning	39	6.33 (14.86-7.8)	5	0-23	4-6	2	4.53
After mating	7	50.86 (32.75-68.97)	49	29-77	32-69	37	19.58
After farrowing	1	7	-	7-7	-	-	-
After abortion	1	1	-	1-1	-	-	-

Min-Max = minimum-maximum, SD = Standard Deviation

Thirty nine gilts/sows (81.25%) were culled at an average of 6.25 days after weaning. One sow was culled for management reasons 23 days after weaning. She was used to nurse piglets from other sows. Seven gilts/sows were culled post-mating. Two were gilts with the reason for culling given as failure to farrow. Both were grossly normal and close to ovulation and histopathology indicated chronic endometritis in one and absence of any disorder in the other.

Two sows were culled during pregnancy on account of rectal prolapse in one and lameness in the other. The lame sow was classed as an error of judgment in culling as she was culled at 69 days after mating and would reasonably have been expected to complete the pregnancy. The sow with rectal prolapse was at 77 days of gestation, the condition was severe and the gross findings fully justified the decision to cull.

Of sows culled after mating, four sows were culled because of lameness; chronic endometritis was found in 1 gilt and 2 sows, and subacute endometritis was found in 1 sow. If pregnant sows are excluded, the sows were culled at an average of 46 days after mating. The significance of substantial delays in culling after mating as a component of non-productive days, and the value of accurate pregnancy diagnosis in minimizing that delay period have been discussed elsewhere in this thesis. One sow was weaned the day after farrowing and was culled 6 days later for reasons of low farrowing productivity.

Culling and stage of oestrous cycle

Of the culls, 62.5% were in follicular phase, 22.92% were in luteal phase, 12.5% were anoestrus, and 2.08% had aborted (Table 4-11). One (2.56%), 8 (20.51%), 12 (30.77%), 2 (5.13%), 2 (5.13%), 1 (2.56%), 1 (2.56%), 1 (2.56%) follicular stage sows were culled 0, 4, 5, 6, 7, 11, 12, and 18 days after weaning, respectively.

Table 4-11: Cull gilts/sows classified according to stage of oestrous cycle

Phase of oestrous cycle	*Count*	*Percent*
Follicular	30	62.50
Luteal	11	22.92
Anoestrus	6	12.50
Abortion	1	2.08

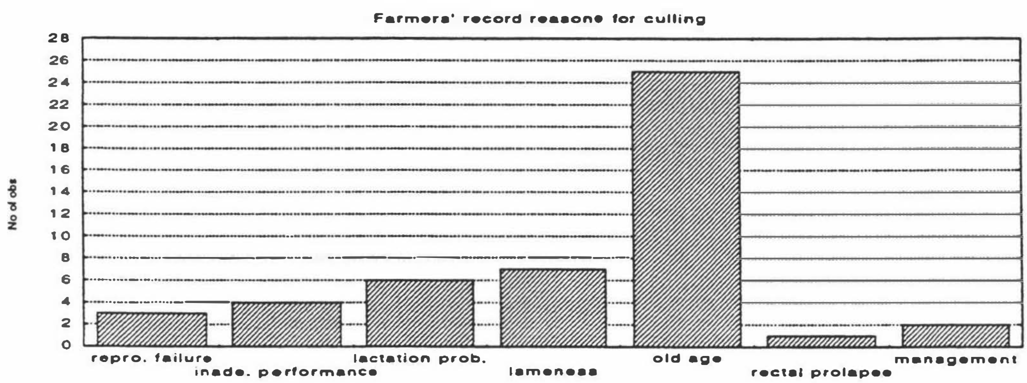
Reasons for culling

Table 4-12 and Figure 4-1 show the frequency of farmers' reasons for culling. The average parity of those culled for old age was 7.12. Overall, 37 animals (77.08%) were culled as a result of positive management decisions and for 11 animals (22.92%) there were enforced culling reasons (lameness, reproductive failure, and rectal prolapse).

Table 4-12: Frequency of farmer reasons for culling gilts/sows

Farmers' record reasons for culling	*Count*	*Percent*
Reproductive failure	3	6.3
Inadequate farrowing or weaning performance	4	8.3
Lactation problems	6	12.5
Lameness	7	14.6
Old age	25	52.1
Miscellaneous	1	2.1
Management	2	4.2

Figure 4-1: Histogram of farmer reasons for culling gilts/sows



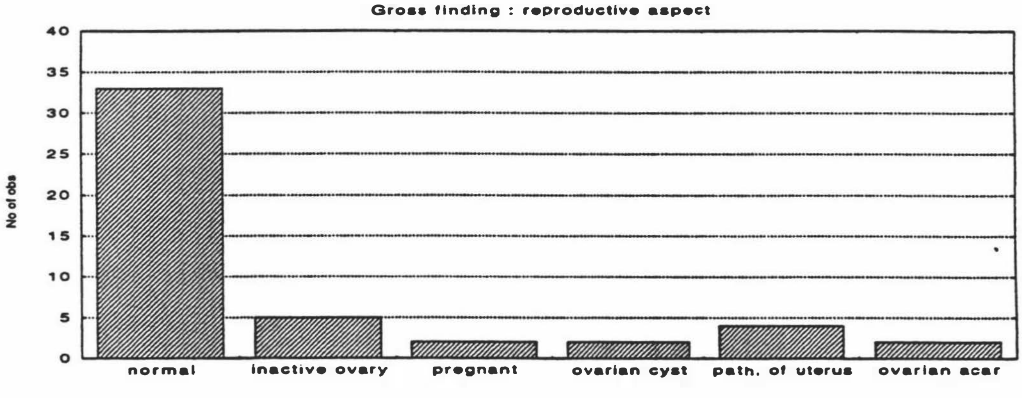
Gross examination of the reproductive tract

Table 4-13 and Figure 4-2 show how culls were classified following gross examination of the reproductive tract.

Table 4-13: Classification of culls according to findings from gross examination of the reproductive tracts

	Count	*Percent*
Normal	33	68.75
Inactive ovaries	5	10.42
Pregnant	2	4.17
Cystic ovarian disease	2	4.17
Uterine pathology	4	8.33
Ovarian scar	2	4.17

Figure 4-2: Classification of culls according to findings from gross examination of the reproductive tract



Grossly detectable conditions other than reproductive disorders

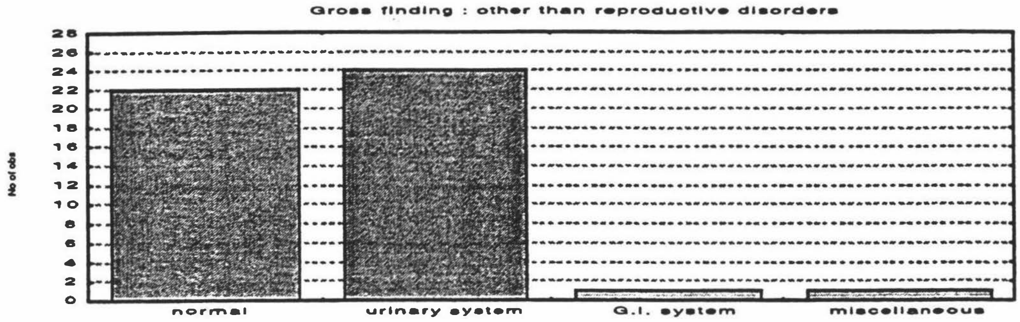
Table 4-14 and Figure 4-3 show the frequency of occurrence of grossly detectable conditions other than disorders of the reproductive system.

Table 4-14: Frequency of grossly detectable conditions other than reproductive disorders in culled gilts/sows

	Count	*Percent*
Normal	22	45.8
Urinary system disorder	24	50
Gastric ulcer	1	2.1

Miscellaneous	1	2.1

Figure 4-3: Histogram showing frequencies of culled gilts/sows with gross findings other than reproductive tract disorders



Agreement between farmer reasons for culling and findings from gross examinations

Table 4-15 and Table 4-16 show the levels of agreement and disagreement between farmer reasons for culling and gross findings by the investigator. Only 2 sows (4.17%) were considered as producing disagreement, whereas 46 gilts/sows (95.83%) were considered as in agreement.

Table 4-15: Cross-tabulation of farmer reasons for culling and findings from gross examinations where there was no apparent conflict between the observations for 46 gilts/sows

Farmer's reason for culling	*Gross findings*
old age	just ovulated, hydronephrosis
old age	non cycling
old age	cycling
old age	just ovulated
lameness	mild cystitis
lameness	fluid from endometrium
lameness	just ovulated
lactation/weaning problem	cycling
lactation/weaning problem	vulvitis
small litter size	cycling
management	cycling
poor farrowing productivity	non cycling
rectal prolapse	pregnant
abortion	abortion
fail to farrow	just ovulated

Table 4-16: Cross-tabulation of farmer reasons for culling and findings from gross-examinations in 2 sows where there was lack of accord between the observations

Farmer's record	Gross findings
old age (parity 3)	non cycling
lameness	pregnant

Culling and parity

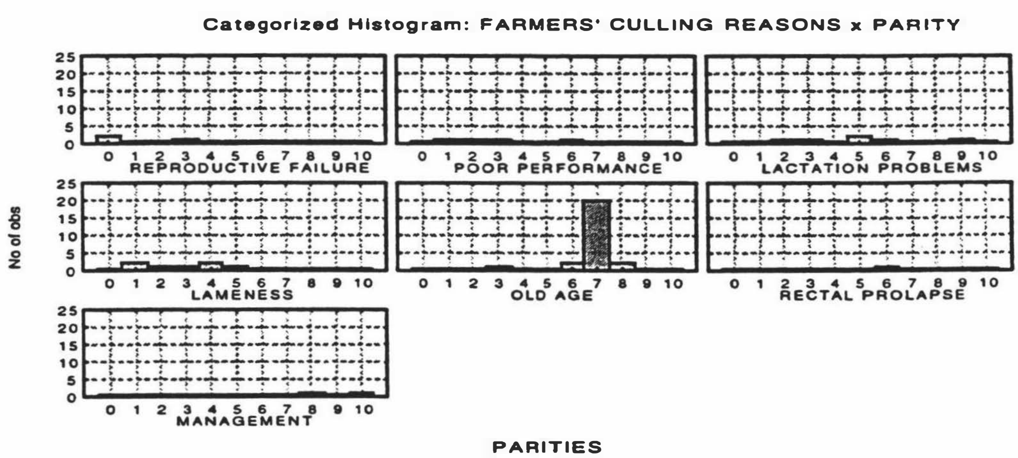
Twenty animals (41.7%) were culled in parity 7 and the most common reason for culling was old age (see Table 4-17 and Figure 4-4).

Table 4-17: Cross-tabulation of farmer reasons for culling and parity showing numbers and percentages of animals

	Parities											Row
	0	1	2	3	4	5	6	7	8	9	11	Total
Reproductive failure	1	0	0	1	0	0	0	0	0	0	0	2
Percentage %	2.08	0	0	2.08	0	0	0	0	0	0	0	4.17
Poor performance	0	1	1	1	0	0	1	0	0	0	0	4
Percentage %	0	2.08	2.08	2.08	0	0	2.08	0	0	0	0	8.33
Lactation problem	0	1	1	1	1	2	1	0	0	1	0	8
Percentage %	0	2.08	2.08	2.08	2.08	4.17	2.08	0	0	2.08	0	16.7
Lameness	1	1	1	1	1	1	0	0	0	0	0	6
Percentage %	2.08	2.08	2.08	2.08	2.08	2.08	0	0	0	0	0	12.5
Old age	0	0	0	1	0	0	2	20	2	0	0	25
Percentage %	0	0	0	2.08	0	0	4.17	41.7	4.17	0	0	52.1
Rectal prolapse	0	0	0	0	0	0	1	0	0	0	0	1
Percentage %	0	0	0	0	0	0	2.08	0	0	0	0	2.08
Management	0	0	0	0	0	0	0	0	1	0	1	2
Percentage %	0	0	0	0	0	0	0	0	2.08	0	2.08	4.17
Total	2	3	3	5	2	3	5	20	3	1	1	48
Percentage %	4.17	6.25	6.25	10.4	4.17	6.25	10.4	41.7	6.25	2.08	2.08	100

Poor performance = farrowing or weaning performance; Shaded cells = number counts > 10

Figure 4-4: Histograms showing farmer reasons for culling categorized by parity



Culling and reproductive tract disorders

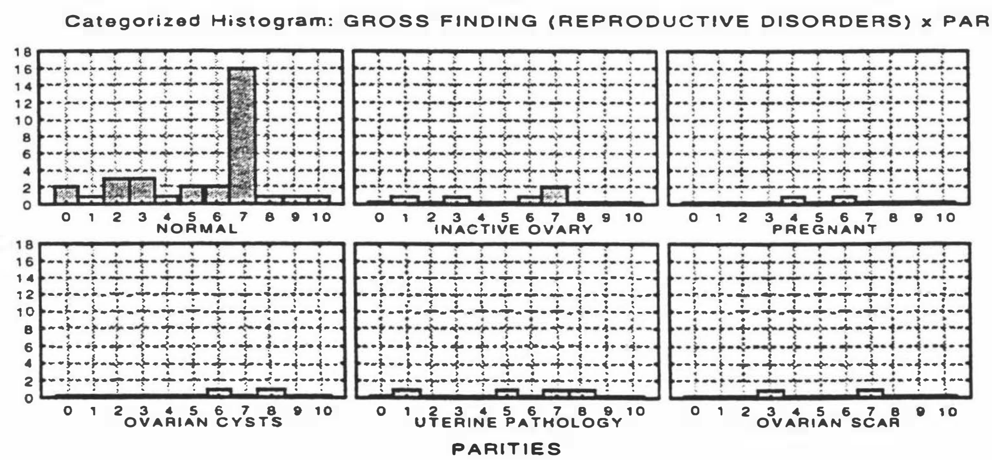
Of the 20 animals culled for old age, 16 were normal, 2 had inactive ovaries, 1 showed uterine pathology and the other had scarring of the ovary (Table 4-18 and Figure 4-5) in terms of reproductive tract disorders.

Table 4-18: Cross-tabulation of findings from gross examination of the reproductive tracts and parity showing numbers and percentages

	Parities											*Row*
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*11*	*Total*
Normal	2	1	3	3	1	2	2	16	1	1	1	33
Percent	4.17	2.08	6.25	6.25	2.08	4.17	4.17	33.3	2.08	2.08	2.08	68.8
Inactive ovary	0	1	0	1	0	0	1	2	0	0	0	5
Percent	0	2.08	0	2.08	0	0	2.08	4.17	0	0	0	10.4
Pregnant	0	0	0	0	1	0	1	0	0	0	0	2
Percent	0	0	0	0	2.08	0	2.08	0	0	0	0	4.17
Ovarian cysts	0	0	0	0	0	0	1	0	1	0	0	2
Percent	0	0	0	0	0	0	2.08	0.00	2.08	0	0	4.17
Path. Of uterus	0	1	0	0	0	1	0	1	1	0	0	4
Percent	0	2.08	0	0	0	2.08	0	2.08	2.08	0	0	8.34
Ovarian scar	0	0	0	1	0	0	0	1	0	0	0	2
Percent	0	0	0	2.08	0	0	0	2.08	0	0	0	4.17
Total	2	3	3	5	2	3	5	20	3	1	1	48
Percent	4.17	6.25	6.25	10.4	4.17	6.25	10.4	41.7	6.25	2.08	2.08	100

Gross finding (reprod.) = Gross finding (reproductive aspect); Shaded cells = number counts > 10

Figure 4-5: Histogram showing gross reproductive disorders categorized by parity



Conditions other than reproductive tract disorders

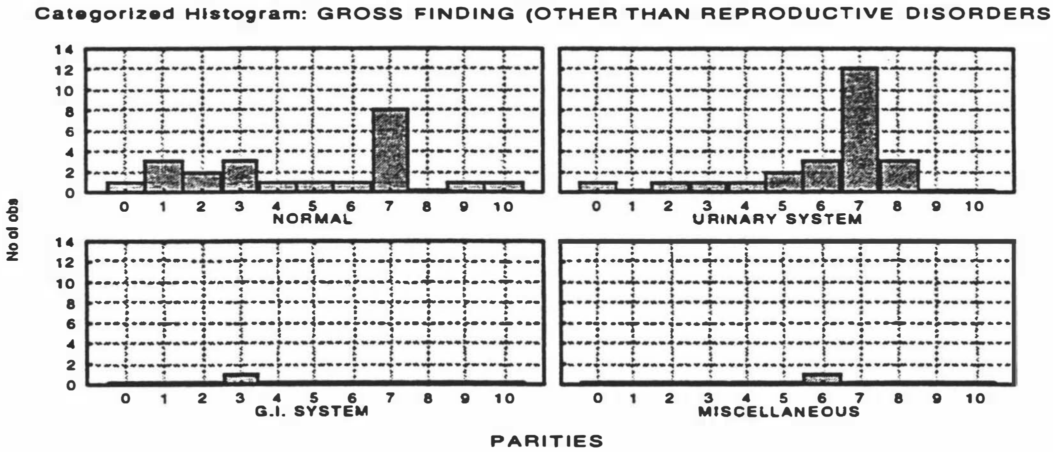
When gross findings of conditions other than reproductive disorders in parity 7 were considered for 8 (16.7%) were normal and 12 animals (25%) had kidney and/or urinary bladder abnormalities (Table 4-19 and Figure 4-6).

Table 4-19: Cross-tabulation of findings from gross examination of conditions other than reproductive tract disorders and parity showing numbers and percentages of culled gilts/sows

	Parities											*Row*
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*11*	*Total*
Normal	1	3	2	3	1	1	1	8	0	1	1	22
Percentage %	2.08	6.25	4.17	6.25	2.08	2.08	2.08	16.7	0	2.08	2.08	45.8
Urinary system	1	0	1	1	1	2	3	12	3	0	0	24
Percentage %	2.08	0	2.08	2.08	2.08	4.17	6.25	25.0	6.25	0	0	50.0
gastric ulcer	0	0	0	1	0	0	0	0	0	0	0	1
Percentage %	0	0	0	2.08	0	0	0	0	0	0	0	2.08
miscellaneous	0	0	0	0	0	0	1	0	0	0	0	1
Percentage %	0	0	0	0	0	0	2.08	0	0	0	0	2.08
Total	2	3	3	5	2	3	5	20	3	1	1	48
Percentage %	4.17	6.25	6.25	10.4	4.17	6.25	10.4	41.7	6.25	2.08	2.08	100

Shaded cells = number counts > 10

Figure 4-6: Histograms showing gross finding of conditions other than reproductive tract disorders categorized by parity



Size of reproductive organs

Descriptive statistics of the size of ovaries and uterine horns and the thickness of the epithelial layer of the endometrium of all sows/gilts and subgroups in anoestrus or in follicular and luteal and anoestrus phases of the oestrous cycle are presented in Table 4-20 to Table 4-23 and graphically in Figures 4-7 to Figure 4-10.

Reproductive organ sizes were largest in animals in the luteal phase, and smallest in anoestrous animals with the exception of the diameters of uterine horns which were smallest in animals in the follicular phase. The epithelium of the endometrium was thickest in the follicular phase and had the fewest layers in the luteal phase.

Table 4-20: Descriptive statistics of the size of ovaries and diameter and thickness of the uterine horns and the epithelial layer of the endometrium in culled gilts/sows

	Valid N	*Mean (95% CL)*	*Median*	*Minimum - Maximum*	*Lower-Upper Quartile*	*Quartile Range*	*SD*
Length L ovary	45	3.57 (3.36-3.78)	3.6	1.0-5.0	3.20-3.8	.6	.70
Thickness L ovary	45	1.68 (1.46-1.90)	1.4	0.8-3.7	1.20-2.0	.8	.73
Width L ovary	45	1.96 (1.82-2.11)	2.0	1.0-3.5	1.70-2.2	.5	.48
Volume L ovary	45	13.11 (9.99-16.24)	10.6	1.9-49.0	6.69-15.0	8.3	10.41
Length R ovary	47	3.54 (3.36-3.72)	3.6	1.6-5.2	3.20-4.0	.8	.61
Thickness R ovary	47	1.64 (1.50-1.77)	1.6	0.6-3.0	1.40-1.9	.5	.46
Width R ovary	47	1.94 (1.81-2.08)	2.0	1-3.2	1.60-2.2	.6	.47
Volume R ovary	47	12.07 (10-14.14)	10.8	1-43.7	7.20-14.4	7.2	7.04
Diameter L horn	47	3.51 (2.94-4.07)	3.2	1.8-14	2.70-3.5	.8	1.92
Diameter R horn	47	3.56 (2.98-4.14)	3.1	1.8-14	2.60-3.6	1.0	1.96
Horn thickness	46	0.37 (.32-.42)	.4	0.1-0.7	0.20-.5	.3	.16
Ave. epith thick	41	0.17 (.15-.20)	.18	0.04-0.34	0.12-.22	.10	.07

L = left; R = right; Ave. epith thick = average epithelium of endometrium thickness (cm), SD = Standard Deviation

Table 4-21: Descriptive statistics of the size of ovaries and diameter and thickness of the uterine horns and the epithelial layer of the endometrium in culled gilts/sows in the follicular phase of the oestrous cycle

	Valid N	*Mean (95% CI)*	*Median*	*Minimum - Maximum*	*Lower-Upper Quartile*	*Quartile Range*	*SD*
Length L ovary	30	3.54 (3.29-3.79)	3.65	1.00-4.90	3.20-3.80	0.60	0.67
Thickness L ovary	30	1.73 (1.44-2.02)	1.40	1.00-3.70	1.20-2.00	0.80	0.79
Width L ovary	30	1.89 (1.75-2.02)	1.80	1.20-3.00	1.70-2.00	0.30	0.36
Volume L ovary	30	12.34 (8.8-15.9)	10.3	1.92-44.40	7.49-13.38	5.89	9.47
Length R ovary	30	3.51 (3.33-3.69)	3.60	2.60-4.50	3.20-4.00	0.80	0.50
Thickness R ovary	30	1.68 (1.53-1.83)	1.60	1.00-3.00	1.40-2.00	0.60	0.40
Width R ovary	30	1.91 (1.74-2.07)	1.95	1.20-3.20	1.70-2.00	0.30	0.43
Volume R ovary	30	11.51 (9.6-13.4)	10.78	4.68-25.60	7.20-13.68	6.48	5.08
Diameter L horn	30	3.08 (2.82-3.34)	3.00	2.00-5.20	2.50-3.50	1.00	0.69
Diameter R horn	30	3.06 (2.80-3.32)	3.00	1.80-5.30	2.50-3.40	0.90	0.71
Horn Thickness	30	0.38 (.33-.43)	.40	0.15-.70	0.30-.50	0.20	0.13
Ave. epith thick	26	0.21 (0.18-0.23)	0.2	0.1-0.34	0.17-0.24	0.07	0.06

L = left; R = right; Ave. epith thick = average epithelium of endometrium thickness (cm), SD. = Standard Deviation

Table 4-22: Descriptive statistics of the size of ovaries and diameter and thickness of the uterine horns and the epithelial layer of the endometrium in culled gilts/sows in the luteal phase of the oestrous cycle

	Valid N	*Mean (95% CI)*	*Median*	*Minimum-Maximum*	*Lower-Upper Quartile*	*Quartile Range*	*SD*
Length L ovary	8	3.93 (3.39-4.46)	3.8	3.2-05	3.4-4.4	1	0.64
Thickness L ovary	8	1.94 (1.53-2.34)	1.8	1.2-2.8	1.7-2.25	0.55	0.49
Width L ovary	8	2.36 (1.87-2.86)	2.35	1.4-3.5	2.1-2.55	0.45	0.59
Volume L ovary	8	19.6 (9-30.2)	16.6	0.54-49	15.23-19.39	4.15	12.68
Length R ovary	10	3.78 (3.4-4.16)	3.65	3.2-4.5	3.2-4.3	1.1	0.52
Thickness R ovary	10	1.7 (1.49-1.91)	1.6	1.4-2.4	1.5-1.8	0.3	0.3
Width R ovary	10	2.12 (1.78-2.46)	2.15	1.6-3	1.7-2.4	0.7	0.47
Volume R ovary	10	13.9 (10.2-17.5)	13	7.17-21.8	9.79-17.54	7.75	5.08
Diameter L horn	10	4.77 (2.14-7.4)	3.2	2.2-14	3-4	1	3.68
Diameter R horn	10	5.12 (2.51-7.72)	3.55	2.6-14	3.2-5.25	2.05	3.65
Horn Thickness	9	0.34 (0.16-0.52)	0.25	0.05-0.7	0.15-0.5	0.35	0.24
Ave. epith thick	9	0.1 (0.07-0.13)	0.11	0.05-0.14	0.07-0.13	0.05	0.03

L = left; R = right; Ave. epith thick = average epithelium of endometrium thickness (cm), SD. = Standard Deviation

Table 4-23: Descriptive statistics of the size of ovaries and diameter and thickness of the uterine horns and the epithelial layer of the endometrium in culled anoestrus gilts/sows

	Valid N	*Mean (95% CI)*	*Median*	*Minimum Maximum*	*Lower-Upper Quartile*	*Quartile Range*	*SD*
Length L ovary	6	3.40 (2.55-4.25)	3.35	2.60-4.90	2.80-3.40	.60	.81
Thickness L ovary	6	1.25 (.73-1.77)	1.10	0.80-2.20	1.00-1.30	.30	.50
Width L ovary	6	1.95 (1.27-2.63)	2.10	1.00-2.80	1.40-2.30	.90	.65
Volume L ovary	6	10.1 (-.59-20.8)	6.54	2.60-30.18	4.62-10.17	5.55	10.20
Length R ovary	6	3.28 (2.08-4.49)	3.20	1.60-5.20	3.10-3.40	.30	1.15
Thickness R ovary	6	1.37 (.46-2.27)	1.20	0.60-3.00	0.80-1.40	.60	.86
Width R ovary	6	1.83 (1.15-2.52)	1.80	1.00-2.80	1.40-2.20	.80	.65
Volume R ovary	6	12.1 (-4.6-28.7)	7.17	0.96-43.68	3.58-10.00	6.41	15.86
Diameter L horn	6	3.35 (1.82-4.88)	2.95	1.80-5.50	2.20-4.70	2.50	1.46
Diameter R horn	6	3.43 (1.84-5.03)	2.80	2.20-6.00	2.30-4.50	2.20	1.52
Horn Thickness	6	.33 (.16-.49)	.30	0.15-.50	0.20-.50	.30	.16
Ave. epith thick	5	0.13 (0.05-0.21)	0.15	0.04-0.18	0.09-0.18	0.09	0.06

L = left; R = right; Ave. epith thick = average epithelium of endometrium thickness (cm), SD. = Standard Deviation

Figure 4-7: Box andWhisker plot of ovarian length, thickness, and width (cm) in phases of the oestrous cycle

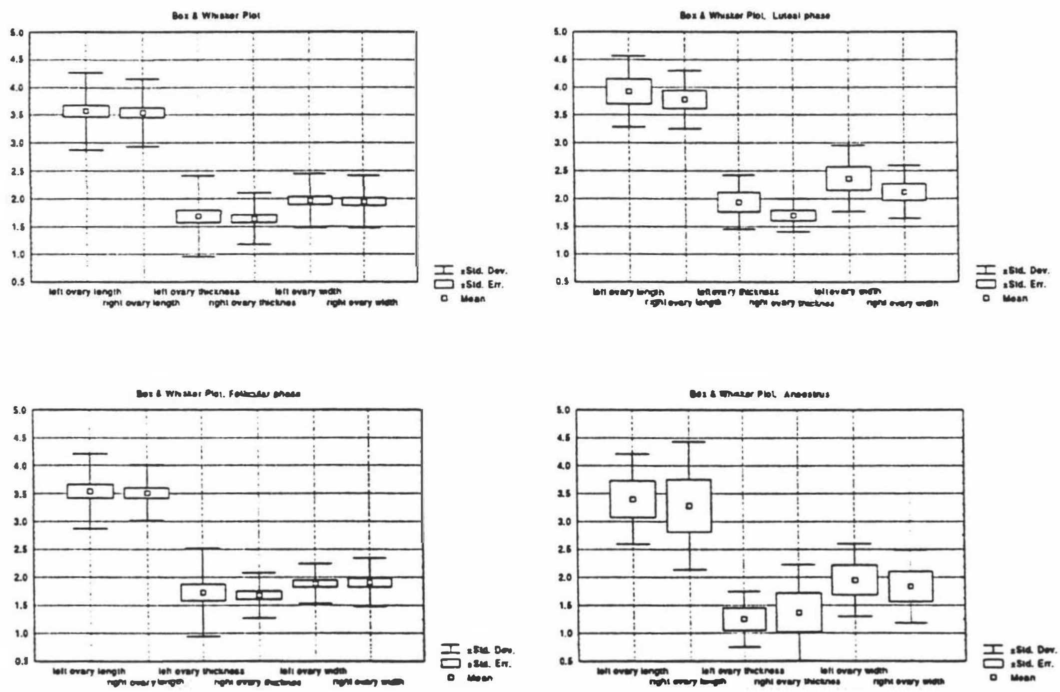


Figure 4-8: Box and Whisker plots of volume of left and right ovaries (cm^3) in phases of the oestrous cycle

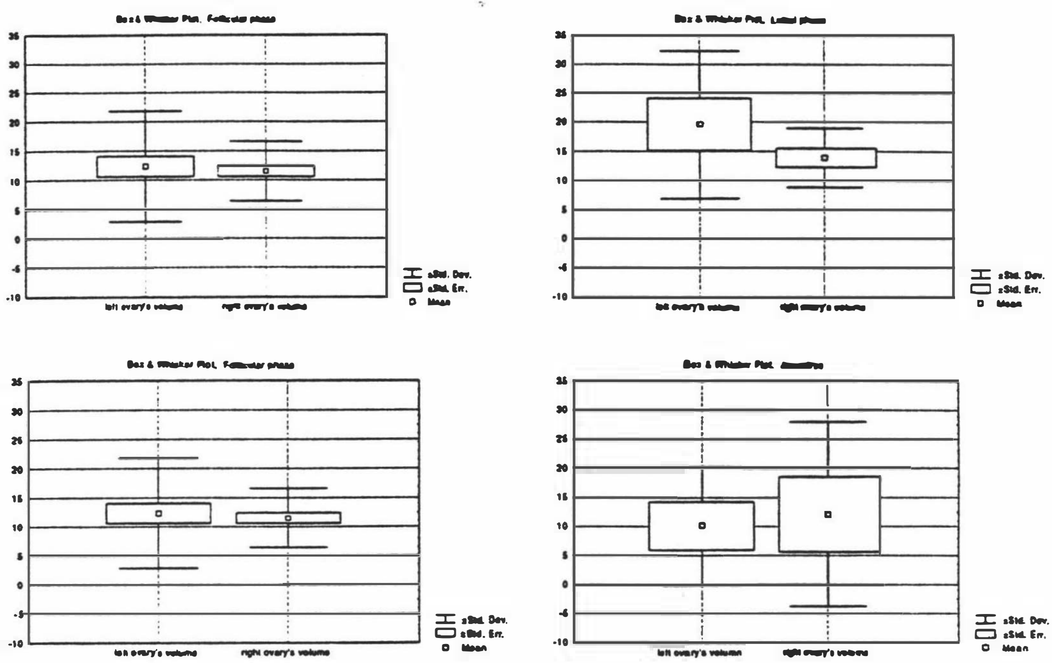


Figure 4-9: Box and Whisker plots of left or right uterine horn diameters (mm) in phases of the oestrous cycle

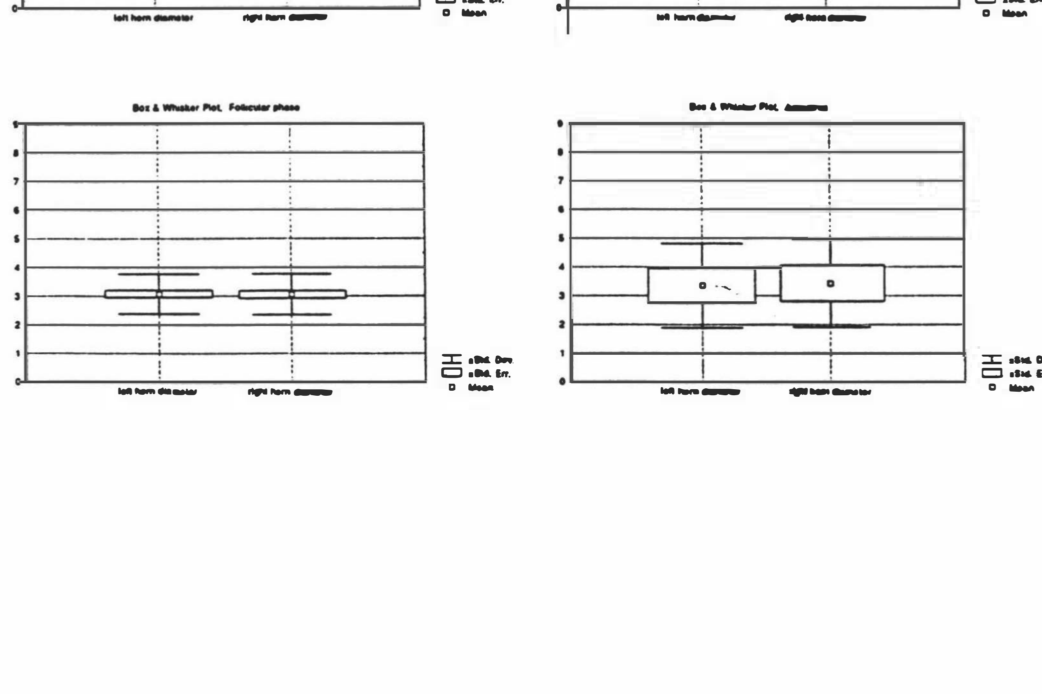
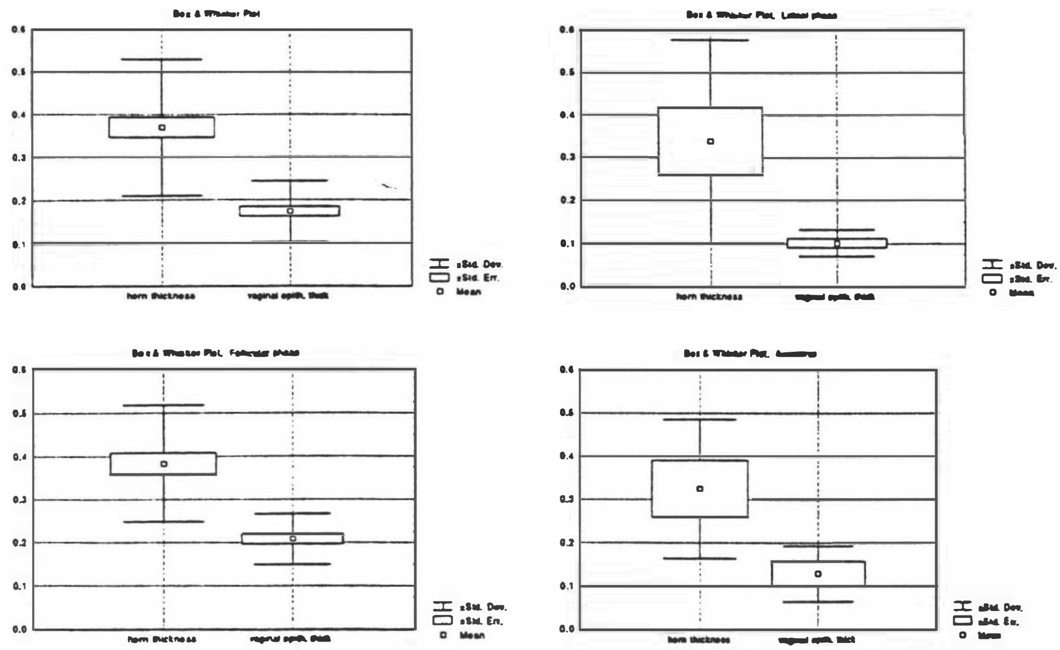


Figure 4-10: Box and Whisker plots of uterine horn thickness and vaginal epithelial thickness (cm) in phases of the oestrous cycle



Endometritis

From histopathology, 30 animals (62.5%) were diagnosed as normal while 12 (25%) had chronic endometritis, 4 (8.33%) had subacute endometritis and 2 (4.17%) had moderate acute endometritis (Table 4-24). This table and Figure 4-11 show that the prevalence of endometritis was highest in the group of sows culled for old age, and of the 10 sows with endometritis in that group, the disease was chronic in 8 and subacute in 2. One sow was culled 7 days after farrowing and had histopathological signs of moderate acute endometritis but these signs were considered as consistent with the normal involution process following parturition.

Table 4-24: Cross tabulation of uterine states of normality and disease and farmer reasons for culling, showing numbers and percentages of affected animals

	Subacute endometritis	*Chronic endometritis*	*Moderate acute endometritis*	*Normal*	*Row Total*
Reproductive failure	0 (0)%	1 (2.08%)	0 (0%)	2 (4.17%)	3 (6.25%)
Poor performance	1 (2.08%)	1 (2.08%)	1 (2.08%)	1 (2.08%)	4 (8.33%)
Lactation problems	0 (0%)	0 (0%)	0 (0%)	6 (12.5%)	6 (12.5%)
Lameness	1 (2.08%)	2 (4.17%)	0 (0%)	4 (8.33%)	7 (14.58%)
Old age	2 (4.17%)	8 (16.67%)	0 (0%)	15 (31.25%)	25 (52.08%)
Rectal prolapse	0 (0%)	0 (0%)	0 (0%)	1 (2.08%)	1 (2.08%)
Management	0 (0%)	0 (0%)	1 (2.08%)	1 (2.08%)	2 (4.17%)

shaded area = counts > 10

Figure 4-11: Histograms showing farmer reasons for culling categorized by uterine disease status

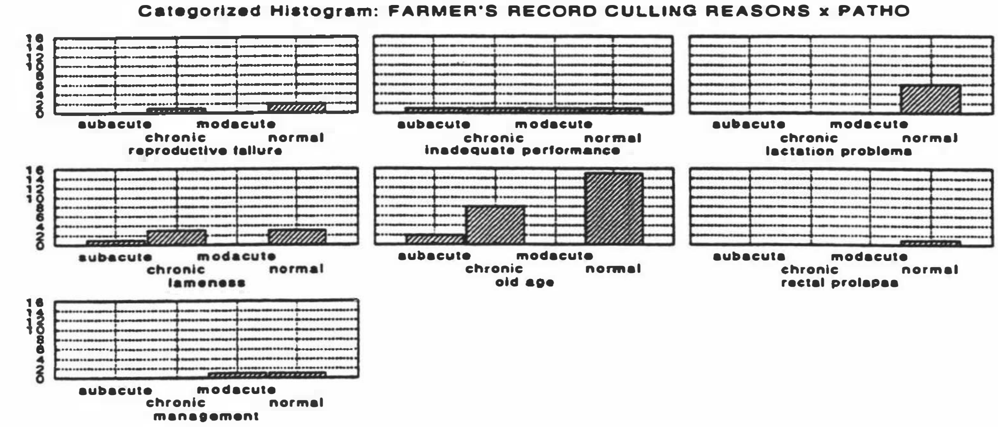


Table 4-25 and Figure 4-12 show the distribution of cases of endometritis among sows which appeared normal as had gross signs of reproductive tract disorders. Gross evidence of endometritis was only seen in 3 of all animals with endometritis.

Table 4-25: Cross tabulation of uterine states of normality and disease and gross reproductive disorders

	Subacute endometritis	*Chronic endometritis*	*Moderate acute endometritis*	*Normal*	*Row Total*
Normal	1 (2.08%)	8 (16.67%)	0 (0%)	24 (50%)	33 (68.75%)
Inactive ovaries	1 (2.08%)	2 (4.17%)	1 (2.08%)	1 (2.08%)	5 (10.42%)
Pregnant	0 (0%)	0 (0%)	0 (0%)	2 (4.17%)	2 (4.17%)
Ovarian cysts	1 (2.08%)	0 (0%)	0 (0%)	1 (2.08%)	2 (4.17%)
Uterine pathology	1 (2.08%	1 (2.08%)	1 (2.08%)	1 (2.08%)	4 (8.34%)
Ovarian scar	0 (0%)	1 (2.08%)	0 (0%)	1 (2.08%)	2 (4.17%)

shaded area = counts > 10

Figure 4-12: Histograms showing gross reproductive disorders categorized by uterine disease status

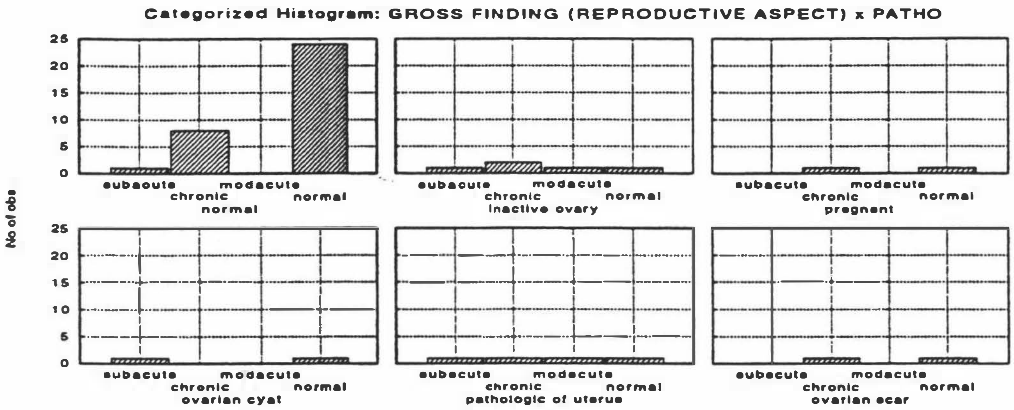


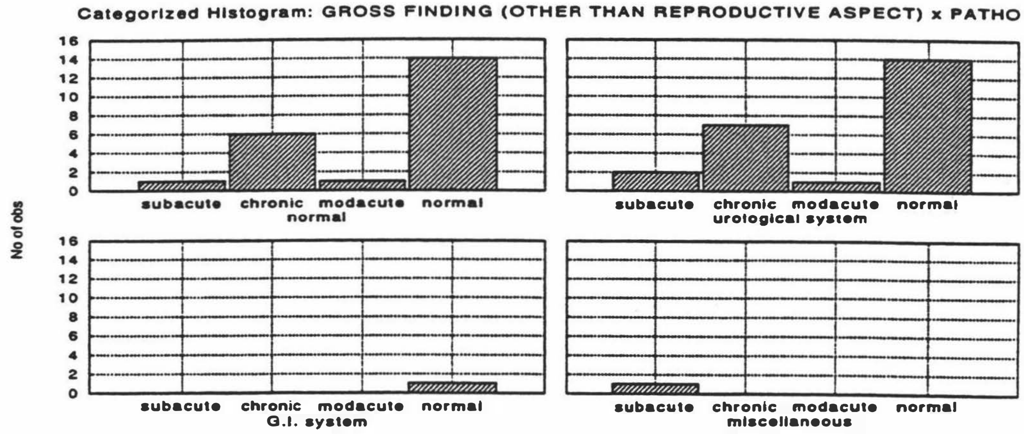
Table 4-26 and Figure 4-13 show that urinary system disease was common in cases of endometritis. Seven animals with chronic endometritis, 2 with subacute and 1 with moderate acute endometritis had urinary tract disease. Of animals with urinary tract disease, 42% had endometritis and 58% were considered normal.

Table 4-26: Cross tabulation of uterine states of normality and disease and conditions other than reproductive tract disorders

	Subacute endometritis	*Chronic endometritis*	*Moderate acute endometritis*	*Normal*	*Row Total*
Normal	1 (2.08%)	5 (10.42%)	1 (2.08%)	15 (31.25%)	22 (45.83%)
Urinary system pathology	2 (4.17%)	7 (14.58%)	1 (2.08%)	14 (29.17%)	24 (50%)
Gastric ulcer	0 (0%)	0 (0%)	0 (0%)	1 (2.08%)	1 (2.08%)
Miscellaneous	1 (2.08%)	0 (0%)	0 (0%)	0 (0%)	1 (2.08%)

shaded area = counts > 10

Figure 4-13: Histograms showing gross findings of conditions other than reproductive tract disorders categorized by uterine disease status



Discussion

Veterinarians consider slaughter check to be on of their most valuable tools for investigating poor reproductive performance and monitoring disease status on pig farms.

In this study, about 30% of culling decisions were enforced and this level is similar to the 20% reported by Richardson (1994) and 27% by Jones (1967). Most of the enforced culls were young animals. Lameness occurred in parities 0 - 5, and there were reproductive failures in two animals in parity 0 and 3 respectively and a rectal prolapse in parity 6.

Endometritis is a relatively common disease in sows and frequently causes returns to service and some embryonic losses (Scotfield *et al*., 1974). The incidence of endometritis can be increased by faulty mating practices, in particular by forced matings when sows are not in oestrus (Meredith, 1986; de Winter and de Kriuf, 1991). In this study, there was gross evidence of uterine pathology in 8% of culls and histopathological evidence of chronic endometritis in 25%, subacute endometritis in 8% and moderate acute endometritis in 4%. The prevalence of chronic endometritis was highest in older age culls and this is a common observation in slaughter checks.

Two animals (4%) had multiple large ovarian cysts and this level of prevalence is consistent with the 4% prevalence reported by Cutler *et al*. (1981) in slaughtered sows.

Multiple large cysts are common with this condition (Miller, 1984; Roberts, 1986) and are usually associated with permanent or temporary sterility. They occur most commonly in post-parturient sows following weaning (Miller, 1984). Scarring of the ovaries was found in a further 2 animals (4%). Scarring may occur following rupture of cysts and affected sows are generally considered to be subfertile or infertile.

Evidence of kidney disease and/or cystitis was found in 24 animals (50%). The prevalence was highest in older animals, with 12 animals (25%) in parity 7 and three sows (6%) in parities 6 and 8. This older age distribution of cystitis is consistent with reports of the disease by Dee (1992).

Eubacterium suis was cultured from the urinary bladder of one sow. The organism has been suspected in earlier cases but not previously reported as confirmed in New Zealand. Unfortunately, the true prevalence of this organism could not be determined because of difficulties experienced by the laboratory in cultural procedures and techniques.

Farms in this study did not recognize cystitis or urinary tract disease as a problem *per se* and this disease was not cited as a reason for culling. More studies of urinary tract disease and in particular that are associated with *E. suis* are warranted in New Zealand because of the serious nature of the disease syndrome.

One sow (2%) suffered from gastric haemorrhage presumably due to oesophago-gastric ulceration. This disease is commonly associated with the feeding of finely ground meal, use of pelleted feed, low fibre intake and other risk factors.

Culling is normally performed after weaning and in this study 39 sows (81%) were culled after weaning, seven animals (15%) were culled after mating, one (2%) was culled after farrowing and another after aborting.

Culling decisions need to be made as early as possible to reduce non-productive sow days. With a weekly culling system, animals should be culled within 7 days after weaning. Five sows were culled at 11, 12 and 18 days after weaning. One sow was culled at 23 days after weaning but she had been used as a nurse sow.

Two sows which were culled at 29 and 32 days after mating had chronic endometritis and one culled at 35 days post-mating had subacute endometritis. These sows may have suffered disruptions of pregnancy as a result of endometritis.

In conclusion, the most common disorder in this group of 48 gilts/sows was cystitis, and this condition was not recognized by the participating farmers. The level of chronic endometritis was high but was not unexpected, although the condition is not obvious in the live animal. There was good agreement between the farmer's reasons for culling and gross findings at slaughter, although judicious pregnancy testing could have saved some wastage through pregnant culls and those which were culled late after mating.

CHAPTER 5

A STUDY OF PREGNANCY LOSS IN THE SOW USING REAL TIME (B-MODE) ULTRASOUND SCANNING

Chapter 5: Study of pregnancy loss in the sow using real time (b-mode) ultrasound scanning

Literature review

On pig farms, priority is given to management procedures which minimise the number of open days[1] and non-productive sow days (NPD)[2] The use of efficient methods for both oestrus detection and diagnosis of early pregnancy are central to efficient reproductive management. Poor oestrus detection leads to an increase in the number of open days and not-in-pig days. Efficient management systems aim to detect non-pregnant individuals as soon as possible after service to allow prompt economic decisions on whether to cull or re-mate them (Walker, 1972). The regular use of an effective pregnancy test is part of this strategy.

Almond and Dial (1987) set out the following criteria for an acceptable pregnancy test. It should be highly accurate with high sensitivity and specificity in excess of 95%, i.e. the rate of false negatives and false positives should be <5%. The test should be safe, simple and inexpensive, provide results within a few minutes and preferably be applicable in advance of the time the sow is likely to return to oestrus (at about 21 days). A final important requirement is that the test should require a low investment of labour.

Many techniques have been developed for determining the pregnancy status of pigs, but few have met the above criteria, particularly with regard to accuracy, cost and practical feasibility. Various techniques which have been promoted include doppler ultrasound, A-mode (pulse-echo/amplitude-depth) ultrasound, real-time (B-mode) ultrasound, estimations of blood progesterone and oestrone sulphate, rectal palpation, testing for early pregnancy factor (oestrone sulphate), laparoscopy, testing for prostaglandin $F_{2\alpha}$ and biopsy of the vagina. Real-time ultrasound scanning is a relatively new technique which meets most of the criteria. The application of real-time ultrasound scanning and its usefulness are reviewed here.

Real time ultrasound scanners produce cross-sectional images of tissue interfaces in the area being scanned. There are two main types: viz. linear array (rectangular image) and sector (sectoral image, pie shape). The latter has the advantage of requiring a smaller area of skin

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1 For sows this is the period from the first oestrus after weaning to a successful service, and for gilts it is the period from attainment of breeding age to a successful service.

2 The total number of days that all gilts and sows are non-productive; that is, neither pregnant nor lactating.

contact with the transducer (Meredith, 1988). A linear-array transducer has piezo-electric crystals (which emit high frequency sound waves on being energised) arranged in a row, while the sector transducer has fewer crystals. Transducers usually come in 3.0, 3.5, 5.0, and 7.5 MHz frequency ranges. The degree of tissue penetration by sound waves and hence the quality of image resolution depends on the frequency of the transducer used. A 3.0 MHz transducer gives greater tissue penetration and less detail than a 7.5 MHz transducer, which gives minimum tissue penetration but maximum resolution. A transducer of 5.0 MHz is adequate for general purposes, and provides reasonably detailed images of ovaries and uteri. It has been shown that a 5 MHz or a 7.5 MHz transducer tends to provide more reliable results than does a 3.0 MHz or a 3.5 MHz transducer for early pregnancy diagnosis in cattle (Rajamakendran *et al.*, 1994).

Because it is more convenient and less time consuming, transcutaneous scanning is more often used than transrectal scanning. There are relatively minor differences among the anatomical locations recommended by various authors for siting the transducer for pregnancy diagnosis in gilts or sows. Martinez *et al.* (1992) used the area caudal to the umbilicus, just lateral to the nipples, with the transducer head directed towards the uterus. Szenci *et al.* (1992) placed the transducer on the right abdominal wall, just above the row of teats and immediately cranial to the hind leg. Botero *et al.* (1986) placed the probe against the skin in the area of the abdominal flank of a standing sow and manipulated it between the first and third posterior teats. Inaba *et al.* (1983) placed the transducer head in contact with the lower flank of the standing sow about 5 cm posterior to the navel and just lateral to the nipple line and directed it toward the uterus. Jackson (1986) placed the transducer on the right side of the standing sow slightly above the nipples, caudal to the umbilicus. Almond and Dial (1987) positioned the transducer probe near the flank, caudal to the umbilicus, lateral to the nipples, and directed toward the uterus. A more prolonged scanning of the left and right ventral abdominal wall is recommended when searching for abnormalities in the reproductive tract (Martinez *et al.,* 1992).

Image interpretation

Images vary according to tissue density (the denser the organ the whiter that section of the image). Black areas correspond to fluid-filled structures such as the bladder or uterus while grey areas represent tissue (Szenci *et al.*, 1992). A finding of several anechoic (dark) areas on the image was considered by Martinez *et al.* (1992) to be indicative of pregnancy, with these areas representing the embryonic vesicles. If no dark areas were seen, the sow was diagnosed as non-pregnant. Hyperechoic (white) structures within the dark areas were considered to represent embryos and pulsatile movement within the hyperechoic structures was considered to represent foetal cardiac activity.

A pig was considered to be pregnant when several irregular, nonechogenic black spots, representing the fluid-filled conceptuses within the uterine lumen, appeared on the monitor (Szenci *et al.*, 1992). Non-echogenic areas without any definite form and within the uterine lumen were considered to represent abnormal intrauterine fluid. Positive diagnoses were usually made within a few (<10) seconds, and if no dark areas were detected quickly the long side of the sector transducer was placed on the left side of the abdomen. If an image of a pregnant uterus on both sides of the abdomen was not apparent within 60 seconds, the result of the test was considered negative (Szenci *et al.*, 1992).

Szenci *et al.* (1992) reported that amniotic vesicles become visible with real-time ultrasound by 18 or 19 days after breeding, with embryos visible by 21 days and easily detected by 25 days. Martinez *et al.* (1992) reported that embryos were first observed inside the embryonic vesicles on days 23-25 with cardiac function clearly distinguishable after 32-37 days of gestation. Because amniotic vesicles are larger than embryos and provide greater contrast from surrounding maternal tissue, they are more easily visualized during early gestation (Szenci *et al.*, 1992). This author also reported a near-linear increase in the diameter of amniotic vesicles between approximately 20 and 30 days with discrimination of the gravid uterus improving with time between 18 and 30 days. Foetuses become visible at >32 days (Howe, 1985; Szenci *et al.*, 1992), and foetal movement can be observed after day 60 (Szenci *et al.*, 1992) but foetuses do not appear on the screen as clearly due to the foetal fluids being more dispersed (Howe, 1985). Despite this, accurate diagnoses can be made right up to full term (Howe, 1985).

The proportion of false negatives declines as the mating-to-test interval increases from 18 - 21 days through 22 - 25 days up to 25 - 30 days (Scenzi *et al.*, 1992; Scenzi *et al.*, 1993; Botero *et al.*, 1986). Testing at 22 - 25 and 25 - 30 days gave acceptable proportions of false negatives but the proportion of false positives was less influenced by the longer time periods.

Table 5-1 shows sensitivity, specificity and predictive values of examination procedures, in which the gold standard is farrowing record, abortion, or return to oestrus.

Table 5-1: Sensitivity (SE), specificity (SP), predictive value of positive (PVP), and predictive value of negative (PVN) pregnancy diagnosis stratified by time post-service, as reported by various authors.

Authors	Post-service (days)	SE	SP	PVP	PVN
Scenzi et al (1992)	21-22	87.8	33.3	90	28.6
	23-24	99	100	100	90
	25-27	99.3	63.6	97.2	87.5
	28-30	100	80.9	97.8	100
Martinez et al (1992)	21-22	90.8	81.1	95.2	68.2
	23-25	91.8	100	100	70.5
	26-28	93.6	100	100	77.3
	32-37	93.6	100	100	77.3
	46-49	94.2	100	100	79.5
van de Wiel et al (1992)	28	96.2	67.9	95.6	71.2
Scenzi et al (1993)	18-23	100	56	93.1	100

Real-time scanning has high sensitivity (>87.8%), but specificity varies from 33.3% - 100% depending on the time of scanning with the false positive rate decreasing as the service-to-scanning interval increases.

In the early stages, false negative diagnoses are most probably due to the smaller volume of allantoic fluid, especially in sows with smaller litters, although there are conflicting views on that point between Martinez *et al.* (1992) and Scenzi *et al.* (1993). The false positive diagnoses most probably arise from embryonic mortality or from the presence of intra-uterine fluid other than allantoic fluid.

From analyses of linear array scanning data, it appears that pregnancy diagnosis before 18 days after service is very difficult due to the very small amount of allantoic and amniotic fluid (1-3 ml per embryo) present in swine (Goldstein *et al.*, 1980). Porcine pregnancies can be detected from 18 days after insemination by this method, but it only becomes highly accurate at 22 days (Inaba *et al.*, 1983; Botero *et al.*, 1986) or 24 days (Taverne *et al.*, 1985; Jackson 1986; Szenci *et al.*, 1993) post-service. Howe (1985) supports these findings. He used a linear array scanner, and found no images of blastocysts and difficulty recognising uteri prior to day 18, but reported that from day 19 on, blastocysts start to become recognizable. According to Inaba *et al.*, (1983), the ultrasound test appears to have >95% specificity after 21 days for the identification of non-pregnant sows and gilts. Accuracy was adversely affected if the sow was not tethered or when there were fewer than five piglets present (Botero *et al.*, 1986).

Low specificity with the real-time ultrasonic test may be encountered in the presence of various reproductive disorders, and in particular in cases of embryonic mortality or where there is intra-uterine fluid other than allantoic fluid. The non-farrowing category of sows comprises those which return to oestrus at regular intervals, sows with delayed returns, sows with genital abnormalities (inactive ovaries, cystic ovaries, genital tract infections) and sows which were pregnant at the time of testing but whose pregnancy failed to persist to farrowing. Ultrasound scanning is useful for in the diagnosis of endometritis, cystic ovaries, total embryonic mortality and abortion, but repeated scannings of inseminated/mated sows need to be made if high proportions of false positives are to be avoided (Martinez *et al.*, 1992). A limited number of observations by Jackson (1986) showed that scans of sows with vaginal discharge sometimes produce an image, presumably representing abnormal fluid accumulation in the uterus, similar to that of pregnant sows at 20 to 22 days post-service.

Real-time ultrasound has several other potentially useful applications in addition to pregnancy diagnosis. In particular, pseudopregnant sows, gilts with mummified foetuses *in utero* and sows with retained foetuses can be recognised. Endometritis can usually be diagnosed and confidently distinguished from later stages of pregnancy, but not from 18 to 21 day pregnancies (Szenci *et al.*, 1992). The ultrasonographic image of endometritis shows the 'snow storm', of white floating particles and the more subtle signs of inflammatory reactions in the endometrium and uterine wall (Bekana *et al.*, 1994).

In summary, real time ultrasound is a very useful technique with high overall sensitivity, but its low specificity when used prior to day 22 of pregnancy may be unacceptable in some circumstances.

Experimental study

Introduction

The purpose of this study was to estimate the sensitivity and specificity of pregnancy diagnosis using real-time ultrasound scanning in gilts and sows; to detect the time of failure in cases of unsuccessful pregnancies for gilts/sows mated during summer/autumn, and to monitor the physical status of ovaries of gilts/sows during normal and failed pregnancies over the summer/autumn period in conjunction with a separate study of the effect of feed supplementation on occurrence of summer/autumn infertility.

Materials and methods

Observer preparation

Reproductive tracts and ovaries of 15 culled gilts or sows were collected from a slaughter house and were scanned with a 5 MHz portable real-time ultrasound scanner under supervision of an experienced instructor. Live gilts/sows with known histories at a Massey University pig farm were scanned daily for 1 month to enable the author to become familiar with the physiological changes of the uterus. The monitoring of ovaries was abandoned when it became apparent that the structures on the ovaries were too small and the distance between the probe and the ovaries too large to allow accurate definition using percutaneous scanning with the 5 MHz probe.

Farm selection

A pig breeding farm with 200 sows near Massey University, which used hand mating was selected. This farm had a comprehensive database recorded in pig herd management software (PigCHAMP® version 3.01, University of Minnesota). From an examination of records for this herd over the previous decade, it was found that pregnancies which failed during summer/autumn were for the most part late pregnancy losses.

Real-time ultrasound scanner

A real time, B-mode, diagnostic ultrasound scanner (Model SSD-210DX) equipped with an electronic linear-array and a 5.6 cm long 5 MHz transducer probe designed for transrectal examinations in cattle and horses was used.

Duration of study

This investigation used gilts/sows which were served between 15 January 1995 and 30 April 1995.

Study method

Gilts and sows were scanned for the first time during the third week post-service. Follow-up scans were conducted in weeks 4, 5, 7, 9 and 11. All scans were done on the Monday of each week. The pigs were scanned while standing in their crates and were fed if they were reluctant to stand still. The author (scanning person) was positioned in the same crate or in the crate adjacent to the pig being scanned. The probe was placed on the right side just lateral to the 2nd and 3rd hindmost nipples and was moved forward and medially. It was pushed in if the anechoic area (dark) was not detected at that stage. If the anechoic area was not detected on the right side of the animal, the probe was placed on the left side of the animal and the procedure repeated.

Scanning interpretation

Gilts/sows were judged pregnant if many black irregular anechoic areas were detected and negative if none was seen. Small litter size was diagnosed if more than one but few clear black areas were detected, and suspicious if some gray areas (unclear) were detected. It was possible to detect skeletal structure from the 6th week of pregnancy on, and from that stage this was the criterion for diagnosis.

Data recording

The results of each examination were recorded on a data recording sheet as positive, negative, suspicious, small litter size or as an abnormality. The data were entered on the day of recording into a database set up in a database management software (Paradox® version 4.5, Borland International. Inc.).

Data analysis and interpretation

Sensitivity, specificity and predictive values for the diagnostic method were calculated using the statistical analysis software Epitable 6 (USD, Inc., Georgia). The gold standard for pregnancy status at each particular examination was inferred from histories of individual sows (farrowing, remating, abortion, removal events) recorded in PigCHAMP. Sensitivity was defined as the probability of having a positive scan test in those pigs assessed as pregnant based on the gold standard. Specificity was defined as the probability of having a negative scan test in those pigs assessed as non-pregnant. The predictive values are conditional probabilities describing the accuracy of the diagnosis with reference to a given test result.

The predictive value of a positive test (PVP) is the probability of a sow being pregnant according to the gold standard, given a positive scanning result. The predictive value of a negative test (PVN) is the probability of a sow not being pregnant according to the gold standard among the animals having a negative scanning result.

Prevalence (P, true prevalence) is the proportion of pigs diagnosed as pregnant based on the gold standard (i.e. the occurrence of positive diagnoses in the pregnant population). The level of test positive (Q, apparent prevalence) depends on the quality of the scanning : number scanned as positive/N or [(true positive + false positive)/N] (Kraemer, 1992). The complement of the level of the test is Q' : (Q' = 1-Q) (Kraemer, 1992). The efficiency is the probability that a scanning result and the gold standard pregnancy assessment agree (Kraemer, 1992). For a true positive test (TP) result, both the scanning result and the gold standard have to be positive. False positive (FP) is a positive scanning result where the gold standard is negative. True negative (TN) is where both the scanning result and the gold standard are negative. False negative (FN) is a negative scanning result where the gold standard is positive. Sensitivity ranges from Q to 1 and specificity ranges from Q' to 1.

As suggested by Kraemer (1992), the chi-squared test was used to determine if the test outcome was due to chance or legitimate.

Results

The scanning examination was conducted on six occasions for each pig, on days 18-24 (mean = median = 21, range = 6), 25-31 (mean = median = 28, range = 6), 32-40 (mean = median = 35, range = 8), 46-54 (mean = median = 49, range = 8), 60-68 (mean = median = 63, range = 8), 74-82 (mean = median = 77, range = 8), for the post-service weeks 3, 4, 5, 7, 9, and 11, respectively. The number of gilts/sows scanned on successive scanning occasions was 153, 148, 148, 144, 136 and 137. The reduction in the number of animals was due to return gilts/sows being remated, culled or transferred from the farm. Diagnoses for each of the six scanning examinations are summarized in Table 5-2.

Table 5-2: Cross tabulation of ultrasound scanning results and week post-service

Scanning result	Number of weeks after service					
	3	4	5	7	9	11
Positive :No. (%)	128 (83.66%)	136 (91.89%)	137 (92.57%)	139 (96.53%)	135 (99.26%)	137 (99.27%)
Suspect :No. (%)	15 (9.8%)	3 (2.03%)	2 (1.35%)	1 (0.69%)	0 (0%)	0 (0%)
Negative :No. (%)	8 (5.23%)	8 (5.41%)	8 (5.41%)	4 (2.78%)	1 (0.74%)	1 (0.73%)
Small litter :No. (%)	2 (1.31%)	1 (0.68%)	1 (0.68%)	0 (0%)	0 (0%)	0 (0%)
Total :No. (%)	155 (100%)	151 (100%)	148 (100%)	150 (100%)	136 (100%)	137 (100%)

Table 5-3: Codes used for interpretation of scanning result in relation to the gold standard

Scanning result	*True pregnancy status*	*Gold standard interpretation*
+	negative	false +
-	positive	false -
+	positive	true +
-	negative	true -
+/-	positive	suspected +
+/-	negative	suspected -
small litter size	small litter size (<6)	true <6
small litter size	big litter size (>6)	false <6

The codes (gold standard interpretation) defined in Table 5-3 were used in the comparisons between scan results and the true pregnancy status of gilts/sows in the study.

Table 5-4 provides a summary of the various sequences of scan test results found in gilts/sows including their status with regard to database history and the gold standard interpretation (see Table 5-3) for purposes of evaluation of the test at each examination time. The reasons behind judgements for cases where all test results were not the same or where the sow was not followed to farrowing are explained in the footnotes below the table.

Table 5-4: Summary of sequences of scan examination results, subsequent history and the gold standard interpretation for gilts/sows in this study

Week							Database	Interpreted test
3^{rd}	4^{th}	5^{th}	7^{th}	9^{th}	11^{th}	No. cases	history	result category
		+	+	+	+	1	farrow	true +
	+	+	+	+	+	2	farrow	true +
+		+	+	+	+	1	farrow	true +
+	+	+		+	+	1	farrow	true +
+	+	+	+			1	farrow	true +
+	+	+	+		+	1	farrow	true +
+	+	+	+	+	+	116	farrow	true +
+	+	+	+	+	+	1	cull/management	A
+	+	+	+	die		1	die	B
+	+	+	+	removed		1	cull/fertility	C
+	+	+/-	+	+	+	1	farrow	D
+	+/-	-	-	-	-	1	cull/fertility	E
+	-	+	+	+	+	1	farrow	F
+	-	+	return			1	regular return	G
+	-	-				1	late return	true +, true - H
+/-	+	+	+	+	+	7	farrow	I
+/-	+	-	+	return		1	late return	J
+/-	+/-	-	-			1	cull/fertility	K
+/-	-	-	return			2	regular return	L
+/-	removed					1	cull/fertility	M
+/-	return					3	regular return	N
-	+	+	+	+	+	2	farrow	O
-	+/-	+/-	+/-	removed		1	cull/fertility	P
-	-	-	-	removed		1	cull/fertility	true -
-	-	-	-	return		1	farrow	true -
-	-	removed				1	cull/MGM	true -
-	removed					1	cull/fertility	true -
-	return					1	regular return	true -
small	+	+	+/-	+	+	1	farrow	Q
small	small	+	+	+	+	1	farrow	R

blank cells = animals were not scanned.
A, B, C = These gilts/sows were excluded from the analysis as the true pregnancy status could not be determined.
D = This sow farrowed; the results are true + except on the 5^{th} week post-service which is suspect +.
E = This sow was judged pregnant but the pregnancy apparently terminated. She showed no evidence of regular return to oestrus or abortion. The test at 3^{rd} week was classed as true +, at 4^{th} weeks as suspect - and at 5^{th}, 9^{th}, and 11^{th} weeks as true -.
F = This sow farrowed. All test results were true + except for week 4 which is a false -.
G = This sow returned regularly and was judged non-pregnant. Test results were false + at week3, true - at week 4 and false + at week 5.
H = This sow was judged to have an early failure of pregnancy as she was a late return to oestrus. The results were true + at 3^{rd} week and true - at 4^{th} and 5^{th} week.
I = These gilts/sows farrowed. The results were suspect positive at 3^{rd} weeks, and true + on other occasions.
J = This sow was a late return to oestrus was judged to have a pregnancy which failed after weeks 4-5. The results were suspect + at week 3, true + on week 4, true - on week 5, and false + on week 7.
K = It is unlikely that this sow was pregnant. The results at weeks 3 and 4 were classed as suspect - and as true - on weeks 6 and 8.
L = The sow returned regularly. The result at week 3 was classed as suspect -, and as true - on weeks 4 and 5.
M = It is unlikely that this sow was pregnant. The result at week 3 was classed as suspect -.
N = The gilts/sows showed regular return to oestrus. The result at week 3 was classed as suspect -.
O = This sow farrowed. The result were false - at 3^{rd} week, and true + on other occasions.
P = This sow was judged to be non-pregnant. The suspect + results which were recorded three times probably indicate that there was an abnormality in the reproductive tract. The results at week 3 was classed as true -, suspect - at week 4, 5, and 7.
Q = It is considered that this sow was a true <6 pigs at week3, true + at weeks 4, 5, 9 and 11, and suspect + at week 7.
R = It is considered that this sow was a false <6 pigs at week 3 and 4, and true + at weeks 5-11.

The data described in Table 5-4 were further summarized in Table 5-5 to present the numbers of sows/gilts in each interpreted test result category at all examination times.

Table 5-5: Cross tabulation of number (%) of gilts/sows by interpreted test result category for scanning examination period between 3 and 11 weeks after service

Category	No. gilts/sows in each category, (%)					
	week 3	week 4	week 5	week 7	week 9	week 11
true +	124 (82.67)	134 (91.78)	135 (93.75)	134 (95.04)	134 (99.26)	135 (99.26)
true -	6 (4)	7 (4.79)	6 (4.17)	4 (2.84)	1 (0.74)	1 (0.74)
false +	1 (0.67)	0 (0)	1 (0.69)	1 (0.71)	0 (0)	0 (0)
false -	2 (1.33)	1 (0.68)	0 (0)	0 (0)	0 (0)	0 (0)
suspect +	8 (5.33)	0 (0)	1 (0.69)	1 (0.71)	0 (0)	0 (0)
suspect -	7 (4.67)	3 (2.05)	1 (0.69)	1 (0.71)	0 (0)	0 (0)
true <6 pigs	1 (0.67)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
false <6 pigs	1 (0.67)	1 (0.68)	0 (0)	0 (0)	0 (0)	0 (0)
Total	150 (100)	146 (100)	144 (100)	141 (100)	135 (100)	136 (100)

Only 3 gilts/sows (E, H, J) could be used to determine the time of failure of pregnancy. The scanning results and subsequent performance indicated that these gilts/sows apparently failed during weeks 3-4 post-service (the positive scanning result of sow J on week 7 post-service was considered to be false positive).

The percentage of animals classified as true positives was lowest for scans conducted during the early phase of pregnancy but increased as the period between service date and date of scanning examination increased. The percentage of animals categorized as true negatives decreased with time as non-pregnant animals were resubmitted for service or removed, in order to keep the level of non-productive sow days within acceptable limits. These management decisions were made by the farm manager in accordance with normal commercial practice.

Most suspect results were recorded during the early stages of pregnancy, and during this time there was a fairly even distribution of suspect positives and negatives. No suspect results were recorded after the 7th week post-service. During the 3rd week post-service (15 suspect cases), 53% were suspected to be pregnant, 47% non-pregnant. The probability for suspect cases to be non-pregnant was 1.0 in week 4 post-service (3 suspect cases), at that examination there were no suspect positives. Small litter size was diagnosed in 2 sows, twice for sow R in the same parity and once for sow Q. Sow R subsequently farrowed 6 piglets and sow Q 10 piglets.

Sets of two-way contingency tables were constructed from counts of gilts/sows, classified according to their test results and true pregnancy status. Separate tables were constructed based on: (a) including suspect scan results as positive scans (Table 5-6), (b) as negative scans (Table 5-7) or (c) excluding them (Table 5-8). The operating characteristics of the test, using those same criteria, were calculated and are shown with prevalences of state of pregnancy in Table 5-9, Table 5-10, and Table 5-11. Based on the result of the chi-squared test, which could only be used for data from week 3 onwards, the pregnancy test result was found to be a legitimate test interpretation for suspect negative cases.

Table 5-6: Cross tabulation between week of examination, scanning results and true pregnancy status including suspect results as *positive* scan results for all scans from 3 to 11 weeks after service

Week after service	Scan result	True pregnancy status	
		positive	negative
Week 3	positive	134	8
	negative	1	6
Week 4	positive	135	3
	negative	1	7
Week 5	positive	136	2
	negative	0	6
Week 7	positive	135	2
	negative	0	4
Week 9	positive	134	0
	negative	0	1
Week 11	positive	135	0
	negative	0	1

Table 5-7 :.Cross tabulation between week of examination, scanning results and true pregnancy status including suspect results as *negative* scan results for all scans from 3 to 11 weeks after service

Week after service	Scan result	True pregnancy status	
		positive	negative
Week 3	positive	124	1
	negative	10	13
Week 4	positive	134	0
	negative	1	10
Week 5	positive	135	1
	negative	1	7
Week 7	positive	134	1
	negative	1	5
Week 9	positive	134	0
	negative	0	1
Week 11	positive	135	0
	negative	0	1

Table 5-8: Cross tabulation between week of examination, scanning results and true pregnancy status excluding suspect results for all scans from 3 to 11 weeks after service

Week after service	Scan result	True pregnancy status	
		positive	negative
Week 3	positive	126	1
	negative	2	6
Week 4	positive	135	0
	negative	1	7
Week 5	positive	135	1
	negative	0	6
Week 7	positive	134	1
	negative	0	4
Week 9	positive	134	0
	negative	0	1
Week 11	positive	135	0
	negative	0	1

Table 5-9: Summary statistics for each examination week describing the prevalence of pregnancy and the operating characteristics of the scanning examination treating suspect cases as *positive* scan results

	week 3	week4	week5	week 7	week 9	week 11
Prevalence (P)	90.60	93.15	94.44	95.74	99.26	99.26
Complement of P (P')	9.40	6.85	5.56	4.26	0.74	0.74
Level of test (Q)	95.30	94.52	95.83	97.16	99.26	99.26
Complement of Q (Q')	4.69	5.47	4.16	2.83	0.74	0.73
Efficiency	0.94	0.97	0.99	0.99	1.00	1.00
True positive	89.93	92.47	94.44	95.74	99.26	99.26
False negative	0.67	0.68	0.00	0.00	0.00	0.00
False positive	5.37	2.05	1.39	1.42	0.00	0.00
True negative	4.03	4.79	4.17	2.84	0.74	0.74
Sensitivity (95% CI)	99.26 (95.3-100)	99.26 (95.4-100)	100.00 (96.6-100)	100.00 (96.6-100)	100.00 (96.5-100)	100.00 (96.5-100)
Specificity (95% CI)	42.86 (18.8-70.4)	70.00 (35.4-91.9)	75.00 (35.6-95.5)	66.67 (24.1-94)	100.00 (5.5-100)	100.00 (5.5-100)
PVP (95% CI)	94.37 (88.8-97.4)	97.83 (93.3-99.4)	98.55 (94.3-99.7)	98.54 (94.3-99.7)	100.00 (96.5-100)	100.00 (96.5-100)
PVN (95% CI)	85.71 (42-99.2)	87.5 (46.7-99.3)	100 (57.1-100)	100 (39.6-100)	100 (5.5-100)	100 (5.5-100)
Chi-squared (p-value)	*	*	*	*	*	*

PVP = predictive value positive, PVN = predictive value negative, 95% CI = 95% confidence interval, * = less than 10 observations in marginal cells

Table 5-10: Summary statistics for each examination week describing the prevalence of pregnancy and the operating characteristics of the scanning examination treating suspect cases as *negative* scan results

	week 3	week4	week5	week 7	week 9	week 11
Prevalence (P)	90.54	93.10	94.44	95.74	99.26	99.26
Complement of P (P')	9.46	6.90	5.56	4.26	0.74	0.74
Level of test (Q)	84.46	92.41	94.44	95.74	99.26	99.26
Complement of Q (Q')	15.54	7.58	5.56	4.26	0.74	0.74
Efficiency	0.93	0.99	0.99	0.99	1.00	1.00
True positive	83.78	92.41	93.75	95.04	99.26	99.26
False negative	6.76	0.69	0.69	0.71	0.00	0.00
False positive	0.68	0.00	0.69	0.71	0.00	0.00
True negative	8.78	6.90	4.86	3.55	0.74	0.74
Sensitivity (95% CI)	92.54 (86.4-96.2)	99.26 (95.3-100)	99.26 (95.4-100)	99.26 (95.3-100)	100.00 (96.5-100)	100.00 (96.5-100)
Specificity (95% CI)	92.86 (64.2-99.6)	100.00 (65.5-100)	87.50 (46.7-99.3)	83.33 (36.5-99.1)	100.00 (5.5-100)	100.00 (5.5-100)
PVP (95% CI)	99.20 (95-100)	100.00 (96.5-100)	99.26 (95.4-100)	99.26 (95.3-100)	100.00 (96.5-100)	100.00 (96.5-100)
PVN (95% CI)	56.52 (34.9-76.1)	90.91 (57.1-99.5)	87.5 (46.7-99.3)	83.33 (36.5-99.1)	100 (5.5-100)	100 (5.5-100)
Chi-squared (p-value)	65.56 (<0.001)	*	*	*	*	*

PVP = predictive value positive, PVN = predictive value negative, 95% CI = 95% confidence interval, * = less than 10 observations in marginal cells

Table 5-11: Summary statistics for each examination week describing the prevalence of pregnancy and the operating characteristics of the scanning examination excluding suspect cases

	week 3	*week 4*	*week 5*	*week 7*	*week 9*	*week 11*
Prevalence (P)	94.81	95.10	95.07	96.40	99.26	99.26
Complement of P (P')	5.19	4.90	4.93	3.60	0.74	0.74
Level of test (Q)	94.07	94.41	95.77	97.12	99.26	99.26
Complement of Q (Q')	5.93	5.59	4.23	2.88	0.74	0.74
Efficiency	0.98	0.99	0.99	0.99	1.00	1.00
True positive	93.33	94.41	95.07	96.40	99.26	99.26
False negative	1.48	0.70	0.00	0.00	0.00	0.00
False positive	0.74	0.00	0.70	0.72	0.00	0.00
True negative	4.44	4.90	4.23	2.88	0.74	0.74
Sensitivity (95% CI)	98.44 (93.9-99.7)	99.26 (95.4-100)	100.00 (96.6-100)	100.00 (96.5-100)	100.00 (96.5-100)	100.00 (96.5-100)
Specificity (95% CI)	85.71 (42-99.2)	100.00 (56.1-100)	85.71 (42-99.2)	80.00 (29.9-98.9)	100.00 (5.5-100)	100.00 (5.5-100)
PVP (95% CI)	99.21 (95-100)	100.00 (96.6-100)	99.26 (95.4-100)	99.26 (95.3-100)	100.00 (96.5-100)	100.00 (96.5-100)
PVN (95% CI)	75 (35.6-95.5)	87.5 (46.7-99.3)	100 (51.7-100)	100 (39.6-100)	100 (5.5-100)	100 (5.5-100)
Chi-squared (p-value)	*	*	*	*	*	*

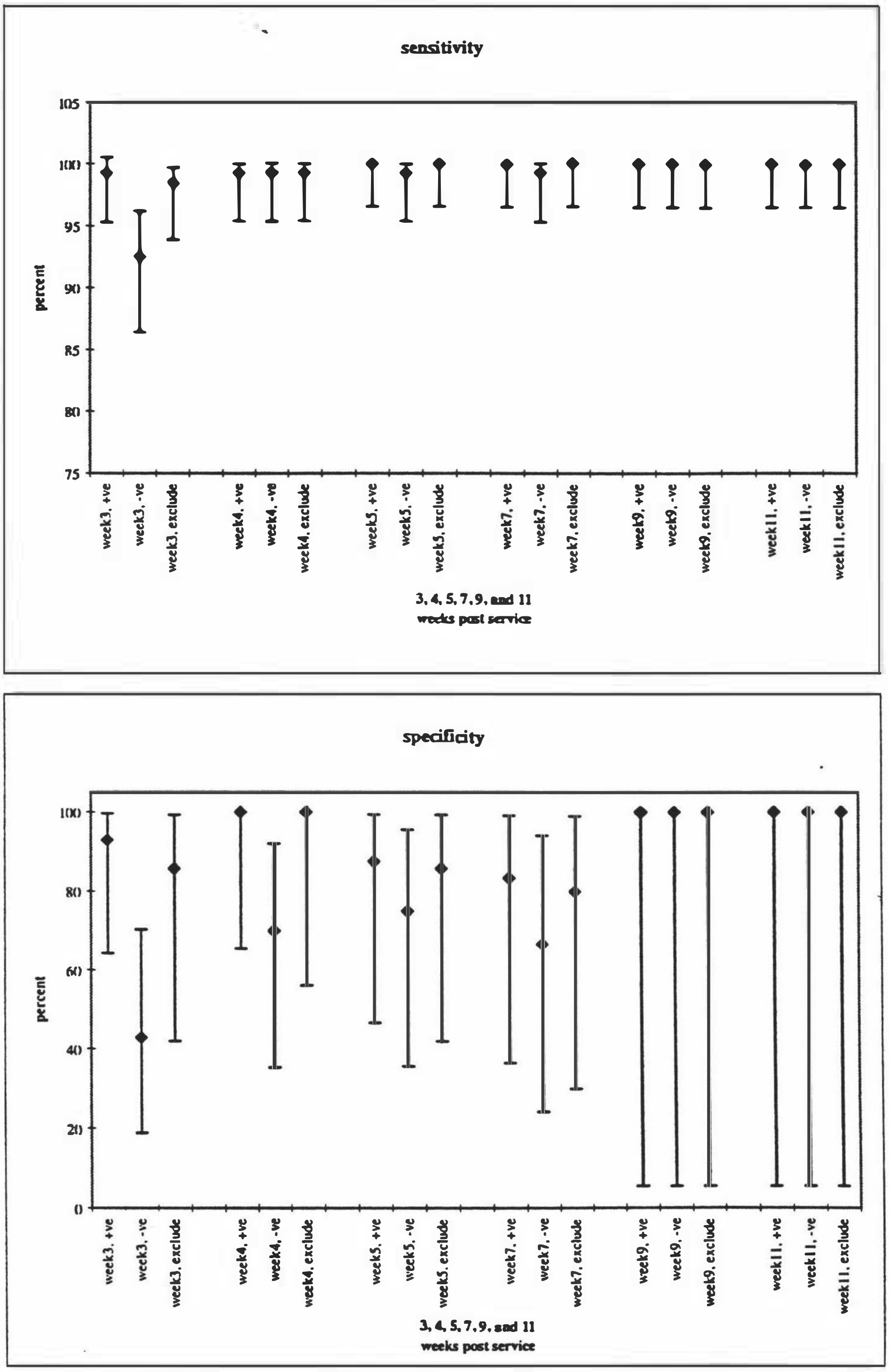
PVP = predictive value positive, PVN = predictive value negative, 95% CI = 95% confidence interval, * = less than 10 observations in marginal cells

The sensitivity of the ultrasound test was higher than 90% for each of three interpretations of the suspect results (Table 5-9, Table 5-10, and Table 5-11). The specificity of the procedure was low (43%) when the suspect results were treated as positive scan results for the 3rd week post-service tests. The level of the test was lower during week 3 post-service but improved gradually over the following weeks.

The predictive value of a positive scanning (PVP) was high on all occasions irrespective of the criteria used for interpretation of suspect scan results. This means the probability of animals which showed a positive scanning result being truly pregnant was high. The predictive value of a negative scanning (PVN) was high when all suspect results were treated as negative, except for the 3rd week post-service where PVN was lowest under these assumptions. This means that in week 3 the probability was low that animals with negative test results were in fact not pregnant. On the other hand the test appeared to be reasonably efficient at that stage in its positive predictive value. High efficiencies indicate that the probability that scanning result and true pregnancy status agree is high.

The temporal changes in sensitivity and specificity of the ultrasound test as pregnancy proceeded are illustrated in Figure 5-1 for the three criteria set for the gold standard.

Figure 5-1: Time plots showing sensitivity and specificity of the diagnostic method for the different examination periods based on the three different interpretations of suspect cases (negative (-ve), positive cases (+ve) or excluded (exclude); error bars = 95% confident intervals, ◆ = point estimates of sensitivity or specificity at week 3, 4, 5, 7, 9, and 11 post-service (from left to right))



Discussion

The sensitivity of real-time ultrasound operated by the author as a diagnostic tool for determining pregnancy status in pigs was found to be greater than 90%. Examinations which gave suspect results had a strong influence on sensitivity and specificity, and false positives and negatives were more common when tests were applied relatively soon after service. In normal commercial practice, sows which give suspicious results are rechecked again after a few days, by which time the proportion of suspect results should have decreased. This practice permits a more confident diagnosis of pregnancy to be made, based on combined information from both successive tests.

High specificity is a pre-requisite for pregnancy tests for sows because early recognition of non-pregnancy enables such sows to be resubmitted for service as soon as possible in order to keep non-productive sow days to a minimum. In this study the suspect results were treated in three separate analyses as positive, negative and excluded. Kraemer (1992) warns against the practice of excluding suspect cases when evaluating tests since it leads to a biased sample and biased results.

Selection bias was prevented in this study by including all scanning results over the period under consideration. Some inadvertent operator bias may have occurred after the first examination, since sows were kept in the same crates and some animals were easily recognized and remembered at subsequent examinations. However, the author was aware of this possibility and took steps to minimize its occurrence.

The calculated sensitivities and specificities have to be interpreted with some caution for the latter part of the study. By that time many non-pregnant pigs had been remated, culled or otherwise removed and were therefore not included in the analysis. The loss of non-pregnant pigs introduced considerable sampling bias into the analysis, since by then estimates were derived almost solely from pregnant pigs.

Kraemer (1992) cautions against analysing test results unless there are at least 10 counts in each of the marginal positions of the contingency table. If her criterion had been strictly applied, the analyses would not have been done on the data from weeks 4 to 11 after service. The studies however were done in a commercial piggery and it was not possible to keep non-pregnant animals for testing throughout the whole period.

Due to the small number of negative diagnosis sows, a sufficient sample size for chi-squared analysis was only available for week 3 (suspect cases treated as negative). In this case there was an association between true pregnancy status and test result.

A sensitivity of 92.54% and a specificity of 92.86% were found at week 3 when suspect cases were treated as negative. If suspect cases were treated as positive, the sensitivity was 99.26%

and specificity was 42.86%. Using the same rule, sensitivity was 99.26 and specificity was 70% in week 4. This variation in estimates demonstrates the influence of the interpretation of suspect cases on specificity.

The numbers of false negative and false positive results were consistent with the finding by Szenci (1992). He suggested that sensitivity could be related to litter size, with false negative sows giving birth to less than 6 piglets, in line with Bortero *et al.*'s (1986) suggestion. They both reported that the majority of diagnostic errors were made between 18 and 21 days of pregnancy in sows which subsequently gave birth to less than 5 piglets. They found that only 54% of non-pregnant sows were correctly identified in that period. In this study, no conclusion could be drawn on this issue as only one litter had less than 7 piglets. The overall low specificity of the real-time ultrasound method may be due to non-defined reproductive disorders occuring during the weeks following service. The apparently false-positive diagnoses were most likely the result of embryonic mortality (Martinez *et al.*, 1991).

The diagnosis of time of pregnancy failure can be interpreted from the overall result on only 3 gilts/sows which failed during week 3-4 post-service. On the study farm, the incidence of pregnancy failures was low but scanning is very useful for early recognition of failure and for reducing the non-productive-sow days and could have profitably been applied to sows E, K, and L.

The study showed that real-time ultrasound scanning using a 5 MHz transmitter can be used successfully for early pregnancy diagnosis (3rd week, 18-24 days after service) with the proviso that suspect cases are re-scanned during the following week. The accuracy of this method of pregnancy diagnosis is dependent on the knowledge and the experience of the person performing the scan. The specificity of the method improves with increased experience because of the reliance on image interpretation for accuracy particularly in the early stages of pregnancy.

CHAPTER 6

THE EFFECT OF WEANING PROCEDURE ON SOW AND LITTER PERFORMANCE

Chapter 6: The effect of weaning procedure on sow and litter performance

Literature review

Definition and its usage

One of the strategies used to improve production in pig farming is to increase the number of pigs weaned per sow per year, a tactic which can be constrained by inferior breeds of boars and/or sows, departures from optimum lactation length, poor condition in gilts and sows and a delay in the interval from weaning to oestrus. This latter delay is common in the pig industry and is more pronounced in primiparous than in multiparous animals (Rojkittikhun *et al.*, 1990). The anoestrous interval which all sows experience for a few days after weaning tends to increase in summer and affect sow productivity at that time. An increased incidence of delayed returns to oestrus following weaning creates difficulties for producers in their efforts to maintain the number of pigs in breeding herds at optimum levels. Production costs are increased because prolonged weaning to oestrus intervals contribute to excessive non-productive sow days (Almond, 1992).

Split or fractionated weaning is the permanent removal of part of a litter a few days before complete weaning (Matte *et al.*, 1992). Sibly *et al.* (1987) showed that when the heavier half of a litter was weaned at 4 weeks, the piglets remaining with the sow obtained 31% more milk per day and grew faster than pigs from non-split weaned gilts/sows. The remaining piglets obtained more milk by exploiting more teats than was possible before. Split weaning is not detrimental to the growth and development of piglets during the treatment period (Stevenson and Britt, 1981), if done when piglets are mature enough to consume creep feed in significant amounts, as they are then less dependent upon the availability of sow's milk and their growth performance is therefore not sensitive to either interrupted suckling or split-weaning (Matte *et al.*, 1992).

Lievens and Van der Heyde (1984) reported no significant differences in growth rate, carcass length, backfat thickness or leanness between heaviest piglets early weaned at 12 days of age, heaviest piglets late weaned at 40 days of age, and lighter remaining littermates weaned at 40 days of age. The lightest piglets which remained with the sow gained more weight than piglets in intact litters (Cox *et al.*, 1983; English *et al.*, 1987). Cox *et al.* (1983) and Gibertson (1989) reported that differences in average liveweight between intact and fractionated litters disappeared two weeks after full weaning. Rojkittikhun *et al.* (1991)

weaned the 4-5 heaviest piglets in the litter on day 33 of lactation and the remainder 2 days later and found a trend towards a shorter weaning to mating interval, although the difference (4.8 days vs 5.6 days for 6 pairs of sows) was not statistically significant. In 1990, the same author conducted a further trial in a 1000-sow commercial farm in Thailand and found that fractionated weaning increased the percentage of primiparous sows bred within 7 days of weaning, but had no significant effect on the time to return to first oestrus (6.7 ± 0.4 days for the control group *vs* 6.4 ± 0.4 for the fractionated group) for 69 pairs of Large White x Landrace gilts after taking off the heavier half of the litter on the 27^{th} day of a 30-day lactation period. There was no effect on the number of piglets born in the second parity.

Stevenson and Davis (1984) found that after reducing the number of suckling pigs to 3 pigs for 5 days before weaning, the post-weaning intervals to oestrus and conception in summer and winter months were shorter than those of controls weaned as a single unit 5 weeks after farrowing. Cox *et al.* (1983) also reported that reduction of litter size by one-half for 2 or 5 days before the time of complete weaning tended to reduce the average number of days to first oestrus in summer and winter. They reported that weaning half of the litter 2 days before complete weaning during summer and winter was associated with increased percentages of sows in oestrus by 10 days after weaning, compared with sows split-weaned 5 days before complete weaning or sows in the control group (77%, 58% and 51% respectively). They suggested that the initial weaning stimulated endocrine changes that were enhanced at the final weaning, provided that this was done at the optimum time. If the period was 5 days until final weaning, the effects of the initial stimuli may have waned. Newton *et al.* (1987) suggested that the variation among different studies could be due to a combination of genetic and hormonal effects that help determine the weaning to oestrus interval.

Hormonal changes

There is inhibition of hypophyseal secretion of gonadotropins during lactation, and follicular development is only modest. Suppression of serum luteinizing hormone (LH) release and the infrequent episodic releases of gonadotropins during lactation are followed by a rise in basal and episodic LH secretion during weaning. It has been suggested that LH and follicle-stimulating hormone (FSH) secretion are controlled by separate mechanisms during lactation (Almond, 1992). Almond (1992) considers that suckling modulates gonadotropin-releasing hormone (GnRH) synthesis and secretion, thereby controlling LH release. In contrast, FSH secretion is most likely regulated by an ovarian factor, termed inhibin. Gonadotropins and gonadotropin-releasing hormones, which are suppressed during lactation, gradually rise after weaning in multiparous sows (Cox and Britt, 1982). Rojkittikhun found that 4-6 piglets were sufficient to stimulate the release of prolactin during lactation and found no difference in prolactin measured about weaning time between the fractionated group (4-5 heaviest piglets weaned on day 33 of lactation, 2 days before the remainder) and the control group. Weaning half of the litter apparently does not affect sows, as the diurnal rhythm of cortisol concentration did not change after the first weaning. In a trial involving 12 sows, he found that reducing the number of suckling piglets 2 days before weaning produced no significant effect on the average and base levels of LH or the number of LH pulses. Oestrogen and progesterone remained low until weaning in both groups, but after weaning, oestrogen in the fractionated group rose faster than in the control group.

Weight loss and litter weight

Sows which had 2-day half-litter split weanings losts less weight during lactation than sows which had 5-day half-litter split weanings (Cox *et al.*, 1983). Rojkittikhun (1991) also found that sow weight loss during lactation was less for the two stage weaning group than it was for control sows (17.0 *vs* 26.2 kg).

Cox *et al.* (1983) compared the effects of split weaning between summer and winter, and found that during summer, the weight gains of the light weight piglets which remained on sows for 2 or 5 days after the heaviest pigs were weaned, were above the average gain of all piglets in control litters.

Piglets per litter

Kunavongkrit (1984) reported that there needed to be more than one nursing piglet present to suppress oestrus during lactation in sows, and that reducing litter size to an average of 3.3 piglets throughout 5 weeks of lactation shortened the interval from weaning to oestrus. Suckling intensity may be involved in the synthesis and/or release of the gonadotrophic hormones (Kunavongkrit, 1984). The complete removal of the litter may be necessary for some critical periovulatory hormonal events to occur (Cox *et al.*, 1983).

Timing

Foxcroft *et al.* (1987) found no statistically significant effect on the period of return to oestrus following removal of the heavier half of the litter on the 11th day of a 17 day lactation period, but there appeared to be some effect on live litter size at the following parity. It appears that the number of remaining piglets and the lactation days are both important components of split weaning for reducing weaning to oestrus intervals.

Using meta-analysis of 13 reported studies, Matte et al. (1992) estimated that after standardizing for litter size, the predicted weaning to mating interval decreased by 0.15 days for each additional hour of isolation. He concluded that optimal treatment effects were obtained with a minimal number of piglets remaining with the sow for a pre-weaning period of 4.7 days (from 3 to 5), and that the weaning to service interval could be expected to increase by 1.7 days for each additional piglet remaining with the sow. The size of the effect of split weaning on the weaning to service interval is thus related to the number of piglets withdrawn.

Summary

Benefits

- Anoestrus after weaning can be reduced by the practice of split weaning, and there are no ill effects on the welfare and well-being of sows.
- Split weaning is not detrimental to the growth and development of piglets during the treatment period, although creep feed needs to be available. There are no long term effects on piglet growth rates after weaning, carcass length, backfat thickness or leanness.
- Light piglets which remain with the sow show improved gains and tend to catch up to their heavier littermates as a consequence of their preferential continuing access to the sow.
- The procedure produces a trend towards a shorter postweaning interval to oestrus and conception in summer and winter months, and increases the proportion of primiparous sows bred within 7 days of weaning.
- Weaning one-half of the litter 2 days before complete weaning during summer and winter is more effective than split weaning 5 days before complete weaning. There does not seem to be any clear cut physiological explanation for this effect. After weaning, oestrogen levels in fractionated sows rise faster than in control sows.
- Fractionated sows lose less weight during lactation than conventionally weaned sows.
- Light weight piglets benefit and heavier piglets are not disadvantaged.

Disadvantages

- More work and effort is required to wean twice rather than once.
- The weaning deck need to be prepared for the first weaning pigs earlier and this shortens the length of time that the deck can be spelled.
- Sows are subjected to the stress of separation from their piglets twice.

Field study

Introduction

This field study was designed to investigate the effects of split weaning on weaning to service intervals of parity one sows, and on pig weight gains from weaning to about 130 days.

Materials and Methods

Trial size estimation

A sample size sufficient to detect a different average of 2 days between the weaning to oestrus intervals of treated and control pigs using a power of 0.80, an α-error of 0.05, a standard deviation of 1 was estimated using NCSS-PASS version 1 (Kaysville, Utah). It was calculated that a minimum of 60 gilts was needed to detect treatment effects of that size and at those prescribed levels of statistical significance.

Farm selection

Two commercial farms were selected, a North Island unit with 220 sows and one in the South Island with 100 sows. The breeds were Landrace and Large White, and neither farm routinely practised early weaning.

Timing of the study

Study animals were weaned between 15/8/94 and 18/5/95 on the North Island farm and between 24/11/95 and 4/5/95 on the South Island farm.

Method of allocation to treatment and control groups

Identification numbers of gilts due to farrow during the study period were extracted from computerized records (PigCHAMP® version 3.01, University of Minnesota) and allocated to treatment and control groups using a simple random sampling procedure. Group sizes were 34 controls and 37 treatments for the North Island farm, and 17 controls and 15 treatments for the South Island farm.

Methods

North Island farm

The weights and body condition scores of all study group gilts were recorded at their time of entry into the farrowing houses. Customary husbandry procedures were followed up to the weaning week in the 4th week of lactation. The larger and stronger piglets were weaned on the Monday of the weaning week and the four smaller and weaker piglets left with the sow until the routinely practiced weaning day (Thursday) of the same week. Pigs (N = 594) were weighed on the day of weaning and again at about a mean of 138 days (range = 120-195, standard deviation = 9.91). Sows were weighed and body condition scored on the last weaning day, at which stage they left the farrowing houses.

South Island farm

Similar procedures were followed in the South Island farm although it was not possible to weigh the study group gilts and only body condition scores were recorded. The larger and stronger halves of litters were weaned on the Monday and the remainder on the Thursday of the weaning week. On several occasions piglets from the strong halves of litters weighed less than 7.5 kg and those piglets were fostered on to older sows. A total of 277 pigs were weighed on the day of weaning and again at about a mean of 130 days (range = 113-165, standard deviation = 7.45).

Data recording

Animal identification numbers, farrowing dates, weaning dates, service dates, condition scores, number of pigs weaned and body weights were recorded on a standard form prior to entry into the database, Paradox®.

Data analysis

Descriptive statistics

Means, medians, 95% confidence interval limits, maxima, minima, lower quartiles, upper quartiles and standard deviations were calculated for the following variables: sow farrowing weight, sow farrowing body score, number of pigs weaned, sow weight at weaning, sow condition score at weaning, next litter size, next litter mummies, next litter stillborns, sow weight loss during lactation, sow body condition score change during lactation, weaning to first service interval and farrowing to first service interval.

Statistical analysis

The non-parametric Mann-Whitney U test of equality of medians was used to compare all measurements recorded for control and treatment groups and calculated statistics for weight and condition score gains and losses.

Analysis of covariance (ANCOVA) was used to compare overall weight gains and weight gains per day of pigs from the litters of treatment and control group sows while controlling statistically for the confounding variables, weaning age and weaning weight.

Comparisons were also made with ANCOVA between overall weight gains and weight gain per day between the 4 smaller pigs, selected from weights at weaning, from the litters of control and treatment group sows. Multiple pairwise comparisons of means of weight gain and weight gain per day between treatment and control groups stratified by breed and sex were made using the post-hoc Scheffe's test procedure.

Survival analysis was used to analyse the effect of treatment on weaning to service intervals. Weaning to first service intervals of greater than 21 days or less than 43 days were considered indicative of silent oestrus and were treated as censored observations.

The Cox regression or proportional hazards model was used for this comparison and the effect of lactation length on the outcome variable was examined by stratifying lactation length into 4 periods (<26 days, 26-32 days, 33-39 days and 41-43 days) and treating it as dummy variables.

All statistical analyses were conducted using the statistical package Statistica® version 5 (StatSoft, Tulsa).

Results

Descriptive statistics and results of the univariate statistical analysis

Table 6-1 sets out the descriptive statistics for the following parameters: farrowing weight and farrowing body score, litter size, number of pigs weaned, sow weaning weight and body score, number of pigs born alive, number of mummies and number of stillborns in the next litter, lactation length, sow weight loss, change in body score, weaning to first service interval, farrowing to first service interval, weaning age, pig weaning weight, pigs age and weight at time of second weighing, pig weight gain, and pig weight gain per day.

Table 6-1: Descriptive statistics and statistical comparisons (Mann-Whitney U test) between treatment and control groups from individual farms

Variable	*Farm location*	*Group*	*N*	*Mean (**)*	*Median*	*Min*	*Max*	*SD*	*p-value**
Farrowing weight	NI	Cont	34	199.7 (193.7-205.8)	198.5	166	234	17.4	0.08
		Treat	37	192.7 (187.2-198.1)	190.0	166	230	16.2	
Farrow body score	NI	Cont	34	4.1 (3.9-4.2)	4.0	3	5	0.4	0.45
		Treat	37	3.9 (3.8-4.1)	4.0	3	5	0.4	
	SI	Cont	17	3.1 (2.8-3.3)	3.0	2	4	0.4	0.98
		Treat	15	3.1 (2.9-3.2)	3.0	3	4	0.3	
Litter size	NI	Cont	34	10.4 (9.6-11.1)	11.0	5	15	2.1	0.46
		Treat	37	9.9 (9.1-10.7)	10.0	3	15	2.5	
	SI	Cont	17	11.2 (10-12.4)	12.0	6	15	2.4	0.002
		Treat	15	8.8 (7.7-9.9)	9.0	4	11	2	
No. of pigs weaned	NI	Cont	34	9.8 (9.2-10.4)	10.0	5	14	1.7	0.42
		Treat	37	9.4 (8.8-9.9)	10.0	4	12	1.6	
	SI	Cont	17	10 (9.6-10.4)	10.0	9	12	0.9	0.16
		Treat	15	9.3 (8.6-9.9)	10.0	7	11	1.3	
Sow weaning weight	NI	Cont	34	180.3 (173.9-186.6)	176.0	143	227	18.1	0.39
		Treat	37	176.9 (170.8-182.9)	172.0	140	217	18.2	
Sow weaning body score	NI	Cont	34	3.4 (3.1-3.6)	3.0	2	5	0.6	0.52
		Treat	37	3.2 (3-3.4)	3.0	2	4	0.6	
	SI	Cont	17	2.9 (2.6-3.1)	3.0	2	4	0.5	0.73
		Treat	15	2.8 (2.6-3)	3.0	2	3	0.4	
Next litter pigs born alive	NI	Cont	33	10.9 (10.1-11.9)	11.0	5	15	2.5	0.69
		Treat	29	10.2 (8.9-11.6)	11.0	0	15	3.6	
	SI	Cont	14	11.4 (9.8-13)	11.5	7	15	2.8	0.45
		Treat	14	10.1 (7.8-12.5)	11.0	0	14	4.1	
Next litter mummies	NI	Cont	33	0.3 (0.04-0.6)	0.0	0	3	0.7	0.72
		Treat	29	0.3 (0.1-0.6)	0.0	0	2	0.7	
	SI	Cont	14	0.4 (-0.06-0.9)	0.0	0	3	0.9	0.91
		Treat	14	1.1 (-0.6-2.9)	0.0	0	11	2.9	
Next litter stillborns	NI	Cont	33	0.4 (0.2-0.7)	0.0	0	3	0.7	0.72
		Treat	29	1.3 (-0.1-2.6)	0.0	0	18	3.5	
	SI	Cont	14	0.6 (0.2-1.1)	.5	0	2	0.7	0.22
		Treat	14	1.2 (-1.1-3.5)	0.0	0	15	3.9	
Lactation length	NI	Cont	34	32.7 (31.1-34.2)	32.0	21	41	4.5	0.65
		Treat	37	33.4 (32.1-34.7)	34.0	25	43	3.8	
	SI	Cont	17	28.4 (26.7-30.1)	29.0	22	35	3.3	0.03
		Treat	15	31.1 (29.6-32.6)	32.0	26	35	2.7	

Min.= minimum; Max = maximum; NI = North Island; SI = South Island; Cont = control group; Treat = treatment group; ** = 95% confidence limits; SD = standard deviation; * = p-value calculated using the Mann-Whitney U test of equality of medians of treatment and control groups; Shaded cells indicate p-values ≤0.05.

Table 6-1 (continued)

Variable	*Farm location*	*Group*	*N*	*Mean (**)*	*Median*	*Min*	*Max*	*SD*	*p-value**
Sow weight loss	NI	Cont	34	19.5 (14.6-24.4)	21.0	-12	45	13.9	0.23
		Treat	37	15.8 (12.6-18.9)	18.0	-4	29	9.6	
Sow body score change	NI	Cont .	34	0.7 (0.5-0.9)	1.0	-1	2	0.6	0.92
		Treat	37	0.8 (0.5-0.9)	1.0	0	2	0.7	
	SI	Cont	17	0.2 (-0.02-0.4)	0.0	0	1	0.4	0.66
		Treat	15	0.3 (0.01-0.5)	0.0	0	1	0.5	
Weaning-service interval	NI	Cont	34	4.4 (4.2-4.7)	4.0	3	6	0.6	-
		Treat	. 37	10.8 (6.3-15.3)	4.0	2	48	13.5	
	SI	Cont	17	5.2 (4.2-6.3)	5.0	3	11	1.9	-
		Treat	15	7 (3.01-10.9)	4.0	3	25	7.2	
Farrowing-service interval	NI	Cont	34	37.1 (35.6-38.7)	36.5	25	45	4.5	-
		Treat	37	39 (33.3-44.7)	38.0	0	85	16.9	
	SI	Cont	17	34.3 (31.7-36.9)	34.0	27	47	4.9	-
		Treat	15	38.1 (34.1-42.1)	36.0	32	58	7.2	
Pig weaning age	NI	Cont	272	32.5 (31.9-33.1)	32.0	21	42	4.6	0.05
		Treat	322	31.7 (31.3-32.2)	32.0	22	46	4.2	
	SI	Cont	149	28.6 (28.1-29.1)	29.0	22	35	3	0.11
		Treat	128	29.5 (28.9-30.1)	29.0	23	40	3.3	
Pig weaning weight	NI	Cont	272	8.6 (8.4-8.9)	8.6	3.7	14.2	2.1	0.05
		Treat	322	8.3 (8.1-8.5)	8.1	4	13	1.8	
	SI	Cont	149	7.7 (7.5-7.9)	7.7	3.7	13	1.4	<0.001
		Treat	128	8.6 (8.4-8.8)	8.75	5.5	11.5	1.2	
Weight at 2^{nd} weighing	NI	Cont	272	80.1 (79.3-80.9)	80.0	54	101	6.7	<0.001
		Treat	322	78.4 (77.7-79.1)	78.0	47	99	6.6	
	SI	Cont	149	78.9 (77.8-80)	79.0	32	96	6.9	0.02
		Treat	128	81.1 (79.9-82.2)	81.0	64	101	6.4	
Age at 2^{nd} weighing	NI	Cont	272	137.9 (136.7-139)	136	121	171	9.8	0.77
		Treat	322	137.5 (136.5-138.7)	136	120	195	10	
	SI	Cont	149	131.3 (130-132.6)	130	113	165	7.9	0.05
		Treat	128	129.4 (128.2-130.6)	131	115	145	6.7	
Pig weight gain	NI	Cont	272	71.5 (70.7-72.2)	71.1	46	93.2	6.5	0.01
		Treat	322	70.1 (69.4-70.8)	70.0	41.1	91	6.3	
	SI	Cont	149	71.2 (70.1-72.3)	71.8	24.5	87.2	6.9	0.24
		Treat	128	72.4 (71.3-73.6)	72.7	57.2	91.9	6.4	
Pig weight gain per day	NI	Cont	272	0.68 (0.67-0.69)	0.7	0.4	0.9	0.1	0.02
		Treat	322	0.67 (0.66-0.68)	0.7	0.3	0.9	0.1	
	SI	Cont	149	0.70 (0.68-0.71)	0.7	0.2	0.9	0.1	0.001
		Treat	128	0.73 (0.71-0.74)	0.7	0.6	0.9	0.1	

Min.= minimum; Max = maximum; NI = North Island; SI = South Island; Cont = control group; Treat = treatment group; ** = 95% confidence limits; SD = standard deviation; * = p-value calculated using the Mann-Whitney U test of equality of medians of treatment and control groups; Shaded cells indicate p-values ≤0.05.

Comparison of characteristics and performance of control and treatment groups

Sows

Table 6-1 shows that for the North Island farm, control and treatment group were well matched for farrowing weight, farrowing body score, litter size, number of pigs weaned, weaning weight, weaning score, and lactation length, but for the South Island farm, there were statistically significant differences between the control and treatment groups for litter size (median of control = 12 *versus* median of treatment = 9, p = 0.002) and lactation length (median of control = 29 *versus* median of treatment = 32, p = 0.03). Lactation length therefore was stratified into 4 groups to control for any effect from the different lactation lengths on weaning to first service interval during the following analysis.

The univariate analysis indicates that split weaning had no statistically significant effect on body weight loss or the change in body score between farrowing and weaning, or on the size of the next litter and the number of mummies and number of stillborns therein.

Pigs

There were small but statistically significant differences between the control and treatment group from the North Island farm for pig weaning age, pig weaning weight and pig weight at the second weighing, with the control group having higher values for all three parameters (Table 6-1).

For the South Island farm, pig weaning weight and weight at the second weighing were greater in the treatment group but age at the second weighing was lower in the control group.

Pig weight gain per day

Analysis of covariance was used to test the fixed effect of treatment status and its interaction with the random effect variables sex and breed on weight gain per day. A statistically significant difference was detected (F = 9642.1, p = 0.006) for South Island farm pigs. Post-hoc testing indicated that Large White pigs in the treatment group had a greater average weight gain per day than control group pigs [0.74 (95% CL = 0.72-0.75) *versus* 0.7 (0.68-0.71) kg per day] and the effect was apparent for both male and female pigs (0.74 *versus* 0.71 and 0.7 *versus* 0.68 respectively).

Overall weight gain

Average overall weight gain was significantly higher (F = 4.02, p = 0.05) in control group pigs than in treatment group pigs in the North Island farm, 71.45 kg (95% CL = 70.68-72.23) *versus* 70.16 kg (95% CL = 69.42-70.18) although the difference was only apparent in Large White pigs (F = 3.93, p = 0.05), (71.94 kg *versus* 69.77 kg).

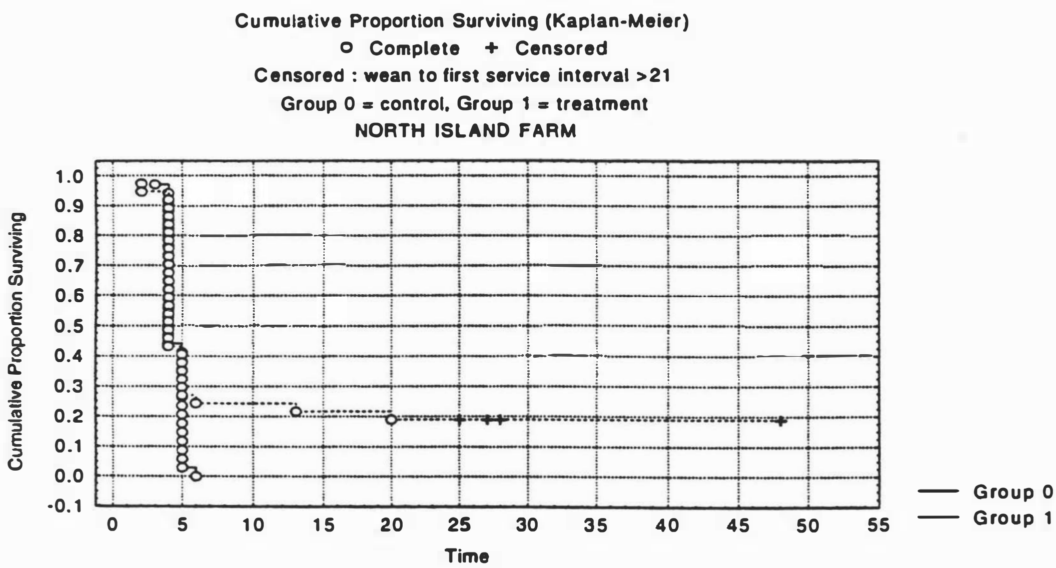
In the South Island farm, male pigs in the treatment group had higher average overall weight gains than male control animals (F = 4.02, p = 0.05), [74.06 kg (95% CL = 72.63-75.5) *versus* 71.35 kg (95% CL = 70.02-72.69)].

Differences between other groups were not statistically significant and no significant differences were detected when weaning age and weaning weight were used as covariates.

Weaning to first service interval

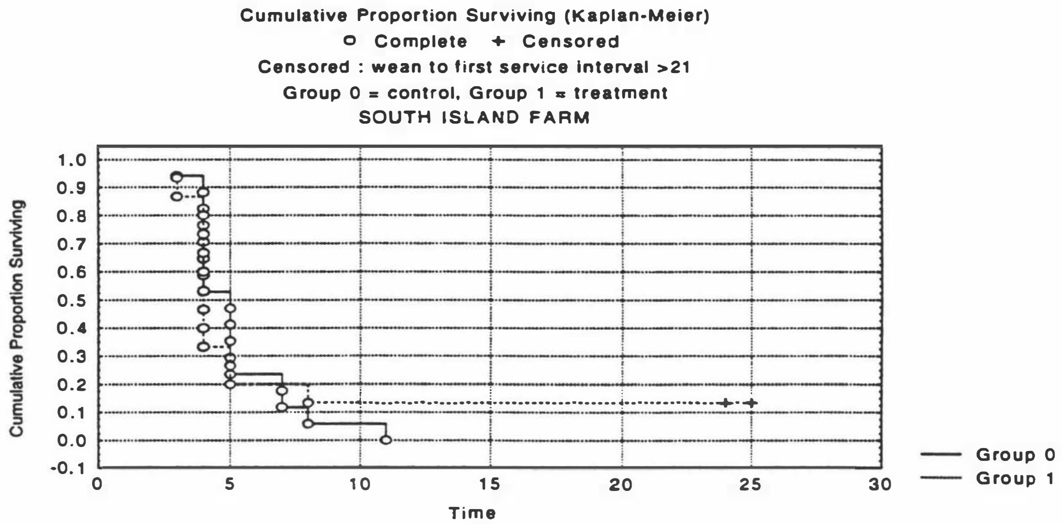
Survival function curves were constructed for control group sows (N = 34) and split weaned treated sows (N = 37, 7 censored) for the North Island farm (Figure 6-1). All but one sow in the control group was served within 5 days of weaning compared to 75% of treatment group sows served within 5 days, but no statistically significant differences were detected between the two groups ($\chi^2 = 1.25$, p = 0.26).

Figure 6-1: Estimated weaning to service interval survivor function curves for parity one sows in the North Island farm



Survival function curves were also constructed for control group sows (N = 17) and treatment group sows (N = 15, 2 censored) for the South Island farm (Figure 6-2). The patterns of weaning to first service intervals were very similar for both groups, an exception being that one of the control group sows had a weaning to first service interval of > 10 days. Split weaning had no apparent effect on the weaning to first service interval ($\chi^2 = 0.017$, p = 0.354).

Figure 6-2: Estimated weaning to service interval survivor function curves for parity one sows in the South Island farm



Discussion

Split weaning had no effect on the weaning to first service interval of primiparous gilts in the two study farms. The weaning to first service intervals on both farms were already consistent with high level performance at 4.4 days (95% CL = 4.2-4.7) for the North Island farm and 5.2 days (95% CL = 4.2-6:3) for the South Island farm. This suggests that it is difficult to improve upon an already high level of performance. Rojkittikhun *et al.* (1991) were also unable to show any effect, although Stevenson and Davis (1984) showed beneficial effects in a study using Yorkshire X Duroc mixed parity sows.

Both farms were also efficient in rearing pigs, and their high level of performance in that area of husbandry may account for the only demonstrable beneficial effect of split-weaning being confined to Large White pigs in the South Island farm. The lack of an overall effect on weight gain per day and the conflicting results for overall weight gains does not support that isolated result, and it is probably best considered as an interesting finding, rather than as a result which could be confidently reproduced in future studies.

Although this study did not demonstrate any clear beneficial effects from split-weaning on these two farms, it should not be inferred that the practice is of no value. Future efforts should be directed towards defining husbandry conditions and litter characteristics which may influence the benefits of this procedure which have been demonstrated in other studies (Stevenson and Davis, 1984; Sibley *et al.*, 1987; Cox *et al.*, 1983; English *et al.*, 1987 and van der Hoyde, 1984).

A more detailed investigation of weight gain per day performance may also be warranted because post-weaning management may obscure short term beneficial effects. It is common practice on commercial farms for weaners to be pooled into groups of about 20 pigs for rearing.

An interesting consequence from this study was that the manager of the South Island unit has now adopted the practice of split-weaning for those litters containing a proportion of obviously smaller piglets and also for large litters.

CHAPTER 7

GENERAL DISCUSSION

Chapter 7 : General discussion

Reproductive problems are a major factor limiting production in large scale pig operations. The various studies presented in this thesis examine factors influencing reproductiveperformance in sows, especially aspects of a syndrome called seasonal or summer/autumn infertility. Longitudinal herd recording data was analysed to assess the presence of this syndrome in a sample of New Zealand pig herds and investigate its quantitative relationship with standard reproductive performance measures. An intervention trial was conducted to assess the impact of increased energy intake in dry sows on reproductive performance with a view to this technique being used to prevent seasonal infertility. Another intervention trial looked into the effect of the management technique split weaning on subsequent reproductive performance in sows. The effectiveness of ultrasound scanning was quantified in a separate study, both to investigate pregnancy losses in sows over summer, and to assess its merits as a technique for pregnancy examination. Another study was conducted in slaughtered culled sows to describe the status of their reproductive tract in biological and pathological terms, in order to identify the range of pathological states which might affect reproductive performance.

Seasonal effects have been hypothesized as having a significant effect on sow reproductive performance, notably in the United States and in Australia. In New Zealand, anecdotal information from producers does indicate that at certain times of the year, especially during the summer/autumn period, farrowing rates are decreasing and return rates in sows are increasing. The analysis of reproductive sow performance data in this thesis did not confirm the presence of a summer/autumn infertility syndrome as a general problem for New Zealand pig herds, but the results do suggest that under certain conditions reproductive performance may drop on some farms. Field evidence is that this drop can be spectacular on occasions. It is possible that multiple management related factors are involved. Group housing of sows, for example, which is a common husbandry system in the South Island of New Zealand, does seem to have a negative impact on reproductive performance in general. As there were no obvious and consistent seasonal patterns in the data included in this analysis, it was relatively difficult to classify individual observation periods (summer/autumn and winter/spring) into problem or non-problem intervals. It can be concluded that during the period 1991-1994 represented in this analysis summer/autumn infertility did not cause major economic losses on the farms which had provided their recorded production information.

This particular analysis was based on information provided by producers as a PigCHAMP database. It illustrates the usefulness of this type of herd recording information beyond the within-herd analysis for making useful comparisons between farms and investigating temporal patterns. As most of these analyses have to be conducted using software other than the system the data was recorded in, these packages should provide more suitable procedures for export of data. A major issue with this type of analysis is the decision on whether to use individual parity information or aggregated farm data. Both types of analysis have their use. Individual parity data does introduce a complication in that the datasets to be analysed tend to become very large. The statistical techniques which should be used for this type of data should allow the inclusion of clustering effects due to dependence introduced by farm and repeated observations. As this particular area of statistical methodology is not yet widely accessible, clustering effects were ignored in this study. There is a possibility that some of the effects which appeared to be significant in this analysis would become non-significant if clustering were taken account of.

The feeding trial assessing the effect of an increased quantity of dry sow ration on reproductive performance did not show a significant effect in the pig herds included in this study. A factor to be taken into account in the interpretation of these results is the fact that in New Zealand sows are being fed relatively high amounts of dry sow ration already in the period after weaning. Thus sows were already receiving the amount of dry sow ration considered "therapeutic" in Australian research on the subject . As part of this study an economic spreadsheet simulation model was developed representing the events relevant to reproduction and survival of the sow, and growth of her offspring. The input for the model parameters was obtained from PigCHAMP data for each of the farms included in this analysis. The information was used to generate probability distributions representing the uncertainty associated with the model parameters. The economic analysis did show that there could be some benefit in adopting an increased dry sow ration on particular farms. Given the parameter settings it appeared that the impact of a control measure such as increased dry sow ration on litter size was more important than the effect on non-productive sow days. The model will be useful for assessing the economic impact of other parameters affecting reproductive sow and grower performance as well as any measures targeted at improving performance parameters.

The investigation into the status of the reproductive tract of cull sows revealed that most sows (53%) were culled by farmers because of their age. A significant number of culls were due to lameness (15%) and lactation problems (13%). The examination of the uterine tracts showed that 38% of the sows had been suffering from endometritis. In 50% of cull sows pathological changes were found in the urinary tract. This could be used as an indicator of the commonness of both conditions in cull sows. Urinary tract infections may be common causes of reproductive problems in sows. None of the sows had been culled because of problems which could have been caused by endometritis and cystitis. Further investigations into the prevalence of cystitis and its impact of reproduction as well as potential risk factors are necessary. *Eubacterium suis* was isolated from the bladder of one cystitis-affected sow. This pathogen has been reported in the literature as an important cause of urinary tract disease.

The trial investigating the effect of split weaning suggests that this technique does not reduce the weaning-to-first-service interval in gilts. The two farms involved in the trial already had a short interval to oestrus and it therefore would have been difficult to further improve it. It is possible that under different circumstances with regard to management and breed characteristics this technique could be beneficial for reproductive performance.

Early diagnosis of pregnancy is an important management method for improving reproductive performance in sow herds, especially within the context of the occurrence of summer/autumn infertility it can be used to identify sows which are not in pig. Early recognition of non-pregnant sows will allow repeat mating as well as early culling decisions. Any diagnostic technique requires a high sensitivity, in that it does not miss pregnancies, but should also be specific so that sows are not classified wrongly as pregnant. The evaluation of real-time ultrasound scanning demonstrated a high sensitivity of above 90% and a specificity of more than 90%. The technique can be useful for detecting pregnancies during the third week, but suspect cases should be rescanned during the following week. The accuracy of the technique depends on the experience of the operator, and the additional effort and equipment cost involved limits its value to the investigation of difficult reproductive problems, rather than routine use.

The studies conducted as part of this thesis clearly demonstrate how important it is take into account the local situation when dealing with complex disease syndromes such as seasonal infertility. This may seem somewhat surprising as management, breeds and housing characterizing modern pig production might be considered to reasonably standardized around the world, especially with regard to so-called developed countries. It can be misleading to apply experiences from other countries without taking into account local characteristics. This experience confirms that a modern pig production unit is a complex multifactorial system where an epidemiological approach is essential for identifying the underlying causes of disease and production problems.

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